The Influence of Argumentative Discourse on Pre-Service Teachers' Alternative Conceptions of Photosynthesis and Cellular Respiration

by

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Dedicated in memory of my mother who taught me to love learning.

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ABSTRACT

Mediocre science achievement and poor STEM graduation rates have prompted educators to reexamine their traditional focus on factual memorization and seek more effective instructional strategies. One such reform-oriented instructional practice is argumentative discourse. Argumentative discourse is student-driven, reasoned argumentation to promote deliberation, inquiry, and learning about scientific concepts. This qualitative multiple–embedded case study examined the impact of argumentative discourse-based lessons on pre-service teachers' alternative conceptions about the processes of photosynthesis and cellular respiration. Participants engaged in small group tasks and discussions to choose claims, develop arguments, and defend those arguments based on provided evidence. Three groups of pre-service teachers were examined in detail. These groups had been formed based on the participants' epistemic beliefs about science, with one group having primarily constructivist beliefs, one with moderate beliefs, and one with beliefs that were more traditional. Conceptual changes were analyzed at the individual level and at the collective group level. Most participants' individual alternative conceptions were noticeably reduced, while their accurate conceptual knowledge increased. Those with more constructivist epistemic beliefs experienced marginally better conceptual change results. The results of this study add to the literature regarding argumentative discourse's potential to effect lasting conceptual change in pre-service teachers learning science content.

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CHAPTER I: INTRODUCTION

Introduction

This multiple–embedded case study examined the conceptual change outcomes, if any, of pre-service elementary teachers (PSTs) as they participated in argumentative discourse as a method for learning life science content. It also examined the influence, if any, of participants' underlying epistemic beliefs about science on the outcomes. This chapter provides the background of the study by introducing the concern regarding deficiencies in scientific literacy in the U.S. school population. The specific problem of widely held alternative conceptions in science are also discussed, with a focus on the critical need to ensure elementary PSTs have gained appropriate conceptions of science before beginning their teaching careers. The instructional practice of argumentative discourse will be presented as a means to improve PSTs' understanding of life science content by aiding the process of uncovering, addressing, and modifying their alternative conceptions. A brief overview of argumentative discourse and its benefits will be provided. The purpose and significance of this study will be described, and definitions of relevant terms given.

Background of the Study

Ensuring the accuracy of PSTs' science understanding is an important goal, especially in light of the current state of science achievement in the U.S. Elementary and high school students continue to lag behind many other developed nations (Augustine et al., 2010; Gonzales et al., 2008; Organization for Economic Cooperation and Development [OECD], 2016). In 2015, the Program for International Student Assessment ranked the U.S. as 25th in science out of the 65 countries that are members of the OECD (2016). These results were based on the performance of 15-year-olds on an assessment designed to measure scientific literacy. Thus, there remains significant room for improvement in U.S. students' general scientific understanding as compared to other developed nations.

Scientific Proficiency is Lacking

In order to gauge how well students are meeting the domestic standards of science proficiency, the National Assessment of Educational Progress (NAEP) conducts regular assessments. The development of the current science assessment of NAEP was informed by documents such as the *National Science Education Standards* (National Research Council [NRC], 1996) and the *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science [AAAS], 1993). The NAEP is intended to accurately "reflect the nature and practice of science" (National Assessment Governing Board [NAGB], 2010, p. 119). A representative sample of fourth-, eighth-, and twelfth-grade students are tested in alternating academic subjects, with 2009 and 2015 being the most recent years that science was assessed in all three grade levels (National Center for Education Statistics [NCES], 2016).

Results from the 2015 NAEP revealed that 38% of fourth graders, 33% of eighth graders, and 25% of twelfth graders scored at or above proficiency in science (NCES, 2016). Thus, a substantial majority of students at all three grade levels scored below proficiency. These results indicate that a full three-fourths of the nation's students finished their last compulsory year of schooling with so many incomplete and inaccurate science concepts that they failed to score even a minimum level of proficiency (NCES, 2016). It should be noted that the 2015 assessment data showed small but statistically significant improvement over the 2009 scores in both fourth- and eighth-grade students (NCES, 2016). This small improvement is encouraging yet inadequate, especially considering there were no gains made by twelfth graders between 2009 and 2015 (NCES, 2016).

Scientific Literacy is Critical

U.S. students' inadequate scientific literacy compared to other developed nations, and the majority's failure to meet even minimal proficiency on domestic science standards, is concerning. A shortage of effective scientific thinkers and innovators may have troubling ramifications on our society in the future (Laugksch, 2000; President's Council of Advisors on Science and Technology [PCAST], 2010). The nation's economy and quality job growth is driven by advancements in science and technology, which mainly originate with professionals in the fields of science, technology, engineering, and mathematics (STEM) (Augustine et al., 2010; Laugksch, 2000). There are concerns that insufficient numbers of students are entering and persisting in STEM-related degrees and subsequent careers (National Science Board [NSB], 2014). Without sufficient numbers of innovators and a highly prepared workforce, the U.S. may lose its competitive edge in the global system (PCAST, 2010). Statistics reveal this decline may already have begun, as the number of foreign patents has now surpassed national patents, and exportation of high-tech products is in decline while other countries like China surge ahead (NSB, 2014).

Although the impact of school science achievement on STEM jobs and the American economy is apparent, a populace's understanding of science has consequences in many other aspects of society. Citizens can struggle to effectively address and solve societal problems ranging from the individual to the global level if they lack scientific literacy, which is the ability to communicate effectively within and about the discipline of science (Norris & Phillips, 2003). The public must be scientifically literate to participate productively in discussions and make informed choices on personal and global issues as diverse and important as health, energy concerns, and environmental problems (Lewis & Leach, 2006; Marks, Bertram, & Eilks, 2008; Roth & Lee, 2004). They must attain enough foundational understanding to feel competent and motivated to judge challenging scientific issues for themselves, rather than blindly following perceived experts whose motives may be questionable (Cross & Price, 1999).

Sufficient foundational knowledge of all areas of science is important, but it can be argued that life science is the most relevant and necessary scientific discipline for the general population to understand (e.g., McComas, 2007). The study of biology provides information regarding the diversity and interactions of living organisms on this planet, as well as insights into how we as humans function. Thus, it is a subject that is directly applicable to personal choices that students make in their daily lives (Gilbert & Fausto-Sterling, 2003). Understanding biology is crucial for the population as a whole since it provides an appropriate knowledge base from which to make informed decisions about essential personal and societal issues such as public health and the judicious use of the planet's limited natural resources (Lewis & Wood-Robinson, 2000).

Alternative Conceptions

One challenge preventing individuals from achieving scientific literacy is the widespread prevalence of strongly held alternative conceptions (Miller, 1998). These incorrect ideas are typically rooted in naïve and underdeveloped understanding and do not align appropriately with accepted scientific knowledge (Driver, Guesne, & Tiberghien, 1985). Alternative conceptions are problematic for learners. For example, these naïve and inaccurate conceptual frameworks can have a negative influence on their future learning (Chi, Slotta, & De Leeuw, 1994; Driver & Easley, 1978; Michael, 1998; Wandersee, Mintzes, & Novak, 1994). A strongly held alternative conception can prevent a learner from easily acquiring an accurate conception that is being taught (Chi et al., 1994; Michael, 1998). Additionally, research has shown that alternative conceptions tend to be resistant to change (Brumby, 1984; Driver et al., 1985; Harrell & Subramaniam, 2014; Helldén & Solomon, 2004; Songer & Mintzes, 1994).

Alternative conceptions clarified. Alternative conceptions are referred to in the literature with a variety of terms including misconceptions (e.g., Smith, diSessa, & Roschelle, 1994), preconceptions (e.g., Ausubel, Novak, & Hanesian, 1978; Clement, 1982), naïve or intuitive ideas (e.g., Chi & Slotta, 1993), limited or inappropriate propositional hierarchies (Novak, 2002), children's science (Gilbert, Osborne, & Fensham, 1982), alternative frameworks (e.g., Driver & Easley, 1978), and alternative conceptions (e.g., Abimbola, 1988; Gilbert & Watts, 1983; Wandersee et al., 1994). The term *alternative conception* was used for this study rather than any of the other broadly synonymous words since it carries the most neutral, comprehensive, and apt connotation.

The term *misconception*, probably the most common term in the literature, has an overly negative connotation, implying that the learner's conception is inherently and utterly wrong and must be completely removed and replaced with the correct concept (Taber, 2014). Many researchers reject that idea and instead recognize the value and relevance inherent in the learner's alternative conceptual framework (Bransford, Brown, & Cocking, 1999; Smith et al., 1994). Constructivists recognize that the process of learning is highly influenced by what the learner already knows and thinks (Ausubel et al., 1978). Learners build upon and modify their existing conceptual frameworks to make them align better with newly acquired concepts (Pintrich, Marx, & Boyle, 1993; Tanner & Allen, 2005). Linking new information to prior knowledge is much more effective than teaching disconnected facts (Anderson, 1990).

Alternative conceptions in PSTs. Ensuring elementary teachers are properly educated in science before entering the profession is a pre-emptive way to minimize the perpetuation of alternative conceptions in future students. Unfortunately, it has been well documented that elementary PSTs often lack a deep conceptual understanding of science and hold numerous incomplete and alternative conceptions (e.g., Abell & Smith, 1994; Davis, Petish, & Smithey, 2006; Harrell & Subramaniam, 2014; Stevens & Wenner, 1996; Trundle, Atwood, & Christopher, 2002). Abell and Smith (1994) found that the PSTs in their study held the same naïve positivist conceptions of science as seventh-grade students in a previous study by Carey, Evans, Honda, Jay, and Unger (1989). They lamented that the PSTs' understanding of science had apparently failed to meaningfully advance past their childhood views. It is unlikely that teachers who hold the same alternative conceptions as the population of students they teach will be highly effective science educators.

Many elementary PSTs recognize their own conceptual deficiencies and report feeling underprepared and anxious about teaching science (Kazempour, 2014; Mallow et al., 2010; Yuruk, 2011). They view science as being more difficult to teach than other subjects (Mulholland & Wallace, 2002). Interestingly, Bursal's (2012) study of PSTs' science understanding, self-efficacy, and anxiety revealed a contrasting but no less worrisome circumstance. At the end of a science methods course the PSTs reported much more confidence to teach science, yet they lacked appropriate scientific understanding and still held multiple alternative conceptions (Bursal, 2012). This unrealistic optimism has been noted in PSTs in other studies as well (Brookhart & Freeman, 1992; Weinstein, 1990). Thus, Bursal (2012) emphasized that teacher preparation programs should be primarily concerned with preparing PSTs' conceptual understanding of disciplinary content and be careful not to encourage groundless teaching confidence.

Elementary-level PSTs are poised to become powerful influencers in the lives of their future students. Their instructional choices and classroom actions will impact the science interests and attitudes of leaners. Elementary–level teachers play a critical role in encouraging early science interest in their young students and in laying a foundation of correct conceptual knowledge upon which students will continue to develop their understanding throughout the rest of their schooling (Beane, 1988). Research suggests that elementary school is the best time to influence learners' attitudes, interests, and achievements in science, particularly among traditionally low-achieving minority populations (Beane, 1988). In a study on PSTs, Jarrett (1999) found that memorable elementary science experiences predicted later interest and confidence in science. Similar results were obtained more than a decade later when Bulunuz and Jarrett (2010) again found that PSTs' memories of personal elementary science experiences predicted their level of interest in science as adults. Those reporting few memories tended to also fall into the low science interest group. The authors posited that those participants' science experiences in elementary school must have been limited or generally unremarkable.

Reducing alternative conceptions in PSTs. It is imperative that teacher education programs diligently strive to improve the science conceptual understanding of elementary PSTs. Science-focused content courses can better prepare elementary PSTs to be successful teachers by deepening their understanding of science topics that are covered in PreK-6 settings (Bleicher & Lindgren, 2005; Santau, Maerten-Rivera, Bovis, & Orend, 2014; Smith-Walters & Barker, 2015). It should be noted, however, that not all studies of science content and methods courses have shown positive changes in PSTs' conceptual understanding as a result of such a course (e.g., Bursal, 2012).

One thing that may make the difference between courses that notably impact alternative conceptions, and those that do not, could be the instructional methods used (Bleicher & Lindgren, 2005). Research has shown that higher order conceptual change is best supported by reform-oriented instructional methods such as the facilitation of student-centered, small-group learning (e.g., Granger et al., 2012; Orbanić, Dimec, & Cencič, 2016; Springer, Stanne, & Donovan, 1999). Traditional positivist methods such as lecturing and emphasizing rote memorization are typically less effective at encouraging deep conceptual understanding and retention of content (Anderson, Sheldon, & Dubay, 1990; Demircioğlu, Ayas, & Demircioğlu, 2005; Kibirige, Osodo, & Tlala, 2014).

It is necessary to use reform-oriented strategies in pre-service teacher education for three primary reasons: 1) to support PSTs in changing their own alternative conceptions and thus developing a thorough understanding of the content; 2) to provide an effective research-based instructional example upon which PSTs may model their own future instructional practice (Lawson et al., 2002); and 3) to promote the formation of PSTs' pedagogical content knowledge, which is the knowledge of how to match the teaching strategy most appropriately to the content to be taught (Shulman, 1986). The focus of this study was the first imperative of supporting the development of deep and accurate conceptual understanding in PSTs. This investigation examined how the alternative conceptions of PSTs were influenced, if at all, through the experience of engaging in argumentative discourse, a reform-oriented strategy, to learn science content.

It was hypothesized that this research-based instructional method would prove effective in helping reduce the myriad alternative conceptions PSTs had regarding the topics of photosynthesis in plants and cellular respiration in plants and animals. However, this study also aligned with the goals of the second and third imperatives. Engaging the PSTs in argumentative discourse in the role of a learner may be a step toward promoting their incorporation of the method into their own future pedagogy (Lawson et al., 2002).

Scientific Argumentation in the Classroom

The practice of scientific argumentation is recommended for use in science instruction at all levels because it is inherent in professional science practice, even being described as the foundation of the discipline (Kuhn, 2010). Scientific argumentation differs from everyday argumentation in that its primary goal is the use of reason to evaluate evidence-supported claims for the purpose of deepening individual and collective conceptual understanding (Schweingruber, Shouse, & Michaels, 2007). In practice, scientific argumentation consists of making a claim, citing relevant evidence to support that claim, and using appropriate reasoning to connect the evidence to the claim (Cohen, 1987; McNeill & Martin, 2011). It is not emotional or opinion-based (Andriessen, 2006). Evaluation of others' arguments is encouraged, but criticism should center solely on the ideas at hand and not on individuals personally (Schweingruber et al., 2007).

Driver, Newton, and Osborne (2000) highlighted the central role of argumentation to the discipline of science: "Observation and experiment are not the bedrock on which science is built, but rather they are the handmaidens to the rational activity of generating arguments in support of knowledge claims" (p. 297). More than 50 years ago, Schwab (1962) advocated for the inclusion of inquiry methods in science education and stated that it must not be taught as the "unmitigated *rhetoric of conclusions* in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths" (p. 24, original italics). Science education that focuses solely on the methodological, positivist components of science knowledge development, without any emphasis on the interpretive heuristic aspect misrepresents the nature of science (Abd-El-Khalick et al., 2004).

Increasingly, researchers, educators, and stakeholders have been emphasizing the use of argumentation in science education to support students in attaining a better understanding of the content and the nature of science (Newton, Driver, & Osborne, 1999; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013). Martin and Hand (2009) highlighted the primary place argumentation has been given in seminal reform-oriented documents (NRC, 1990, 1996), stating, "This ability to reason scientifically, using the tools of argument, is the primary focus of science education reform" (p. 22). More recently, the Next Generation Science Standards (NGSS) were developed with the purpose of increasing the rigor and consistency of U.S. K-12 science education (NGSS Lead States, 2013). These standards include scientific argumentation throughout, listing it as one of the eight science and engineering practices and embedding it at all levels of science instruction (NGSS Lead States, 2013).

Argumentation can be situated in a relatively independent context or a highly social one. Science professionals engage in individual argumentation when they craft and publish arguments explaining conclusions drawn from their experimentation and observation. Rebuttals and counter-arguments arise later during the peer-review process and in published responses to the original article. Argumentation in a social context involves a pair or group of individuals engaging in a real-time discussion. There is no universally agreed upon term for this type of scientific, argumentative-based discussion as used for instruction. Some terms include interactive argumentation (e.g., Chinn &

Anderson, 1998; Munneke, Andriessen, Kanselaar, & Kirschner, 2007), conceptual change discussion (e.g., Eryilmaz, 2002), argumentation discourse (e.g., Duschl & Osborne, 2002), and argumentative discourse (e.g., Berland & McNeill, 2010), which is the term adopted for use in this study.

Argumentative Discourse

Encouraging learners to engage in argumentative discourse is a way to implement meaningful scientific argumentation in the classroom. Argumentative discourse can be defined as student-driven discussion for the purpose of reasoned argumentation around scientific concepts in order to promote deliberation, inquiry, and conceptual understanding (Felton, Garcia-Mila, & Gilabert, 2009; Meiland, 1989). Argumentative discourse may be considered a specialized subset of collaborative discourse, which is defined as collaborative student discussions around academic content for the purpose of learning (Nussbaum, 2008).

Argumentative discourse may be used as a classroom instructional approach to engage learners in the process of scientific argumentation through peer discussion of competing claims. It is a collaborative process; it is arguing-to-learn (Andriessen, 2006). Argumentative discourse is aligned with strategies for supporting conceptual change (Dole & Sinatra, 1998; Nussbaum & Sinatra, 2003), as well as the sociocultural approach to learning (Sadler, 2006) and reform-oriented science teaching (Martin & Hand, 2009). It also exemplifies the key practices emphasized in standards and reform documents as effectively supporting learners' scientific proficiency (NGSS Lead States, 2013; Schweingruber et al., 2007).

Epistemic Beliefs

A number of factors mediate the effective enactment of a complex learning task such as argumentative discourse (e.g., Gilabert, Garcia-Mila, & Felton, 2013; Munneke et al., 2007; von Aufschnaiter, Erduran, Osborne, & Simon, 2008). For instance, epistemic beliefs about science are thought to influence an individual’s motivation to engage critically and thoughtfully with peers in argumentative discourse, thus influencing the effectiveness of the activity in supporting conceptual change (Nussbaum, Sinatra, & Poliquin, 2008). Epistemic beliefs have been shown to influence participants’ engagement in written argumentation tasks to learn science (Nussbaum et al., 2008). For this study, I investigated whether the elementary PSTs’ varying epistemic beliefs regarding science (i.e., traditionalists, moderates, and constructivists) had an effect on their engagement with the argumentative discourse and any subsequent conceptual changes.

Statement of Purpose

The purpose of the study was to examine the influence of argumentative discourse-based lessons on PSTs’ conceptual understanding of the life science topics of photosynthesis and cellular respiration. This study addressed the following two research questions:

1. How were life science alternative conceptions of PSTs influenced, if at all, by participation in two lessons incorporating argumentative discourse?

2. What, if any, influence did the participants' epistemic beliefs about science have on their conceptual change outcomes following the two lessons incorporating argumentative discourse?

Significance of the Study

Many studies have shown that alternative conceptions about photosynthesis and cellular respiration are commonplace in K-12 students (e.g., Alparslan, Tekkaya, & Geban, 2003; Brown & Schwartz, 2009; Haslam & Treagust, 1987; Özay & Öztaş, 2003; Svandova, 2014), undergraduate students (e.g., Anderson et al., 1990), and PSTs (e.g., Ahopelto, Mikkilä-Erdmann, Anto, & Penttinen, 2011; Bursal, 2012; Krall, Lott, & Wymer, 2009; Öztaş & Öztaş, 2012). This is cause for concern, especially considering these future teachers will influence many students. Photosynthesis and cellular respiration are interconnected functions in the processes of life for plants, animals, and humans. A strong foundation in this conceptual understanding is necessary for making informed decisions and behavior changes regarding pressing societal issues such as climate change, agricultural land use, food production, and energy concerns. A necessary step for ensuring elementary students achieve an appropriate conceptual understanding of photosynthesis and cellular respiration is to first support PSTs in obtaining that knowledge themselves.

The reform-oriented instructional strategy of argumentative discourse has had positive outcomes in K-12 students (e.g., Hardy, Kloetzer, Moeller, & Sodian, 2010; Venville & Dawson, 2010), such as enhanced reasoning and problem-solving abilities (Gillies & Khan, 2008; Gillies, Nichols, & Burgh, 2011), and improved science achievement (Mercer, Dawes, Wegerif, & Sams, 2004). Research has also shown the benefits of argumentative discourse in college science courses (e.g., Adúriz-Bravo, Bonan, Galli, Chion, & Meindardi, 2005; Aydeniz, Pabuccu, Cetin, & Kaya, 2012; Eryilmaz, 2002; Niaz, Aguilera, Maza, & Liendo, 2002). However, there is less research regarding its uses specifically with PSTs. Argumentative discourse may encourage positive conceptual change in PSTs' understanding of critical life science content (Cetin, 2014), while also providing an effective model for their own future teaching practice (Lawson et al., 2002).

This study contributed to the current literature base regarding the use and outcomes of an argumentative discourse-based instructional approach in a sample of elementary PSTs. It revealed how their conceptualization of the topics of photosynthesis and cellular respiration changed over the course of two class periods as they engaged in discussions with peers to construct, analyze, and critique arguments based on provided evidence. The study also provided insights regarding the influence of underlying epistemic beliefs on the participants' conceptual changes. Possible challenges and supports to participants' engagement and subsequent conceptual change as identified in this study will be of interest to practitioners as they make decisions regarding effective instructional method for conveying science content knowledge.

Definition of Terms

To clarify understanding, a list of relevant terms and their definitions as used in this investigation follows. Some of these terms are complex and fluid, lacking precise definitions and therefore holding different meanings when used by different authors in varying contexts. Therefore, it is necessary to define the meaning of these terms as used for the purposes of this study.

The term *alternative conception* was used in this study to indicate any idea that is in part or completely at variance with accepted scientific knowledge (Driver & Easley, 1978). An alternative conception may be a simple mistake, or it may be a fundamental, extensive, and deeply rooted conceptual inaccuracy (Driver et al., 1985; Wandersee et al., 1994).

Argumentative discourse is a peer discussion experience used to engage learners in the practice of scientific argumentation within a social context. It can be defined as student-driven discussion for the purpose of reasoned argumentation around scientific concepts to promote deliberation, inquiry, and knowledge growth (Felton et al., 2009; Meiland, 1989). Argumentative discourse may be considered a specific type of collaborative discourse, especially when emphasizing its focus on shared explanation building over “adversarial argumentation” (Nussbaum, 2008, p. 349).

Collaborative discourse is a peer discussion experience in which learners reflect meaningfully about the academic content under study (Nussbaum, 2008).

Conceptual change, as used in this study, is the process in which a learner’s existing ideas and conceptual frameworks are modified to align more closely with accepted scientific conceptions (Posner, Strike, Hewson, & Gertzog, 1982; Tanner & Allen, 2005). This is in contrast to the philosophy of learning as a straightforward acquisition of new facts or new skills (Sigler & Saam, 2012). Learning as a process of conceptual change recognizes that the assimilation and accommodation of new facts is impacted and moderated by the organization, structure, and content of the learner's preexisting conceptual ecology (Posner et al., 1982).

Epistemic beliefs refer to the underlying beliefs participants hold related to knowledge and ways of knowing (Hofer & Pintrich, 1997; Schommer, 1990). In this study, I focused specifically on the participants' beliefs regarding the domain of science knowledge and knowing. Thus, e*pistemic beliefs* was selected over *epistemological beliefs,* since the term epistemological is often used to refer more to the overarching theory of knowledge rather than the specific beliefs in the learner (Nussbaum et al., 2008). Individuals who believe science knowledge is certain and fixed are considered to have traditional epistemic beliefs, while those who recognize the dynamic and fluid nature of scientific knowledge are considered to hold more constructivist epistemic beliefs (Muis & Franco, 2009).

Scientific argumentation refers to the practice of supporting or refuting a scientific claim with evidence and appropriate reasoning (Cohen, 1987; McNeill & Martin, 2011). Argumentation is a common exercise among professional scientists and has been recommended for inclusion in science education (NGSS Lead States, 2013; NRC, 2012).

Chapter Summary

Adequate scientific conceptual knowledge is seen as necessary for a population to be prepared to make informed decisions regarding critical socioscientific issues such as environmental concerns and issues related to human genetics (Hogan, 2002; Sadler & Zeidler, 2005). The continued economic growth and technological advances of the U.S.

relies upon the educational system to produce individuals with accurate understanding of science (Laugksch, 2000). Alternative conceptions conflict with accepted scientific thought, thus impeding appropriate scientific understanding. It is important that teachers know their content accurately and thoroughly and do not perpetuate alternative conceptions in their students. Ensuring that PSTs gain accurate knowledge of key life science topics like photosynthesis and cellular respiration is an important step in supporting the future achievement of students. The reform-oriented instructional strategy of argumentative discourse has shown promise in combating alternative conceptions in K-12 students (e.g., Gillies & Khan, 2008; Gillies et al., 2011; Hardy et al., 2010; Mercer et al., 2004; Venville & Dawson, 2010) and with elementary PSTs (e.g., Cetin, 2014; Kaya, 2013). This study sought to add to the body of literature regarding the use of argumentative discourse in supporting the science content knowledge of PSTs. The next chapter will present the theoretical framework and relevant literature for this investigation.

CHAPTER II: REVIEW OF LITERATURE

Introduction

Alternative conceptions in science are prevalent in learners at all levels (e.g., Ahopelto et al., 2011; Alparslan et al., 2003; Anderson et al., 1990; Brown & Schwartz, 2009; Bursal, 2012; Haslam & Treagust, 1987; Krall et al., 2009; Miller, 1998; Özay & Öztaş, 2003; Öztaş & Öztaş, 2012; Svandova, 2014). These vague and inaccurate conceptions can impede future conceptual growth and understanding of scientific phenomena (Chi et al., 1994; Driver & Easley, 1978; Michael, 1998; Wandersee et al., 1994). Teachers and PSTs are especially important populations who will influence many future students. It is critical that their conceptual understanding of science be as accurate and well developed as possible to support their teaching effectiveness (Ball, Thames, & Phelps, 2008; Darling-Hammond, 2000; Monk, 1994; Rowan, Chiang, & Miller, 1997; Shulman, 1986). The instructional method of argumentative discourse has been shown to promote positive conceptual changes in learners (e.g., Gillies & Khan, 2008; Gillies et al., 2011; Hardy et al., 2010; Mercer et al., 2004; Venville & Dawson, 2010), including PSTs specifically (e.g., Cetin, 2014; Kaya, 2013). The purpose of the study was to examine how argumentative discourse-based lessons influenced, if at all, the alternative conceptions of PSTs in the topics of photosynthesis and cellular respiration.

The following literature review provides the foundation for this study. It is organized into five main sections, which provide background from the published literature for this study and the interpretation of the results. The first section presents a discussion of the common origins of alternative science conceptions in learners, their durability, as well as some common photosynthesis and cellular respiration alternative conceptions. The second section provides more details concerning the strong negative impact teachers can have on their students when the teachers hold alternative science conceptions. The third section gives an overview of conceptual change theory and the proposed conditions needed for positive conceptual change in science learners. This provides the theoretical framework for the study. The fourth section presents information about the previous use of argumentative discourse as an instructional strategy. The fifth and last section is a discussion of how epistemic beliefs about science may influence the participants’ engagement in the argumentative discourse lessons and subsequently their conceptual change outcomes.

Alternative Conceptions

Alternative conceptions in life science are common in students at all levels as well as the general population (Miller, 1998). This is concerning for many reasons, not least of which life science is the most extensively taught science discipline in the U.S. educational system (McComas, 2007). Typically, students encounter life science and biology content over the course of their elementary, middle, and high school curriculum. In addition, most college students take biology rather than courses such as chemistry or physics to fulfill their general science requirement for many liberal arts degrees (McComas, 2007). Even with this extensive instruction in life science throughout the typical student’s K-16 matriculation, alternative conceptions abound (e.g., Brown & Schwartz, 2009; Haslam & Treagust, 1987; Krall et al., 2009; Miller, 1998). The next section will explore some of the common origins of alternative conceptions.

Origins of Alternative Conceptions

There are many causes that contribute to the development and retention of alternative conceptions (Qian & Guzzetti, 2000; Turkmen & Usta, 2007). Many of these factors may be categorized into four broad groups: pre-instructional naïve conceptions, interaction of naïve conceptions with accurate conceptions, poor instructional methods, and the direct transfer of alternative conceptions from teacher to student. A brief description of each follows.

Pre-instructional naïve conceptions. Even young learners do not enter the science classroom as blank slates. Instead, they bring a level of conceptual understanding already established and shaped by prior experiences and preexisting perceptions of the world (Driver et al., 1985). These naïve conceptions, which include the learner's preexisting attitudes, beliefs, and experience-based knowledge, may align accurately with the material to be learned, but more often, they do not (Brumby, 1984).

Experts have suggested that young children of all cultures develop four main domains of scientific thought prior to formal instruction (Schweingruber et al., 2007). These natural systems of thought align loosely with formal scientific disciplines, including naïve physics (behavior of objects), naïve psychology (behavior of sentient beings), naïve chemistry (makeup of chemical substances), and naïve biology (actions and organization of living things) (Schweingruber et al., 2007).

Children tend to apply consistent reasoning within each domain, although the types of reasoning they use may differ between domains (Spelke, 1994). These naïve conceptions typically do not conform to accepted scientific thought and have been shown to be difficult to dislodge through traditional instructional methods (Anderson et al., 1990; Balci, Cakiroglu, & Tekkaya, 2006; Brumby, 1984; Clement, 1982; Özay & Öztaş, 2003).

Interaction between pre-instructional conceptions and science instruction. Some of these alternative conceptions arise from the interaction of prior conceptions with new science concepts presented during formal instruction (Gilbert et al., 1982). Learners may misapply everyday definitions of words to science terms and fail to internalize the more specialized definitions during instruction (Gilbert et al., 1982; Meyer & Land, 2005; Westbrook & Marek, 1991). As an example, the word *theory* in an everyday sense is associated with an unfounded guess or personal opinion, whereas in a scientific context a theory is a well-established, factual, and highly reliable explanation for a phenomenon.

Also, learners may be introduced to new concepts when they are not developmentally or cognitively ready to accommodate them into their conceptual framework (Abraham, Williamson, & Westbrook, 1994; Lawson & Renner, 1975). Students who are cognitively unprepared to think abstractly may be unable to accurately accommodate and assimilate new information (Posner et al., 1982). This can result in the true meaning becoming altered. It can cause learners to combine ideas inappropriately and make inaccurate connections within their conceptual frameworks (Gilbert et al., 1982).

Poor instructional methods. Not only are alternative conceptions generated organically from naïve views, but ineffective science instruction also contributes to their development and perpetuation (Tullberg, Strödahl, & Lybeck, 1994). Science education in the U.S. has traditionally been characterized by an overemphasis on rote memorization of facts and a reliance on lecturing as the main instructional method. Educational research has repeatedly shown that lecturing is not as effective at supporting conceptual change as other more interactive and student-centered instructional methods (Hake, 1998; Knight & Wood, 2005; Springer et al., 1999). Arons (1997) elegantly summarized the issue more than 20 years ago:

> Finally I point to the following unwelcome truth: much as we might dislike the implications, research is showing that didactic exposition of abstract ideas and lines of reasoning (however engaging and lucid we might try to make them) to passive listeners yields pathetically thin results in learning and understanding except in the very small percentage of students who are specially gifted in the field. (p. vii)

Ineffective pedagogy often fails to support an accurate understanding of the nature of science and leads learners to think of science as simply a vast collection of observed facts (Brumby, 1984). Thus, they are encouraged to use superficial learning strategies such as rote memorization to ensure they will recall all the answers for the test (Brumby, 1984). This type of learning strategy is a poor way to create deep conceptual understanding or support retention of accurate conceptions.

Direct transfer. A final notable factor in the development and perpetuation of alternative conceptions in science is the transfer of alternative conceptions directly from teachers to learners. Like the general populace, elementary school teachers may lack depth of content knowledge and hold incorrect ideas related to scientific content, the nature of science, and the processes of scientific inquiry (Abell & Smith, 1994; Bloom, 1989; Lederman, 1992; Smith & Neale, 1989). Research suggests that teachers who hold alternative conceptions perpetuate them to their students. Evidence for this is found in the remarkable similarities between the alternative conceptions of teachers, both pre-service and in-service, and those of students (e.g., Burgoon & Duran, 2012; Burgoon, Heddle, & Duran, 2011; Liu & Li, 2017; Quílez-Pardo & Solaz-Portolés, 1995; Tullberg et al., 1994; Yip, 1998, 2001; Zeidler & Lederman, 1989).

Sometimes alternative conceptions may arise from a teacher's sincere effort to make the science content more accessible to students. Teachers may oversimplify information, inadvertently leading to confusion and inaccuracies or supporting their students' naïve conceptions rather than confronting and correcting them (Zeidler & Lederman, 1989). There are many specialized words in science that teachers may deem too advanced for their students. In using simplified language, concepts become less precise and less accurate. Research has found that the use of imprecise language without sufficient qualification of scientific terms can negatively impact students' conceptual understanding of the nature of science (Zeidler & Lederman, 1989).

Even using children's trade books in the classroom, arguably a valuable method for supporting science interest and accessibility for all reading levels (Mantzicopoulos & Patrick, 2011; Rice, 2002), can facilitate the development of alternative conceptions (Mayer, 1995). Rice (2002) identified a surprising number of explicit and subtle errors that inaccurately represented scientific principles in a sample of well-respected trade books. Results of the second part of her study revealed that students changed their correct science-related pre-test answers to incorrect post-test answers following the reading of a fictional trade book that contained subtle inaccuracies in the science content inherent in the story.

Also, teachers who lack sufficient conceptual understanding tend to accept without question the science textbook or other source deemed authoritative (Abimbola & Baba, 1996). Unfortunately, textbook explanations can be misleading (McComas, 2007; Roth, Bowen, & McGinn, 1999) or may contain outright errors (Abimbola & Baba, 1996; Storey, 1989; Dikmenli & Çardak, 2004). In such cases, a teacher without accurate personal knowledge will be of little use in preventing the dissemination of textbook-based errors (Abimbola & Baba, 1996).

Durability of Alternative Conceptions

Alternative conceptions in science have been found to be extremely robust and difficult to change permanently (e.g., Brumby, 1984; Driver et al., 1985; Harrell & Subramaniam, 2014; Helldén & Solomon, 2004). Alternative conceptions seem logical and reasonable to the learner. They may be reluctant to reject or adjust their alternative conceptions to more accurate, albeit, counter-intuitive explanations of scientific phenomena. Learners have been shown to adhere so strongly to their prior conceptions that they may even infer support for those ideas in evidence that actually contradicts them (Gunstone & White, 1981; Khalid, 2003). Brumby (1984) creatively termed this phenomenon “amazing eyesight” (p. 500).

Gilbert and colleagues (1982) explained that children may acquire and maintain “two perspectives” (p. 629) after science instruction: the teacher’s view and their original naïve view. They may be unwilling to give up their own conceptual understanding in favor of the accurate concept provided during instruction, even while acknowledging that the new view is what they are supposed to have learned. Helldén and Solomon (2004) found that learners repeated the same erroneous explanations of certain scientific phenomenon every time they were interviewed over a span of more than a decade. These explanations included the same alternative conceptions even after the participants had experienced science instruction that should have eradicated or advanced them closer to accepted scientific understanding. Helldén and Solomon (2004) also found that the participants in their studies often referred to the same naïve personal experiences when providing reasons for their explanations. Those early fixed ideas of the participants were much longer lasting than ideas introduced during schooling.

Even when learners appear to have understood and accepted the more accurate concept, they may still fail to reconceptualize or apply it appropriately in more real-world contexts (Gunstone & White, 1981; Wierdsma, Boersma, Knippels, & van Oers, 2016). Redish and Steinberg (1999) reported on a student who could readily explain Newton's Third Law of Motion (i.e., for every action there is an equal and opposite reaction), yet struggled with a question that asked which vehicle, a small car or large truck, would experience the greatest force in a collision. Although the student could demonstrate knowledge of the appropriate physics concept, she reverted to her naïve conception (i.e., larger things have larger force) when she had to apply the concept to a real world context. The ability to transfer ideas to new contexts is a critical marker of effective learning (Bransford et al., 1999). It can be argued that a learner who is unable to transfer or apply concepts has not really made sense of them or learned them fully and will likely revert to their original alternative conceptions.

Photosynthesis and Cellular Respiration Alternative Conceptions

This study investigated participants' alternative conceptions about two life science topics: photosynthesis and cellular respiration. Extensive previous research has identified numerous naïve conceptions learners hold about plants, photosynthesis, and cellular respiration (e.g., Ahopelto et al., 2011; Alparslan et al., 2003; Anderson et al., 1990; Bursal, 2012; Haslam & Treagust, 1987; Köse, 2008; Krall et al., 2009; Özay & Öztaş, 2003; Öztaş & Öztaş 2012; Sanders, 1993; Svandova, 2014). Learners of all ages have been shown to struggle with these concepts, including elementary PSTs (Cakiroglu & Boone, 2002; Köse, 2008), biology PSTs (Öztaş & Öztaş, 2012), elementary and middle in-service teachers (Krall et al., 2009), and in-service biology teachers (Sanders, 1993).

Alternative conceptions specifically about photosynthesis and cellular respiration are among the most comprehensively examined ones in the science education literature. There are far too many to list here comprehensively. There are, however, some common alternative conceptions that often arose in the groups studied. Some examples are shown in Table 1.

Table 1

Common Alternative Conceptions in Photosynthesis and Cellular Respiration

Selected Alternative Conceptions	Identified By
Plant biomass originates from the soil and/or nutrients found in the soil.	Krall et al., 2009; Kuech, Zogg, Zeeman, & Johnson, 2003
Plants only require soil, light, and water to survive.	Lumpe & Staver, 1995; Özay & Öztaş, 2003
Photosynthesis and cellular respiration are exactly reverse processes.	Alparslan et al., 2003; Çokadar, 2012
Cellular respiration in plants does not occur in the presence of light.	Haslam & Treagust, 1987; Köse, 2008; Krall et al., 2009
Cellular respiration is the same as physical respiration (breathing).	Cakiroglu & Boone, 2002; Köse, 2008

Many of the research studies that identified alternative conceptions have used a misconception survey originally developed by Haslam and Treagust (1987). Their 13-item survey was a two-tier, multiple-choice instrument, which diagnosed 21 alternative conceptions in secondary students. This present study used the Haslam and Treagust (1987) survey to identify alternative conceptions in participants, as well as concept mapping and interviews to reveal any others not identified by the instrument.

Why are these concepts considered difficult? In a large study conducted in the country of Turkey, Gungor and Ozkan (2017) found that photosynthesis was rated by biology PSTs as the concept most difficult to both learn and teach. This topic was chosen first among a list of other challenging subjects and concepts such as genetics, protein synthesis, and the circulatory system (Gungor & Ozkan, 2017). Uno (2009) argued that many learners find the study of plants inherently uninteresting and bemoaned the dwindling prevalence of botanical literacy in modern students. If learners are not motivated to learn about a topic, then that will lead them to consider it difficult.

A major reason photosynthesis and cellular respiration are thought to be especially difficult concepts to learn is because they are highly complex systems. They require an integrated understanding of interrelationships between many biochemical, physiological, and ecological processes (Waheed & Lucas, 1992). They cannot be fully understood in isolation. The learner needs to be able to understand connections between the living and non-living earth system. Learners may compartmentalize functions and concepts inherent in photosynthesis and thus struggle to build that deep, connected understanding (Brown & Schwartz, 2009).

Elementary PSTs have been shown to have difficulties with concepts that require the simultaneous consideration of more than one factor (Akçay, 2017; Harrell & Subramaniam, 2014). For example, Harrell and Subramaniam (2014) found that PSTs focused on only one characteristic (i.e., total particles present or the compactness of those particles) rather than combining them as is accurate when predicting the density of objects during a science methods course. Another study found that PSTs struggled with integrating the macrobiological and microbiological levels of systems when studying biology (Akçay, 2017). Unsurprisingly, the complexity of the processes of photosynthesis and cellular respiration, as well as their interconnectedness, can prove daunting to elementary PSTs who often lack a sufficient base of science content knowledge (Burgoon et al., 2011; Davis et al., 2006; Krall et al., 2009).

Photosynthesis and cellular respiration understanding is critical. Although the scientific concepts related to photosynthesis and cellular respiration in plants may be challenging, they are highly necessary to learn and understand. Barker and Carr (1989) declared that photosynthesis was the most important biochemical process on earth. Photosynthesis and cellular respiration are the foundation of life on our planet, for without plants' ability to create food energy molecules from carbon dioxide and water in the presence of light energy, there would be few ways for other living organisms to obtain energy for life processes. Without plants, the entire food chain would collapse, and subsequently humans and animals would cease to exist.

An understanding of photosynthesis and cellular respiration are also foundational to an integrated view of earth systems such as tracing the flow and interactions of matter and energy in the ecosystem (Brown & Schwartz, 2009; Songer & Mintzes, 1994). They help inform an individual's understanding of carbon cycling and the factors involved in climate change and other pressing environmental concerns. Without basic scientific knowledge, individuals lack the tools to engage in reasoned discussions and decision-making regarding key socioscientific issues (Lewis & Leach, 2006; Miller, 1998).

The previous section has presented some of the main causes of alternative conceptions. It also provided some background on common alternative conceptions related to the processes of photosynthesis and cellular respiration. The next section will examine how alternative conceptions in teachers can negatively impact their science teaching quality and their students' learning.

The Problem of Alternative Conceptions in Teachers

As discussed earlier, the development and persistence of alternative conceptions in science learners are influenced by four broad factors. Three of them are impacted by classroom teachers. Those three are the interaction of preconceptions with new instruction, poor instructional methods, and direct transfer. Extensive research has indicated that one of the most important factors in student learning is the teacher (Darling-Hammond, 2000; Marzano, 2003; Nye, Konstantopoulos, & Hedges, 2004; Stronge, Ward, & Grant, 2011; Wright, Horn, & Sanders, 1997). The positive influence of a highly qualified teacher is substantial, and over the course of one academic year has been shown to result in student learning gains two months ahead of the students of a less qualified teacher (Sanders & Rivers, 1996). This positive effect on learning is compounded by consecutive years with such a teacher (Mendro, Gordon, Gomez, Anderson, & Bembry, 1998). The detrimental effect of poorly qualified teachers is intensified in vulnerable populations such as students in low–performing schools (Rowan et al., 1997).

A complex variety of knowledge and skills contribute to teacher quality (Lewis et al., 1999). Experts agree that the essential knowledge required of effective teachers includes depth of disciplinary content knowledge, appropriate pedagogical knowledge, and the synergistic interaction of both, termed pedagogical content knowledge (Ball et al., 2008; Darling-Hammond, 2000; Monk, 1994; Rowan et al., 1997; Shulman, 1986).

Teachers cannot effectively teach what they themselves do not know or understand. Studies show that teacher understanding of science is correlated with their students' achievement (Diamond, Maerten-Rivera, Rohrer, & Lee, 2014; Hill, Rowan, & Ball, 2005; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013; Wayne & Youngs, 2003). Even with the support of an appropriate curriculum and sufficient resources, teachers may transfer their own alternative conceptions to their students (Burgoon et al., 2011; Quílez-Pardo & Solaz-Portolés, 1995).

Teachers' lack of conceptual understanding impacts more than just their ability to convey accurate information while teaching. There are at least three other notable ways that poor conceptual understanding impacts elementary teacher effectiveness: reduces self-efficacy in teaching science, reduces the time they choose to spend teaching science, and reduces the likelihood of using effective student-centered, reform-oriented teaching strategies. A description of each of these follows.

Reduced Science Teaching Self-Efficacy

Weak conceptual understanding can contribute to a lack of confidence and low self-efficacy in teaching science (Bandura, 1993; Bursal, 2008; Dembo & Gibson, 1985; Swackhamer, Koellner, Basile, & Kimbrough, 2009). Self-efficacy is a critical factor in overall teacher effectiveness (Bandura, 1993; Cakiroglu & Boone, 2002; Newton & Newton, 2011; Riggs & Enochs, 1990; Yuruk, 2011). Teachers' low self-efficacy has been shown to negatively impact the academic achievement of their students (Dembo & Gibson, 1985; Tschannen-Moran, Woolfok-Hoy, & Hoy, 1998). It should be noted that while the correlation between high alternative conceptions and low teaching self-efficacy in pre-service and in-service teachers has been noted in the literature, not all research studies have found that consistently. For example, Koc and Yager (2016) found that a group of PSTs had high self-efficacy for teaching, even while holding numerous alternative conceptions in physical science, earth/space science, and life science. Nonetheless, improving the self-efficacy of pre-service and in-service teachers can only enhance their teaching effectiveness.

Reduced Time Spent Teaching Science

Poor science understanding and associated low self-efficacy can influence teachers to avoid spending time teaching science (Czerniak & Chiarelott, 1990; Weiss, 1994). Elementary teachers often have full autonomy in choosing how to allocate instructional time for different subjects during school hours. Wilkins (2009) found that science consistently ranked at the bottom of primary teachers' favorite subjects to teach, which also predisposed them to avoiding spending time teaching the subject.

Reduced Use of Effective Teaching Strategies

One final problem is that teachers with limited science content knowledge are less likely to use inquiry approaches, cooperative learning opportunities, and other reform-oriented teaching methods when they teach science (Czerniak & Shriver, 1994; Roehrig & Luft, 2004; Weiss, 1994). Reform-oriented, student-centered instructional methods emphasize inquiry and the role of the student in directing their own learning (Anderson, 2002). Such strategies have been shown to correlate positively with student achievement (MacIsaac & Falconer, 2002). In contrast, teacher-centered instruction has been shown to be less effective at building integrated knowledge and reducing alternative conceptions than more student-focused strategies (e.g., Champagne, Gunstone & Klopfer, 1983; Driver & Easley, 1978; Eryilmaz, 2002; Granger et al., 2012; Lawson et al., 2002). Teachers who lack deep conceptual understanding, hold alternative conceptions, or teach unfamiliar topics are more likely to resort to teacher-centered instructional strategies (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956; Carlsen, 1992; Carlsen & Hall, 1997). They tend to discourage student discourse, ask less complex and lower-order questions, over-rely on the textbook, and choose lectures over instructional strategies that engage students' higher level thinking skills (Bloom et al., 1956; Carlsen, 1992; Carlsen & Hall, 1997).

The preceding paragraphs have outlined some negative impacts that poor subject-matter knowledge and alternative conceptions have on teaching effectiveness. It is vital for elementary teachers to hold accurate conceptions in science content to provide students with the best learning experience possible. Since alternative conceptions can be so resistant to change, it is critical to understand how conceptual change (from alternative conceptions to accurate conceptions) actually occurs in learners. The next section will present research on how conceptual change is theorized to occur and what types of experiences might support that process.

Theoretical Framework: Conceptual Change Theory

Science educators are tasked with supporting learners in restructuring and revising their existing alternative conceptions to better match currently accepted scientific understanding. This process of augmenting, modifying, and reorganizing alternative conceptions is a vital component of the complex task called learning. Conceptual change is considered to have occurred when a correct conception has been fully accommodated and a previously held alternative conception is no longer present (Posner et al., 1982). Arguably, the main goal of education is to initiate and support the change from an alternative conception to a more accurate one.

To determine methods of stimulating conceptual change in learners, it is first necessary to better understand how and why such a change occurs. The effort to discover answers to those questions has produced a huge body of research. This sub-discipline of conceptual change research, often situated within the fields of cognitive psychology and education, is vast, complex, and sometimes contentious. Studies regularly have raised more questions than they have answered. For the past four decades, researchers have sought to articulate a model that appropriately explained this process. A variety of models have been proposed that suggest what conditions might best support conceptual change in learners (Chi et al., 1994; Duit & Treagust, 2003; Hewson & Hewson, 1984; Posner et al., 1982; Vosniadou, 1994).

Posner and colleagues (1982) were among the first to develop a well-articulated theory of conceptual change. They posited that four cognitive conditions must be met for a learner to restructure their alternative conceptions. These four conditions are as follows:

1. The learner must experience dissatisfaction with their current conception(s).
2. The newly presented conception(s) must be perceived as intelligible.
3. The new conception(s) must be accepted as plausible.
4. The new conception(s) must appear fruitful.

More recent interpretations have presented an increasingly complex view of conceptual change. For example, some models have emphasized the need to explicitly address students' underlying ontological understandings that conflict with the new ideas when seeking to support them in restructuring their conceptual frameworks (Chi et al., 1994). Many models continue to acknowledge the importance of certain cognitive conditions for supporting conceptual change but also emphasize the role of affective conditions such as the learners' own beliefs, motivation, and intentionality in effecting conceptual restructuring (Duit & Treagust, 2003; Pintrich et al., 1993). The models reviewed here align with Posner et al. (1982) in stressing that the learners' prior understanding must be activated and acknowledged as educators seek to promote conceptual changes (Chi et al., 1994; Duit & Treagust, 2003; Hewson & Hewson, 1984; Posner et al., 1982; Vosniadou, 1994). There must be opportunities for learners to compare and contrast their current conceptions with new ideas as they seek to adjust to more accurate understanding (Chi et al., 1994; Dole & Sinatra, 1998; Vosniadou, 1994).

Using conceptual change theory as the framework for this study led to the use of argumentative discourse as an impetus for conceptual change. In addition, it was with this lens that the results were interpreted and conceptual change outcomes identified. The next section will provide more details about how using argumentative discourse as an instructional strategy may be an effective way to encourage and support true conceptual change in learners.

Argumentative Discourse

Research in science education has continued to seek instructional methods that aid learners in the vital process of conceptual change. There is a need to identify and implement reform-oriented strategies that shift the focus of instruction away from the traditional teacher-centric model to a more student-centered one. Argumentative discourse is one reform-oriented instructional method shown to have promise in the science classroom. Argumentative discourse consists of peers discussing scientific phenomena with the goals of both disputation and deliberation (Felton et al., 2009). It is reasoned argumentation from evidence, which promotes scientific inquiry and conceptual sense-making (Felton et al., 2009; Meiland, 1989).

Research has demonstrated argumentative discourse results in a variety of positive cognitive outcomes in K-12 students. For example, it has encouraged enhanced reasoning and problem-solving abilities (e.g., Acar, 2015; Gillies & Khan, 2008; Gillies et al., 2011; Jiménez-Aleixandre & Pereiro-Munhoz, 2002), increased conceptual understanding (e.g., Hardy et al., 2010; Mason & Santi, 1998; Venville & Dawson, 2010; Zohar & Nemet 2002), and improved science achievement (e.g., Mercer et al., 2004; Zohar & Nemet, 2002). Miller and colleagues (2014) demonstrated that simply the expectation of an upcoming argumentative discussion improved the conceptual change results of third and fourth graders after reading scientific texts.

Argumentative discourse has been shown to support positive conceptual change in college students as well. Engagement in such experiences has benefited the conceptual understanding of undergraduates in science courses. This has been demonstrated in the science disciplines of physics (Eryilmaz, 2002), chemistry (Aydeniz et al., 2012; Niaz et al., 2002), and biology (Adúriz-Bravo et al., 2005).

Since argumentative discourse has promoted improved conceptual understanding in science students of all levels, it is important to consider its use specifically in elementary teacher preparation. It has been suggested as an effective strategy to use with PSTs to deepen their science understanding. Better conceptual understanding would encourage confidence with the material, reduce individual alternative conceptions, and help halt the cycle of transferred alternative conceptions from teachers to students (Cross, Taasoobshirazi, Hendricks, & Hickey, 2008).

A review of the literature revealed studies that specifically examined conceptual change outcomes in PSTs following participation in argumentative discourse (e.g., Cetin, 2014; Kaya, 2013; Nussbaum et al., 2008; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002). Kaya (2013) used a quasi-experimental method to examine the content acquisition of chemistry concepts in a group of elementary PSTs. Results showed that the argumentation group, who engaged in instructional tasks such as individual written arguments and whole class argumentative discourse, significantly increased their conceptual understanding over the traditional instruction group. In the second study, Cetin (2014) found significant conceptual advances regarding the subject of chemistry rate reactions in PSTs who engaged in written arguments and argumentative discourse. Although limited in scope, these results suggest the potential for generating conceptual change through argumentative discourse.

Argumentative discourse in the science classroom can support positive learning outcomes, including conceptual change in learners. Three reasons for this emerged from the literature. Argumentative discourse (a) aligns with the conceptual change model, (b) exemplifies sociocultural learning, and (c) supports scientific proficiency. These are explained in more detail in the upcoming sections.

Aligned with Conceptual Change Theory

Argumentative discourse aligns with many of the conditions considered necessary for conceptual change as posited by Posner and colleagues (1982). Argumentative discourse activates prior learning and requires the participants to make their current conceptions explicit to both themselves and others. This helps prepare learners to modify and adjust their conceptual frameworks to align better with the new concept or conceptual framework (Chin & Teou, 2009). By engaging learners in explaining their conceptions, they are forced to recognize the inadequacies of their current understanding (Brumby, 1984). This conceptual conflict is thought to motivate learners to seek to restructure their conceptual frameworks and adjust their understanding to a more scientifically accurate one (Hewson & Hewson, 1984). This has been posited to be an important first step in creating conceptual change (Posner et al., 1982).

Argumentative discourse’s emphasis on evidence, logic, and reasoning provides learners with skills in evaluating ideas and thus discerning those that are most intelligible, plausible, and fruitful (Nussbaum & Sinatra, 2003). It forces them to measure their own ideas against others and use reasoning to determine which are most appropriate and should be adopted. This process supports learners in developing critical thinking skills, epistemic thinking, and conceptual understanding (e.g., Driver et al., 2000; Osborne, Erduran, & Simon, 2004). In a society that has nearly limitless access to both scientific facts and erroneous assertions on the internet, it is critical that science educators seek to develop these evaluative reasoning skills in learners (Osborne, 2007).

In addition to encouraging internal cognitive conditions that may best nurture conceptual change, argumentative discourse can also provide the teacher with important information regarding the learner's current conceptual framework. This can then benefit the learner since the teacher is better able to understand the current conceptions and how to best address them. Through argumentative discourse, learners reveal their patterns of reasoning and details about their current conceptual frameworks (Osborne et al., 2004). This is valuable information for the effective teacher, who can use the insights into students' conceptual understanding for formative assessment purposes (Bell & Cowie, 2001). Having knowledge of what the students do and do not understand allows the teacher to provide relevant student feedback and guides future instruction (Bell & Cowie, 2001). Recognizing the value of discovering learners' existing conceptual frameworks, Ausubel and colleagues (1978) stated, "The most important single thing influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (Ausubel et al., 1978, p. vi).

Exemplifies Sociocultural Learning

Argumentative discourse situates science learning into a social context, thus helping to make the practices of science more collaborative, relevant, and engaging to learners (Nussbaum & Sinatra, 2003). It encourages collaboration and communication among students and emphasizes the socially constructed aspect of science (Newton et al., 1999). This is critical for enhancing students' scientific literacy and aiding their understanding of the nature of science (Driver et al., 2000).

In argumentative discourse, not only must an individual be concerned with making one's own case, they must also critically evaluate others' alternative explanations (Duschl, Schweingruber, & Shouse, 2007). This may serve to support and effect change in alternative conceptions (Cross et al., 2008). Newton and colleagues (1999) summarized it well. They said:

> Talking offers an opportunity for conjecture, argument, and challenge. In talking, learners will articulate reasons for supporting particular conceptual understandings and attempt to justify their views. Others will challenge, express doubts and present alternatives, so that a clearer conceptual understanding will emerge. (p. 554)

Argumentative discourse is an inherently engaging and active learning strategy. Interactive peer discussions using argumentation have been shown to promote learner engagement and motivation to learn (Chin & Teou, 2009; Pintrich et al., 1993). This positively influences the acquisition of appropriate conceptual knowledge (Smith et al., 2009). Wang and Buck (2015) found that argumentation activities promoted student interest and engagement and did not negatively influence subject matter knowledge, according to test scores. They stated, "Engagement is critical in the shift of students' role from passive receivers to active learners" (p. 357). Wang and Buck (2015) postulated that with more time spent on argumentative discourse, more positive growth of students' subject matter knowledge would occur.

Ebert-May and colleagues (1997) found that the incorporation of cooperative learning, peer discussions, and peer debates into a biology course resulted in a number of positive benefits. Learners in the course reported an increased desire to participate and pay attention in class and more recognition of the relevance of the content to their lives. In addition, the learners believed they would remember the content longer. Attendance and overall student participation (i.e., volunteering answers in class) were greater than in the traditionally taught course section.

Lumpe and Staver (1995) reported that peer collaborative group learning tasks better supported the reduction of photosynthesis misconceptions in high school biology students. Although their study did not specifically implement argumentative discourse, they reported that the group discussions included both consonant and dissonant interactions. Furthermore, they specifically recommended that collaborative learning activities should be designed to promote both types of interactions, not just simple agreement (Lumpe & Staver, 1995).

Supports Scientific Proficiency

Argumentative discourse supports learner engagement in the four strands of scientific proficiency, a framework for learning that is grounded in recommendations for reform (Schweingruber et al., 2007). The four strands are: (1) know, use, and interpret scientific explanations of the natural world; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge;

and (4) participate productively in scientific practices and discourse (Duschl et al., 2007). The strands highlight a framework for acquiring science understanding that emphasizes the fully integrated nature of content with practice, and should be used to guide the planning and assessment of lessons (Schweingruber et al., 2007). Research has shown the fourth strand to be particularly critical, yet it is the strand most often overlooked or poorly implemented by many educators (Schweingruber et al., 2007).

The science and engineering practices in the NGSS also emphasize the importance of argumentation (NGSS Lead States, 2013). One of the eight key science and engineering practices, engaging in argument from evidence, is embedded within the performance expectations of K-12 students at all levels (NGSS Lead States, 2013). When engaged in argumentative discourse, learners typically also are given a chance to practice at least three more of the science and engineering practices: a) analyzing and interpreting data, b) constructing explanations and designing solutions, and d) obtaining, evaluating, and communicating information (NGSS Lead States, 2013).

Drawbacks of Argumentative Discourse

The use of argumentative discourse as an instructional approach is not without its critics. Admittedly, there are challenges to its effective implementation in the classroom. Unfortunately, due to the following drawbacks, some teachers may avoid using the strategy all together.

Time consuming. Learning tasks that require students to engage in argumentative discourse are perceived as extremely time–consuming (Kilinc, Demiral, & Kartal, 2017; Sampson & Blanchard, 2012). It can take learners extensive time to research, reason, collaborate, discuss, debate, evaluate, revise, and engage in other practices inherent to scientific argumentation. Unfortunately, that may deter teachers from using a strategy like this that prioritizes deep conceptual learning at a substantial time investment.

The research indicates, however, that the extra time spent on deep, interactive conceptual learning and the resulting reduced time spent on reviewing a surplus of disconnected scientific facts does not have a negative effect on student achievement (Ebert-May et al., 1997; Knight & Wood, 2005). Activities that boost students' reasoning and problem-solving skills and in-depth understanding of a few underlying concepts are arguably more beneficial to students overall (Knight & Wood, 2005). Decades ago, Songer and Mintzes (1994) observed, perhaps sardonically, "It appears that considerably more time will have to be allocated to the topic of cellular respiration in the curriculum if understanding is the goal of instruction" (p. 634). Obviously, student understanding should always be the goal of teaching, even if that understanding comes at a perceived cost in instructional time.

Unstructured nature. One of the most prominent critiques of the use of argumentative discourse for instruction originates in its unstructured nature. Learners are required to reason through evidence, generate reasonable explanations, evaluate others' reasoning, and reach learning goals with minimal direct instruction. These learning experiences epitomize the ideology of a constructivist-based approach and have proven to be effective in supporting student learning (Granger et al., 2012).

The unstructured nature of the above tasks makes it more challenging for teachers to implement and students to participate, as compared to traditional teacher-directed instruction. There are those who advocate for guided instruction and more teacher-directed learning experiences (e.g., Kirschner, Sweller, & Clark, 2006). They argue that students need more structure and guidance than is provided by argumentation to best learn. Additionally, argumentative discourse does not easily lend itself for use in teaching a large number of discrete facts and vocabulary. Thus, teachers who prioritize the memorization of large amounts of scientific facts over the deep conceptual learning of their students may not find argumentative discourse particularly useful for their purposes.

Perceived as cognitively challenging. Learners may also find engaging in argumentative discourse to be challenging or frustrating. This is especially true of learners who are used to traditional science teaching that consists of the teacher lecturing and the learner memorizing the facts in preparation for regurgitating them on the exams. Argumentative discourse requires in-depth thinking and active engagement, within which some learners are not eager to participate. It also requires collaborating and communicating effectively with others, which some students may find difficult, annoying, or uncomfortable (Knight & Wood, 2005).

It is true that argumentative discourse has been found to work well with individuals of high cognition (Dole & Sinatra, 1998), but that does not mean that lower-performing students will not also benefit. Teachers sometimes have an expectation that their lower-performing students are unable to appropriately engage in or benefit from reform-oriented instructional practices (Sampson & Blanchard, 2012). Although this perception may not be reality, it can prevent teachers from attempting a complex instructional approach such as argumentative discourse with their students.

Influence of Epistemic Beliefs

One of the propositions underlying this present study was that individuals' epistemic beliefs about science influence their conceptual change outcomes due to the argumentative discourse-based lessons. This proposition is supported by a body of literature showing that an individual's epistemic beliefs have an effect on a variety of cognitive processes, attitudes, behaviors, and learning outcomes (Nussbaum & Bendixen, 2003; Nussbaum et al., 2008; Schraw, Dunkle, & Bendixen, 1995; Wallace, Tsoi, Calkin, & Darley, 2003).

For example, Schraw and colleagues (1995) found that epistemological beliefs about the nature of knowledge and learning accounted for the variation in participants' solving of ill-defined problems but not in solving well-defined problems. These problems are those "for which there are conflicting assumptions, evidence, and opinion which may lead to different solutions" (Kitchener, 1983, p. 223). These complex problems require higher-order thinking skills and have no clearly defined procedures for solving them.

Epistemic beliefs specifically about science can influence how students engage in scientific argumentation (Noroozi, 2016; Nussbaum & Bendixen, 2003; Nussbaum et al., 2008). For example, Nussbaum and Bendixen (2003) found that epistemic beliefs had an impact on an individual's tendency to avoid or willingness to engage in argumentative discourse about science topics. They reported that the participants who considered science knowledge to be simple and unchanging found argumentation to be particularly anxiety-inducing and thus tried to avoid it (Nussbaum & Bendixen, 2003).

A study by Nussbaum, Sinatra, and Poliquin (2008) was found to be similar to this present study and helped inform its development. In it, Nussbaum and colleagues (2008) explored the influence of underlying epistemic beliefs on the learning outcomes of college undergraduates who engaged in argumentative discourse while solving physics problems. Their study had similar participant demographics to this present study, though a much larger number of participants. Likewise, nearly identical to this present study, Nussbaum and colleagues (2008) were interested in how the participants' epistemic beliefs influenced their engagement in argumentation and their subsequent learning. Unlike this study, though, their study used an experimental and control group in which the experimental group received more training and support related to how to engage in productive argumentation. A closer look at this study is provided in the following paragraphs.

Nussbaum and colleagues (2008) studied a group of undergraduates (N = 88) who were nearly all PSTs, with 94% planning to pursue a teaching credential. The authors stated that few of the participants had strong science or mathematics backgrounds. They first randomly assigned the participants to partners (dyads) and then divided the entire group into a treatment and control group. The dyads in the treatment group were given training in scientific argumentation, while the dyads in the control group were not. The researchers administered surveys that rated each participant's tendency toward argumentativeness as well as their epistemic beliefs. The epistemic beliefs survey used was by Kuhn, Cheney, and Weinstock (2000) and was designed to categorize survey participants into three groups: absolutists, multiplists, and evaluativists. As described by

Kuhn and colleagues (2000), absolutists view knowledge as objective, external, and absolute, essentially completely separate from the individual. This is considered the least sophisticated epistemic belief level. Multiplists recognize the subjectivity of the "knowing subject" (p. 310) and view knowledge as completely subjective, and thus every individual's knowledge is equally valid and true. Evaluativists, considered to hold the most sophisticated epistemic beliefs, blend the objective and subjective nature of knowing. They acknowledge the subjective nature of knowledge, but do not accept all opinions or beliefs as factual. They recognize that some knowledge can "be more right" (p. 311) if it is more supported by evidence.

After the surveys, Nussbaum and colleagues (2008) gave participants a physics problem and asked them to discuss the problem and develop a joint answer in an online discussion forum private to each dyad. Those dyads in the treatment group were provided with access to additional web resources that provided information on the criteria for a good scientific argument. The control group dyads were not. Finally, a second physics problem was provided, and the dyads were instructed again to discuss and develop a joint answer.

The researchers analyzed the resulting written discussions, final arguments, and answers to the problems. The results showed that those in the treatment group considered more ideas, included more thought experiments, and wrote more developed scientific arguments than those in the control group. There was no statistical difference in the two groups regarding the level of misconceptions that increased or decreased over the study. Only 12% of the entire participant group showed a decline in misconceptions. However, those in the treatment group settled on the correct answer for one of the physics problems significantly more often than did those in the control group.

The results regarding the influence of the epistemic beliefs on the learning outcomes are the most instructive in regard to this present study. According to the ratings on the epistemic belief survey (Kuhn et al., 2000), the participants in Nussbaum and colleagues' (2008) study were 12% absolutists, 28% multiplists, and 55% evaluativists. Both the control and treatment groups included participants of all epistemic beliefs, and there was no statistical difference between the two groups as to the makeup of epistemic beliefs.

The results showed that (in both the treatment and control groups), evaluativists suggested more and more diverse ideas during the discussion as compared to absolutists (multiplists were between the two and did not differ significantly from either). Multiplists interacted less than the others and tended to agree with their partners, rarely arguing. Anxiety was ruled out as a factor causing the multiplists to avoid arguments, due to an additional analysis, which found they scored the lowest on argument avoidance. This is in contrast with a study conducted by Nussbaum and Bendixen (2003), which found that those with less constructivist epistemic beliefs (i.e., more traditional beliefs) had more anxiety about engaging in argumentation.

There was no statistically significant difference in the participants' conceptual changes identified during the Nussbaum et al. (2008) study based on epistemic beliefs. However, the researchers indicated there was an observable trend toward more reduced misconceptions in evaluativists even though there was no difference found statistically.

Tellingly, following the argumentative discourse experiences, the evaluativists were four times more likely to have adopted the correct answers to the physics problem than were the absolutists.

In their qualitative analysis, the researchers determined that the evaluativists were more critical of one another's arguments and more willing to suggest additional or divergent ideas. Their reasoning tended to be logical and coherent. The multiplists, in contrast, usually agreed readily with their partner with little discussion. Dyads containing multiplists were the least interactive of all the combinations. Multiplists were less likely to notice or mention inconsistencies in their own thinking. They also exhibited more misconceptions than evaluativists overall. Absolutists, the smallest group in the study, tended to be highly interactive and like evaluativists, exhibited a decline in misconceptions.

Nussbaum and colleagues (2008) concluded that their study supported the hypothesis that more training in the criteria for scientific argumentation would boost the quality of the arguments and subsequently the learning outcomes of the participants. Additionally, their study lent support to the idea that epistemic beliefs influenced the scientific argumentation process and the conceptual shifts in the participants, with differences apparent between evaluativists and multiplists. Evaluativists were more interactive, more critical of ideas, and more reasonable and consistent in their arguments as compared to multiplists. By the end of the discussion with their partner, evaluativists were four times more likely to embrace the correct answers to the proposed physics problems than were multiplists.

The results of the Nussbaum et al. (2008) study demonstrated that participants' underlying epistemic beliefs about science do have an influence on how they engage and participate in argumentative discourse as part of a learning experience. Although there was no statistical difference found in the learning outcomes of their participants based on epistemic beliefs, there was a noticeable anecdotal difference in how they engaged in the argumentation. Thus, Nussbaum and colleagues' study lent support to this present study's proposition that the epistemic beliefs of the participants could impact the extent that the argumentative discourse experience could spur positive conceptual change about photosynthesis and cellular respiration.

Chapter Summary

This chapter presented relevant background literature that established a foundation for this study. Learners of all ages, including PSTs, hold many alternative conceptions related to the important life science topics of photosynthesis and cellular respiration. The instructional strategy of argumentative discourse is suggested as a means of supporting the learners' conceptual change from alternative conceptions to conceptions more in line with accepted scientific thought. This case study examined the experience of a group of elementary PSTs as they engaged in argumentative discourse-based lessons to learn about photosynthesis and cellular respiration. The influence, if any, of their epistemic beliefs about science was also examined.

The next chapter will explain the methodology of this multiple–embedded case study. The research design, context, and participants will be described. Details will be provided regarding survey instruments and other data sources. The procedures for data collection will be outlined, as well as a description of the data analysis procedures and the limitations of the study.

CHAPTER III: METHODOLOGY

Introduction

There has been promising research regarding the positive impact of argumentative discourse on K-12 students' understanding of science (e.g., Gillies & Khan, 2008; Gillies et al., 2011; Hardy et al., 2010; Mercer et al., 2004; Venville & Dawson, 2010). In addition, there have been a growing number of studies showing that this approach works well with populations of PSTs (e.g., Cetin, 2014; Kaya, 2013; Zembal-Saul et al., 2002). The purpose of this present study was to describe how lessons incorporating argumentative discourse opportunities influenced, if at all, the alternative conceptions of PSTs in a life science content course.

This chapter outlines the methods for conducting this present study. An overview of the research design will be followed by a description of the context and participants. Next, a detailed explanation of the data collection instruments and sources will precede a description of the procedures for implementing the argumentative discourse instruction in the classroom and the method of conducting the data collection. Finally, an explanation of the data analysis procedures will be provided and limitations of the study acknowledged.

Research Design

This study employed a descriptive multiple-case study research approach. This qualitative approach was most appropriate because the investigation was concerned with describing a clearly bounded phenomenon situated within a real-life context (Yin, 2014).

In this study, the case was bounded by the parameters of time and place because it consisted of a single life science course for PSTs during the spring semester of 2015.

The investigation was structured as a multiple descriptive case study with embedded cases. There were three cases which were small groups formed of three to four individuals with similar epistemic beliefs about science: the traditional group (Group T), the moderate group (Group M), and the constructivist group (Group C). Each individual within the groups were the embedded cases, examined and reported as an embedded unit of analysis within their respective group case. Each group case was also analyzed as a whole.

A qualitative case study design was chosen due to the descriptive nature of the two research questions. Both questions required detailed descriptions of a specific situation in order to be answered. Thus, the case study design was deemed most appropriate since it allowed for a comprehensive look at a relevant context (Yin, 2014).

The multiple-case study design was chosen to facilitate the examination of how the epistemic beliefs of the participants influenced their conceptual outcomes. Three group cases were formed, made of participants with similar beliefs. One group consisted of participants with mostly traditional beliefs, one with moderate beliefs, and one with strong constructivist beliefs. These multiple cases were theoretical replications carefully selected with the expectation that there would be differing results from each other based on “anticipatable reasons” (Yin, 2014, p. 57). The rationale was to include a case that represented both extremes, called a two-tail design (Yin, 2014). The moderate group case was also included to provide more insights and strengthen the findings.

Within each case were the individual embedded cases. The embedded case design (Yin, 2014) was necessary since the specific results of the individuals addressed the research questions about the conceptual change outcomes for themselves and also for their associated group case. To understand how the alternative conceptions changed over the course of the study, the changes were examined in the individuals.

The participants in this course exemplified a typical or representative case (Yin, 2014). The case was considered representative because it consisted of a standard group of predominantly female PSTs in a typical teacher preparation content course experiencing a new instructional approach. Lessons drawn from this descriptive case study may be relevant to the average elementary PST.

A descriptive case study is typically based upon certain propositions. These theoretical propositions are concepts that provide a focus for the study and should be examined (Yin, 2014). These propositions influence the data collection methods and analytical processes (Yin, 2014). The two propositions for this study originated in the literature and were chosen due to the outcomes of previous studies and the interests of this researcher.

The first proposition was that argumentative discourse can promote conceptual change in learners. The use of argumentative discourse as an instructional method has been shown to increase understanding in learners (Nussbaum et al., 2008). Limited prior research has also suggested that engagement in argumentative discourse positively influenced alternative conceptions (Aydeniz et al., 2012).

The second proposition was that epistemic beliefs could influence the extent to which argumentative discourse impacts conceptual change in learners. Research has shown that epistemic beliefs have an influence on PSTs' attitudes, cognition, choices, and actions (e.g., Sinatra & Kardash, 2004; Yadav & Koehler, 2007). In examining and comparing the three epistemic beliefs groups (i.e., traditionalist, moderate, and constructivist), it was expected that there would be a difference in how effective the argumentative-based lessons were at promoting conceptual change in the group members. I expected to find that in general the constructivist group would experience more conceptual change than the other groups, as their epistemic beliefs would align well with the instructional approach and PSTs would engage more naturally and fully in the learning process. I expected that the traditionalist beliefs group would experience the least conceptual change since their epistemic beliefs were more likely to conflict with the instructional method, making it more difficult for them to engage with the learning process.

Research Context

This study was conducted at a large public university in the southeastern United States. This university was originally founded as a normal school, which was an institution of higher learning preparing high school graduates to be teachers (Labaree, 2008). Most normal schools eventually expanded into regional state universities during the mid to latter part of the 20th century (Labaree, 2008). This university followed that trend and transitioned to official university status.

The university publishes a yearly accounting of the student enrollment and demographics each fall semester. Although this study took place specifically during the spring semester of 2015, the demographics reported here are the official ones reported from the 2014 fall semester. These are illustrative of the demographics during the second semester of the 2014-2015 school year. The total enrollment for fall semester 2014 was 22,729, of which 73% were full-time undergraduate students. Of the total student enrollees, 54% were female and 46% were male. The university served a diverse population. During the fall of the academic year in which this study took place, 4.3% of the student population identified as Hispanic, 4.5% Asian, 19.7% Black, and 67.0% White. The remaining percentage consisted of those identifying as American Indian, native Pacific Islander, Native Alaskan, not specified, and those who identified with two or more ethnicities.

Despite the university's history as a normal school, the College of Education had the smallest enrollment of all the colleges at the institution during fall semester 2014. Undergraduate students seeking certification to teach elementary school grades, including early childhood education, special education, and interdisciplinary studies, composed approximately 4% of the total student body, a decline of about 1% as compared to the previous year, fall semester 2013. A total of 200 undergraduate elementary education degrees were conferred during the 2013-2014 academic year. A total of 159 undergraduate elementary education degrees were conferred during the 2014-2015 academic year, the year in which this study was conducted. It should be noted that these numbers are only elementary level education degrees and do not include those seeking secondary teaching licensure in specific subject areas/majors, such as biology, chemistry, mathematics, and others.

As is common in the field of elementary teacher education, females outnumbered males by a large margin. A total of 820 females were seeking education degrees during fall semester 2014, compared to only 73 males. A large discrepancy in gender was evident in those graduating with a degree in elementary education during the 2014-2015 academic year: 17 males and 183 females. The graduating class of 2014-2015 was similar, with five males and 154 females awarded degrees in elementary education. This large gender difference was evident in the day-to-day makeup of all elementary education courses, which tended to be overwhelmingly female.

The Course

This study examined PSTs enrolled in an undergraduate course designed to provide essential life science content knowledge for those preparing to teach grades PreK-6. The course was situated in the biology department of the university and was focused on building the content knowledge of elementary PSTs. It was not an educational methods course, and pedagogical techniques were not explicitly taught. The university first instituted this content course for prospective elementary teachers more than 20 years previously, in response to the realization that better content knowledge positively impacts a teacher’s self-efficacy thus increasing their effectiveness and their students’ achievement (Bandura, 1993; Bursal, 2008; Dembo & Gibson, 1985; Swackhamer et al., 2009). The course provided four upper division credit hours toward an education degree. It was taught using a combined lecture and laboratory approach. The class met for two hours and five minutes each Monday, Wednesday, and Friday morning during the spring semester of 2015.

The Professor

The life science course in which the study occurred was taught by Dr. Pepper (a pseudonym) during spring semester 2015. Dr. Pepper was a tenured, full professor in the biology department at the university. Dr. Pepper had taught this course at this university for more than 20 years. She held an undergraduate degree in biology and secondary education, as well as a master's degree in curriculum and instruction. Her doctoral degree was in environmental science. Dr. Pepper's passion for environmental education was evidenced by her involvement in research and practitioner-based initiatives, as well as her work providing content for and evaluating international curriculum projects such as Project Learning Tree. Dr. Pepper was the recipient of many teaching and public service awards, highlighting her commitment to her students and the community.

Dr. Pepper's focus in the life science course was to ensure the PSTs deepened their understanding of the life science knowledge they would need to be effective elementary school teachers. Thus, she prepared them in life science topics that were commonly taught in upper elementary school, according to the state's science standards. She also used the life science topics tested on the Elementary and Middle Grades Education Content Knowledge Praxis (Educational Testing Service [ETS], 2014) to guide her choices for content to include in the course. The Elementary Education Content Knowledge Praxis was one of the exams required in this state for elementary teacher certification (ETS, 2015).

Dr. Pepper used a variety of reform-oriented, research-based instructional methods to convey the life science content she determined as most critical for the PSTs to acquire. Although the main goal of the course was for the PSTs to increase their science knowledge, a secondary goal of Dr. Pepper's was to model effective pedagogy for her students to emulate later in their own science teaching practice. Arguably, one of Dr. Pepper's most valuable teaching qualities was her willingness and motivation to continually improve her own pedagogy and to try new instructional methods that best supported her students' learning.

Preparation

Dr. Pepper began implementing argumentative discourse in the course during both fall semester 2014 and spring semester 2015, prior to the start of this study later in the spring semester. Although the argumentative discourse lesson construct was new to Dr. Pepper, she had previously used many of the characteristics of this strategy in her teaching. For example, she placed the PSTs in small groups at tables and implemented cooperative learning activities throughout the course. This had developed a culture of collaboration among the PSTs, and they often engaged in prompted and unprompted peer discussions. Dr. Pepper also sought to provide PSTs with meaningful context for their learning and opportunities for reflection. She emphasized the use of scientific inferences and the development of increasingly sophisticated conceptual understandings. All of these have been identified as aspects of a learning theory that informs effective teaching practice (Bransford et al., 1999; Glaser, 1994) and are considered to be foundational frameworks for scientific inquiry and argumentation (Duschl & Osborne, 2002).

Prior to the treatment lessons in this study, Dr. Pepper implemented two separate argumentative discourse-based lessons. The purpose of these lessons was threefold: 1) to explicitly teach the PSTs about the process of argumentation in science and how to create a good logical argument using McNeill and Krajcik's (2012) Claims, Evidence, and Reasoning (CER) Framework, 2) to provide the PSTs with practice engaging in argumentative discourse, and 3) to provide Dr. Pepper with practice facilitating argumentative discourse learning experiences. The two lessons were developed by myself in consultation with Dr. Pepper, and were implemented by Dr. Pepper. The lessons required PSTs to use the CER framework to write individual arguments and then participate in small group discourse about science topics relevant to the course. The PSTs also developed written arguments in response to essay questions on their exams.

These lessons allowed the PSTs to practice constructing scientific arguments and engaging in argumentative discourse with their group. This increased their familiarity with this type of a learning experiences so they would be better prepared to participate in the treatment lessons. The lessons also helped Dr. Pepper practice implementing the argumentative discourse lesson framework with the PSTs. Since this instructional strategy was not something she had explicitly done before, these lessons helped prepare her to implement the photosynthesis and cellular respiration argumentative discourse lessons for the study.

Participants

The 10 participants that made up the three small group cases for this multiple case study were drawn from a class of 22 undergraduate PSTs enrolled in the life science for elementary teachers course. The course was taught during spring semester 2015. The professor of this course, Dr. Pepper, was willing to implement argumentative discourse into her instruction and also allow me full access to her class for collecting data. The class used in this study was the second section of the two sections taught by Dr. Pepper that semester. The second section was chosen for the study since it was slightly larger and the PSTs tended to be more engaged and talkative than those in the first section.

The PSTs in this course were seeking to become state licensed teachers for varying grade levels and specializations (e.g., preK-3, K-6, Special Education). The gender distribution of the class was entirely female, which was not unusual considering the typical gender demographics of prospective elementary education teachers.

The individuals chosen to comprise the three groups in this multiple case study were purposefully selected from the class based on their epistemic beliefs about science as measured by the Hofer (2000) survey. Their selection was also dependent on their availability and willingness to participate in all of the data collection tasks. Only 20 of the 22 class members took the epistemic beliefs survey. The scores are shown in Table 2.

Table 2

Epistemic Beliefs Scores

Participant Name	Epistemic Beliefs Score
Tess	12.9
Tory	12.6
Noriko	11.8
Tia	11.6
Norah	11.5
Nasima	11.1
Nell	10.8
Nala	10.5
Mari	10.4
Morgan	10.4
Natalie	10.3
Meg	10.1
Macy	10.0
Nina	10.0
Noel	9.9
Claire	9.8
Cady	9.6
Nadine	8.8
Nancy	8.5
Camille	8.0
Nadia	N/A
Nicollette	N/A

The highest achievable score on the survey was 20 (most traditional beliefs) and the lowest was four (most constructivist beliefs). The scores of participants in this study ranged from Tess's high score of 12.9 to Camille's low score of 8.0. Thus, the beliefs of all the class members who took the survey actually skewed toward the more constructivist end of the scale as measured by the Hofer (2000) Epistemic Beliefs survey.

To satisfy the planned design of the study, those with the highest scores of the class were designated as traditionalists, even though strictly their scores were not on the extreme traditional beliefs end of the survey (i.e., near a score of 20). The three individuals with the most traditional views who also were available for all the data collection experiences were formed into Group T, the traditionalists. They were given pseudonyms that began with the letter *T*, and were designated as Tess, Tory, and Tia. Noriko, who also scored toward the traditional end of the epistemic spectrum, was not included in Group T as she was unavailable for the pre- and post-treatment interviews.

The three individuals with the most strongly constructivist views of the class who also agreed to participate fully in the study were formed into Group C, the constructivists. They were given pseudonyms that began with the letter *C*. Thus, the members of Group C were designated as Camille, Cady, and Claire. Nancy and Nadine, who also scored on the strongly constructivist extreme, were not included in Group C because they were unable to commit to the additional pre- and post-treatment interviews required for the study.

Four available individuals with beliefs approximately midway between the two extremes were formed into Group M, the moderates. They were given pseudonyms that began with the letter *M*. Group M participants were designated Mari, Morgan, Meg, and Macy.

The remaining 12 class members were also formed into three more small groups and participated in the treatment lessons, but they were not directly included in this study. The class members who were part of other groups were given pseudonyms beginning with the letter *N* to indicate that they were not one of the embedded cases. Although those participants were not specifically studied, they interacted with those in the study groups during the treatment lessons by presenting, evaluating, and defending group arguments. Therefore, comments made by members of the other groups were included as necessary in dialogue quoted in results of this study.

A diagram of the classroom arrangement shows the six small groups and their members (Figure 1.1). Each group sat at their own table. This style of arrangement was already typical for this class, as Dr. Pepper had purposely seated the PSTs in small table groups from the first day of the semester to facilitate cooperative learning experiences. Periodically, Dr. Pepper reassigned seating. Therefore, the participants did not find it unusual to be assigned to specific groups prior to the start of the study. The participants remained in the same groups throughout the entire study from pre-treatment data collection stage, through the two treatment lessons, and during the post-treatment data collection stage. Dr. Pepper had a lectern at the front of the room, and she stood at the front when giving instructions, working the projector, or writing on the white board. Most of the time, however, she moved around the room listening, observing, and facilitating the groups as they worked throughout the treatment lessons. I was seated near Group C in the back of the room, but I also moved around the room periodically to listen and observe all the small groups more closely.

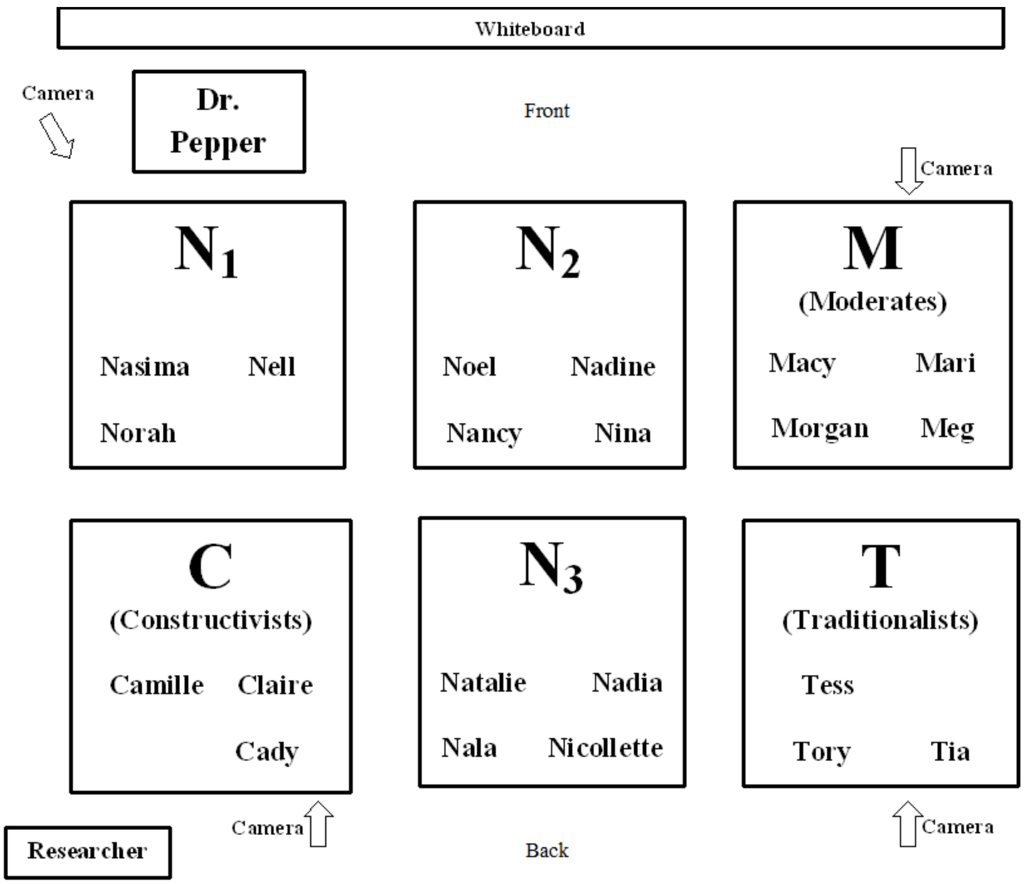

Figure 1.1. Diagram of classroom seating arrangement. The three cases were Group T, Group M, and Group C.

Background of Group T Members

To develop a clearer understanding of how the participants engaged in the argumentative discourse treatment lessons, it was first important to learn about their backgrounds and attitudes at the beginning of the study. During the pre-treatment group interview, I asked about their career goals and their attitudes toward learning and eventually teaching science. They were encouraged to explain how they believed their attitudes toward science developed. This information provides insight about some general attitudes and expectations the participants had at the start of the study. The upcoming paragraphs detail the information the participants gave.

Tess. Tess was a 35-year-old senior majoring in Interdisciplinary Studies, English (grades 4-8). Tess had a clear dislike of science and expressed disinterest in learning or teaching it. She said, “I do not like science. Um, it’s just there’s too much to remember, too much to learn” (Pre-Treatment Interview, 4/10/15). When asked about her career goals, Tess explained emphatically, “I’m middle school English; I shall not teach science” (Pre-Treatment Interview, 4/10/15). Despite those initial negative statements, she further explained that there were aspects of life science she enjoyed. For instance, she said she liked trees. She added, however, “I don’t really want to know everything about [trees]. You know, to me science kind of takes away the beauty and appreciation of it, so, and I will not be teaching science to anyone” (Pre-Treatment Interview, 4/10/15).

Tess did not feel that her previous science instruction was memorable or useful. She said, “It was, like, you know, learn the definition, take the test, learn the definition, take the test” (Pre-Treatment Interview, 4/10/15). Her only enjoyable science learning occurred during high school chemistry. She attributed this to the fact that the teacher “did experiments,” and had a Ph.D. in chemistry, so “he knew what he was doing” (Pre-Treatment Interview, 4/10/15). This description was illustrative of Tess’s generally traditional view of science, believing it to be authoritative and the realm of experts.

Tory. Tory, age not provided, was a junior studying Early Childhood Education (grades preK-3) who planned to teach kindergarten once she completed her degree. She was hesitant about the thought of teaching science. Tory said, “Teaching it? Um, if I do, I would have to make sure that I have my content correct, because it's easy to make a mistake, it seems like" (Pre-Treatment Interview, 4/10/15). She did not plan to teach science often in her future career, saying, "[Kindergarteners] don't have much, like, in-depth science" (Pre-Treatment Interview, 4/10/15).

Tory explained that although she liked science, she felt it required too much memorization. She wanted to be sure that she always had all of her facts correct. In reflecting on past learning experiences, Tory's memories included fun experiences, but she did not remember much about learning content. She said, "I just remembered doing little fun things like we made paper out of, like, wet newspaper pieces and stuff. But I didn't, I can't, I couldn't tell you things that I've really learned a lot of" (Pre-Treatment Interview, 4/10/15).

Tia. Tia was a 20-year-old junior studying for a degree in Interdisciplinary Studies (grades K-6). Tia planned to be a kindergarten teacher and said she thought teaching science would be a lot of fun. Her attitude toward learning science was positive. Tia stated, "[Science] was pretty fun, especially in the last, that physical science class that we had last semester" (Pre-Treatment Interview, 4/10/15). However, she also felt that previous science learning had not adequately prepared her for the learning expectations in this course.

> Well, I just remember being in like elementary school, it was basically learning definitions, do the questions at the end, and that's it, like maybe make a cell project, or a solar project, and that was it. Like, so, coming in and doing all this

> stuff [in this course], it's like overwhelming, because it's, like, I don't even have a foundation for this. (Pre-Treatment Interview, 4/10/15)

Tia contrasted her previous science learning experiences with how they were learning science in this undergraduate course. She explained,

> [Previous science instruction] made me, it kind of made me lazy. It made me think, well, maybe that's what I should do with science, because I just can't imagine getting up in front of my kids and making them do some of the stuff we do. I think, like, I would never think of that. (Pre-Treatment Interview, 4/10/15)

Tia said she felt overwhelmed by the amount of science information she was expected to learn in this course and by the amount of information she felt was necessary to know to be an effective science teacher. She stated, "It's like, how will I be able to teach [science] when I'm, you know, kind of cramming so much information at once" (Pre-Treatment Interview, 4/10/15).

Background of Group M Members

The upcoming section presents background information about each member of Group M. I asked about their current major, future career goals, and attitudes toward learning and teaching science. This information came from the pre-treatment interview that was conducted at the start of the study.

Mari. Mari, a 20-year-old sophomore, was seeking a degree in Interdisciplinary Studies (grades K-6). She hoped to teach young children, ideally those in grades 1-3. Her stated goal was to complete her bachelor's degree so she could go on to "inspire the next generation of learners" (Pre-Treatment Interview, 4/10/15). She also planned to pursue more education: a master's degree and possibly a doctorate someday. When asked if she expected to teach science in the future, Mari said, "I plan to be teaching it, along with all the other subjects. I mean, it's important like everything else" (Pre-Treatment Interview, 4/10/15).

Mari's attitudes toward learning science were generally positive but realistic. She said, "I feel pretty confident with science, as long as, you know, I have a good professor, a good teacher" (Pre-Treatment Interview, 4/10/15). She continued,

> Science can be a challenge; it just kind of depends on the area for me as to whether I think I get it—I grasp it really fast—or I need a little bit of review. So I do think with the learning science I need to review the stuff before I start teaching it more so like our subject today. I remember bits and pieces, but I need to like refit the puzzle. (Pre-Treatment Interview, 4/10/15)

Mari felt confident in her ability to teach science, provided she had reviewed the material beforehand. She said,

> So, but, when it comes to teaching science, if I can do the review, and I can kind of do a memory refresher, I feel pretty confident in being able to teach it, you know, after I just kind of re-teach it to myself to teach the kids. But I think I could do it pretty well. (Pre-Treatment Interview, 4/10/15)

Morgan. Morgan was a 21-year-old junior majoring in Interdisciplinary Studies (grades K-6). Her ideal career goal was to someday teach 3rd or 4th grade. When asked about her previous experiences learning science, she said,

> Learning science has always been, like, the hardest subject I think. And I've always had to, like, try the most with it. Like other things I try with, but like, they come easier. So I think learning science is the hardest for me. (Pre-Treatment Interview, 4/10/15)

Morgan lacked some confidence in her ability to teach science. Because of that, she felt it was important to be well-prepared so she could be the best science teacher possible for her future students. She said,

> Um, as far as teaching science, I would like to say I feel confident but I think because it's such a, like, struggle for me to learn it I get worried that I'm not going to present it in the best way for students in the future. So really just becoming like prepared for that is important to me. (Pre-Treatment Interview, 4/10/15)

Meg. Meg, a 32-year-old senior, was preparing for a degree in Early Childhood Education (grades preK-3). She stated that she hoped to become a 3rd grade teacher and specifically wanted to work at a low-income elementary school. According to Meg, her previous experiences learning science had been negative. Her confidence in her ability to learn and understand science was extremely low. Meg said,

> For me, learning [science] is terrible. I don't get it at all. Like, I understand it while I'm here, but as soon as I walk out the door, it's like, a blank. Like, I don't retain it at all. So I think teaching it would be easier because I would have the information in front of me. But learning it? Forget it. (Pre-Treatment Interview, 4/10/15)

Meg felt that her challenges with science were due to poor teachers, and her goal was to do better than they had done. She said, “So, I think that’s where my wanting to teach comes from, is because I want to be a better teacher than what I was taught” (Pre-Treatment Interview, 4/10/15). Meg explained that at her high school, she was only required to take one science course entitled “Principles of Technology” (Pre-Treatment Interview, 4/10/15). She felt this was inadequate and believed her foundational knowledge of life science was poor.

Meg further explained that she did better learning other subjects because they were more hands-on and project-based. She felt that teaching science would be easier for her than learning science since she would not be required to have all the information memorized. Meg felt that learning science was primarily focused on memorizing factual information, a skill with which she personally struggled.

Macy. Macy, was a 22-year-old senior majoring in Interdisciplinary Studies (grades K-6). When asked about her career goals, Macy said she previously wanted to work with young children, but now thought it would be “really cool” (Pre-Treatment Interview, 4/10/15) to teach 5th or 6th grade. Macy was looking forward to teaching science someday. She had a generally positive attitude toward both learning and teaching elementary–level science, especially life science topics. Macy’s past experiences with and attitudes toward physical science and chemistry were less positive. She indicated the topics were challenging for her, which she partially attributed to having a poor high school chemistry teacher. Macy said,

> Well, I have always enjoyed life science. I love it, I especially love ecology, and I love the outdoors, so I think that, learning about that is definitely easiest for me but then we flip it to like physical science, not happening. That was the hardest class I've taken in college so far, it was physical science. It was just, for me personally, it was the hardest. . . . I had this terrible science teacher in high school. He just made chemistry miserable for everyone, and I think that's why I will forever hate it. Because it was just not good. It was very, very difficult. I took chemistry honors and I shouldn't have. I thought I could do it, and I just couldn't. (Pre-Treatment Interview, 4/10/15)

Although Macy expressed a lack of confidence in her understanding of certain disciplines within science, she felt that with proper review time and preparation she could be successful teaching any science topic. Macy continued,

> Um, I think I'll be fine teaching [science] because I'll have time to prepare what I'm going to teach, and, like, expect questions from my class. So, I really do think I'll enjoy teaching science to the fullest. I think that'll be great, but learning it is a little mixed for me. (Pre-Treatment Interview, 4/10/15)

Background of Group C Members

The upcoming section presents background information about each member of Group C, including planned degrees, future career goals, and attitudes toward teaching and learning science. This information was gleaned from the interviews that were conducted at the start of the study. Unlike the other group's pre-treatment interviews, all members of Group C were unable to meet as a group due to scheduling challenges.

Instead, Cady and Claire were interviewed together, and Camille was interviewed by herself the next day.

Camille. Camille, a 20-year-old junior, was preparing for a degree in Interdisciplinary Studies (grades K-6). Camille's greatest interest was to teach mathematics, and she mentioned looking forward to teaching long division in 3rd grade or teaching mathematics exclusively at the 6th grade level (Camille's Pre-Treatment Interview, 4/13/15). When asked about her attitude toward learning science, Camille explained that she liked it and felt she understood it well. However, she felt she had difficulty translating her understanding to paper, saying, "I can't get across what I'm saying through paper and pencil. I can explain it better when I'm just talking" (Camille's Pre-Treatment Interview, 4/13/15). Camille said,

> I hate chemistry. I hate equations, like scientific equations. I don't like chemistry at all. But, I like the, I like doing labs. Like titrations, and all that different stuff. Yeah. I like hands-on science. Like dissecting stuff and that kind of stuff. (Camille's Pre-Treatment Interview, 4/13/15)

Camille felt that although she could teach science, she was not interested in doing so. She said, "I think I could teach it. I don't really know. I'm more of a learner for science, not a teaching it type. I don't think I would want to teach science. I feel like it's a lot of information" (Camille's Pre-Treatment Interview, 4/13/15).

Cady. Cady was a 20-year-old sophomore majoring in Special Education (grades K-12). At the onset of the study, however, she had decided to change her major and pursue a degree in business instead. Cady gave the following reason for the change.

> I just, well, they're changing the [Special Education] program a bit, doing like the modified much more toward the administrative work. And, as I'm sure you know with, now, Special Ed., it's not necessarily the teacher that's doing it. It's more the aides and I wanted to do something that was more hands-on and I just thought teaching just wasn't right. I decided it wasn't right. (Cady and Claire's Pre-Treatment Interview, 4/12/15)

Cady's attitude toward learning science was mixed. She said, "It's not my favorite subject, but I do like it and it's, it's a challenge to me, but it is definitely a, it is difficult sometimes" (Cady and Claire's Pre-Treatment Interview, 4/12/15). She attributed her negative feelings to her "terrible" and "horrible" high school science teachers (Cady and Claire's Pre-Treatment Interview, 4/12/15). Although she said that sometimes science was difficult for her, Cady had confidence in her understanding of biology. She said her sister was a biology major and she had studied with her and tutored fellow students. Cady stated, "So, so, I might know probably more than the average person" (Cady and Claire's Pre-Treatment Interview, 4/12/15). When asked specifically about her attitude toward teaching science someday, Cady expressed positive feelings.

> I think, I think it's fun. I think you, there's definitely many different ways to do it and if you do it right, it can be a lot of fun and beneficial to the students. And it's all about finding that balance. (Cady and Claire's Pre-Treatment Interview, 4/12/15)

Claire. Claire was a 19-year-old sophomore majoring in Special Education (grades K-12). Unlike her group mate Cady, Claire was extremely committed to the major and the career path. She expressed a desire to teach children with severe disabilities. Claire had an exclusively positive attitude toward learning and teaching science. She explained, “I like learning science. It’s the most fun subject and there’s all kinds of activities and experiments and, I mean, I think that’ll be fun as a teacher, to teach science” (Cady and Claire’s Pre-Treatment Interview, 4/12/15). When prompted for a reason for her feelings, Claire spoke of the influence of previous teachers. “I’ve had some cool science teachers, like Dr. Pepper and, um, I had Dr. S last year for biology, and I loved her. She was awesome. Even in high school, I had pretty good science teachers” (Cady and Claire’s Pre-Treatment Interview, 4/12/15). Claire also mentioned how she enjoyed the experiential aspect of science. “I always liked dissecting things and the hands-on things” (Cady and Claire’s Pre-Treatment Interview, 4/12/15).

Instruments and Data Sources

Case study research relies upon multiple data sources to provide a detailed description of the case under examination (Yin, 2014). The data sources for this study consisted of surveys, direct observations, voice recordings of participant discourse, video recordings of participants engaged in the lessons, individual knowledge lists, small group–generated knowledge structure graphics, and group interviews. In addition to these main data sources, I also took field notes and recorded personal reflections on the research process throughout the study. Each data source is described in more detail in the following sections.

Surveys

Two Likert scale survey instruments were used for data collection in this study. The first survey (Appendix A) identified participants' underlying epistemic beliefs about science and science learning. The second survey (Appendix B) measured the participants' conceptual knowledge regarding photosynthesis and cellular respiration and revealed alternative conceptions they held. Each of these surveys is further described below.

Epistemic beliefs survey. The participants completed an epistemic beliefs survey to identify their underlying beliefs about knowledge and knowing in the discipline of science. The survey (Appendix A) was the Discipline-Focused Epistemological Beliefs Questionnaire (DFEBQ) developed by Hofer (2000). This survey required participants to consider their beliefs within the specific context of science as they answered the items. Hofer's (2000) popular multidimensional framework ranked participants on five belief dimensions, each of which ranged along a belief continuum. The five dimensions were: 1) the certainty of knowledge (ranging from unchanging to evolving); 2) the simplicity of knowledge (ranging from isolated facts to highly interconnected); 3) the source of knowledge (ranging from handed down by authority to constructed within the self); 4) the justification for knowing (ranging from reliance on authority to reliance on personal experience and evaluation); and 5) the attainability of truth (ranging from obtainable to unobtainable). It should be noted that Hofer (2000) combined the first two dimensions listed above into one domain (certainty/simplicity). The questionnaire was slightly modified according to the purposes of this study and suggestions from Muis and colleagues for increasing validity (Muis, Duffy, Trevors, Ranellucci, & Foy, 2014).

Due to the wording of the items, lower scores in each domain (except justification domain, which was reverse-scored) represented a more sophisticated and higher stage of epistemological development, aligning with constructivist views. Higher scores indicated a less sophisticated and lower stage of epistemological development, which was associated with more traditional views of science. The highest score possible on the beliefs survey was 20, and that score actually represented the most traditional and least sophisticated epistemic beliefs. The lowest possible score on the survey was four and would represent the most sophisticated and constructivist epistemic beliefs about science. A score of 12 would be the midpoint of the two extremes.

Alternative conceptions survey. An instrument to evaluate the participants' conceptual knowledge related to photosynthesis and cellular respiration was administered immediately before and after the argumentative discourse treatment lessons, as well as two weeks later. The survey was a modified version of the Photosynthesis and Respiration in Plants Diagnostic Instrument (Appendix B) developed by Haslam and Treagust (1987). This two-tier survey was based on propositional statements about photosynthesis, cellular respiration, and their relationships to one another. These propositions were taken from the secondary school curriculum of the sample of students in their study, year 8-10s (13-15 year olds) in Western Australia.

Haslam and Treagust (1987) developed and refined the survey from information gleaned from interviews, open-ended tests, and literature. Experts were then consulted, and a series of five pilot studies were used to further refine the instrument and lend validity. Reliability was tested using Cronbach's coefficient alpha, with a result of 0.72.

The difficulty level indices ranged widely from 0.12 and 0.78, with a mean of 0.38. The reading age of the survey was rated as appropriate for individuals aged 12 -14, and thus was considered easily understandable to the PSTs.

The first tier consisted of a multiple-choice content question, while the second tier required participants to choose from a set of reasons for the answer they gave. An extra line was provided so participants could write in their own reason if they chose.

The survey was modified slightly for clarity and the purposes of this study. For example, I changed “green plants” to simply “plants” since the classification of fungi as part of the plant kingdom has not existed for more than 40 years (Whittaker, 1969) and thus the green designation was unnecessary. I changed *respiration* to *cellular respiration* for clarity. Many learners already have confusion about the difference between physical respiration (breathing) and cellular respiration (Brown & Schwartz, 2009), so I wanted to be sure participants were clear regarding the process about which they were being questioned. I also added water as a product of photosynthesis in the correct answer for the photosynthesis equation to represent a balanced chemical equation. In addition to those minor changes, a question was added to elicit participants’ conceptions of the origins of a plant’s biomass, a common alternative conception (Krall et al., 2009) I wanted to measure in participants that was not included in Haslam and Treagust’s (1987) original survey.

Individual Knowledge Lists

Prior to the creation of the pre- and post-treatment group knowledge structure graphics (described in next section), participants listed everything they individually knew about photosynthesis and cellular respiration (Appendix C). Participants completed these without consulting their peers. After the participants created their individual knowledge lists, the lists were collected. This short activity gave the participants time to activate their prior knowledge and provided me with a baseline of their individual conceptual understanding prior to other data collection, discussions with their peers, and the treatment lessons.

Group Knowledge Structure Graphics

Following the completion of their individual knowledge lists, the participants collaborated in their assigned groups to combine their initial individual knowledge into one group knowledge structure graphic. This knowledge structure graphic, for the purposes of this study, was a graphic portrayal of a group's cognitive knowledge on a certain topic and the relationships among the individual concepts they chose to include. It was analogous to a concept map and could include text, pictures, connectors, and other symbols.

Participants were not given detailed instructions for the construction of the knowledge structure graphics (Appendix C), so they had the freedom to represent their group's knowledge as they chose. The group knowledge structure graphic was intended to represent their collective understanding. Groups were given the choice to represent the two concepts of photosynthesis and cellular respiration in either one or two separate knowledge structure graphics.

Group Interviews

Group interviews were held with each of the three group cases before and after both the photosynthesis and cellular respiration argumentative discourse treatment lessons. The interview process was guided by a pre- and post-interview protocol (Appendix D) developed based on information in the literature and from my own experiences. The main purpose of the interview was to explain and clarify the responses provided on the groups' knowledge structure graphics. Additionally, the interview sought to reveal more about the group's collaborative learning process, their attitudes toward the argumentative discourse lessons, and their responses on the epistemic beliefs and alternative conception surveys.

Small Group Discussions (Audio)

Audio recording devices were placed with each of the small groups. These devices recorded the discussions and argumentative discourse that occurred during the photosynthesis and cellular respiration treatment lessons. Transcripts of the discourse of the three group cases were prepared and analyzed.

Small Group Discussions (Video)

A video recording device was directed at each of the three groups of interest to record the interactions that occurred during the argumentative discourse treatment lessons. A fourth video recording device recorded the entire classroom scene. The videos provided a visual record of participants' facial expressions and body language, which offered additional insight into the meaning behind their words as they participated in the discourse within their small groups. Unfortunately, the sound quality on the videos was extremely poor, and there were usually only two participants clearly in view due to the angle of the camera. However, the videos were valuable in helping verify things, such as identifying the speaker when it was difficult to decipher who was speaking on the audio recording.

Observation Protocol

An observation protocol (Appendix E) was used to provide guidance and support consistency in analyzing the quality of the group's argumentation. The selected protocol, the Assessing Scientific Argumentation in the Classroom (ASAC), was developed and validated by Sampson, Enderle, and Walker (2012). The observation protocol consisted of 20 items, arranged into three categories: conceptual and cognitive aspects of scientific argumentation, epistemic aspects of scientific argumentation, and social aspects of scientific argumentation. Only the first two categories were used for this study. The first category had seven items with a maximum score of 21 points (three points each), and the second category also had seven items with a maximum score of 21 points (three points each). Higher scores indicated better quality of argumentation and performance that was more sophisticated.

Field Notes

Field notes were taken to document direct observations made at the beginning of the study. The purpose of the field notes was to record details that helped to establish an understanding of the research context. Detailed field notes were not taken during the treatment lessons since there were audio and video recordings being made of each group of interest.

The Researcher

According to Hatch (2002), the qualitative researcher is a key instrument in the data collection process. Qualitative data are filtered through the researcher to assign meaning and draw conclusions. My background prepared me for this role. I taught elementary school for more than seven years, and thus have the perspective of an insider when it comes to what is required for elementary education. I also taught secondary biology and earth science for two years, led classes at an outdoor school, and taught children and adults in a variety of other educational settings. During my graduate studies, I took many upper-division biology content courses and taught biology laboratory sections to undergraduates. In addition, I have team-taught PSTs in education courses and assisted in teaching a life science content course to elementary PSTs. I have also worked with in-service teachers by providing professional development workshops and conducting research.

Additionally, I have qualifications as a qualitative researcher. I have completed coursework in qualitative research and collaborated with others to complete two qualitative studies. Due to my strong content background, my years as an educator, and my experience as a qualitative researcher, I was well-qualified to serve as a research instrument in this study.

Throughout the research process, I kept a reflective journal to explore my own thoughts, responses, personal beliefs, and biases relevant to the experience of conducting this study. In this way, I fulfilled the requirement of researcher reflexivity (Creswell, 2014; Watt, 2007), whereby I disclosed my assumptions and biases that might have influenced the conclusions I drew from the study. I recorded my thoughts and opinions as I made observations, collected, and analyzed the data. The researcher reflections were not analyzed or used to draw conclusions related to the research questions. However, it was useful to document and disclose my own thoughts and feelings to better understand the subsequent interpretation of the events, the data collected, and the conclusions drawn.

Procedures

The procedures for conducting the study are explained in detail in this section. Institutional Review Board (IRB) approval was obtained before any data collection began (Appendix F). The permission and full cooperation of Dr. Pepper, the professor of the life science course used in this study, was secured. The following procedures have been organized according to when they occurred relative to the treatment lessons. The treatment lessons were the two argumentative discourse-based lessons on photosynthesis and cellular respiration under examination in this study. Figure 1.2 summarizes the timeline of the data collection procedures in visual form.

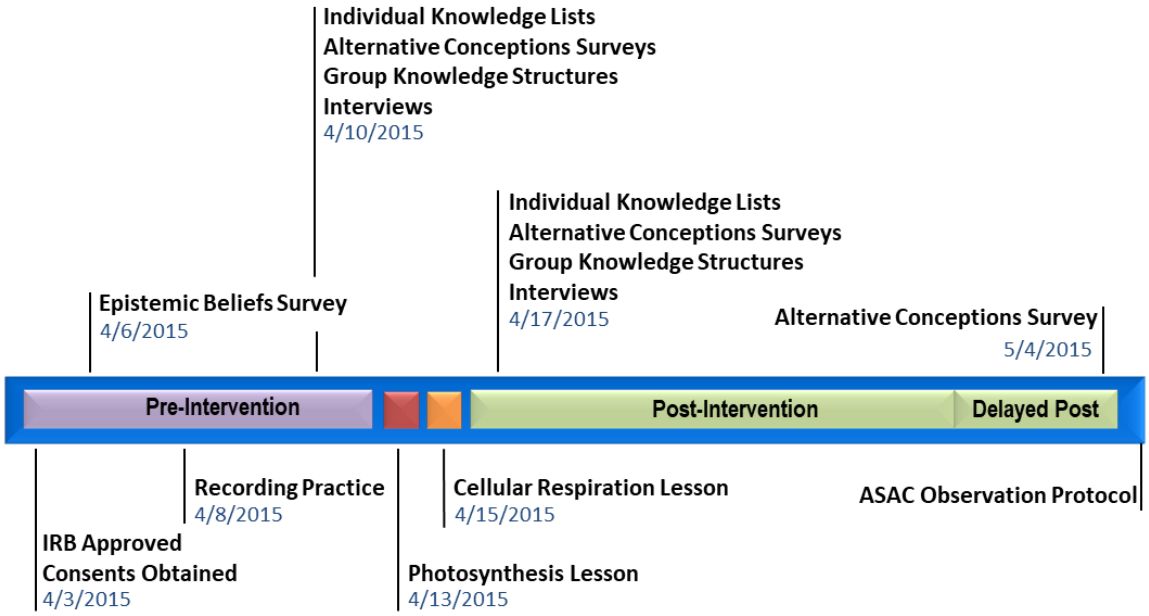

Figure 1.2. Timeline of study procedures.

Pre-Treatment Phase

Before the study began, I observed approximately five times in the class and took field notes to document the research context. It was important that the participants became familiar with me as an observer prior to the treatment lessons. This helped ensure that the participants' behaviors were not unduly influenced by my observations during the study. Additionally, my frequent attendance facilitated the interview process, since the participants had already developed a degree of familiarity with me.

Six audio recorders, one for each group, were placed at the tables prior to the data collection. Additionally, three video cameras were positioned close to each of the three groups of interest. I did two test sessions with the technology to practice using it and solving any technical problems that could arise. This was also so the participants became comfortable with the devices' presence prior to the necessary data collection. I had all the participants audio record themselves saying their study identifier code (not their real name) and a few sentences. These recordings helped me identify voices for the transcriptions later. The rest of these test audio and video recordings, taken during regular class time, were destroyed.

Once IRB approval was obtained, I introduced myself to the class, explained the research process, and invited the PSTs to participate. I obtained signed consent forms from the participants at that time. Then, as a homework assignment, the participants completed the epistemic beliefs survey online (Appendix A) through the university-wide online learning platform. Two members of the class, Nicollette and Nadia, did not complete the epistemic beliefs survey.

Using the results of the beliefs survey and in consultation with Dr. Pepper, I organized the 22 PSTs into six groups of three to four members each, seated at six tables. As described earlier, I carefully formed three of the six groups in order to purposefully select the participants for the cases that would be of focus during the study. When forming the three groups, I could only include participants who had taken the epistemic beliefs survey and were willing and able to meet outside of class for the extra pre- and post-treatment interviews required. Thus, I created one group with strongly held constructivist beliefs (Group C) which consisted of Camille, Cady, and Claire. The group with the least constructivist beliefs of the participants, hereafter referred to as the traditionalists (Group T), was formed from Tess, Tory, and Tia. Finally, I formed a group of moderates who were between the two extremes (Group M), which consisted of Mari, Morgan, Meg, and Macy.

Data collection immediately prior to treatment lessons. During the class period right before the argumentative discourse-based treatment lessons on photosynthesis and cellular respiration, the participants completed the alternative conception survey (Appendix B), which was a slightly modified version of Haslam and Treagust's (1987) Photosynthesis and Respiration in Plants Diagnostic Instrument.

Next, the participants created individual knowledge lists about the topics of photosynthesis and cellular respiration (Appendix C). They were given two half-sheets of letter size (8.5 by 11 inches) paper. At the top of one half-sheet was printed *photosynthesis* and on the other half-sheet was printed *cellular respiration*. The participants were given an initial seven minutes to write down everything they personally knew about each of the two topics. There was no talking allowed during this task. A little additional time was given to allow the participants to finish up. Then the individual knowledge lists were collected.

Finally, the small groups were tasked with creating a group knowledge structure graphic that combined and refined their individual knowledge into a collective whole (Appendix C). For this, each group was given two large pieces of paper (17 by 22 inches), markers, and approximately 15 minutes to create a knowledge structure graphic that best represented their group's complete knowledge of both photosynthesis and cellular respiration (either displayed separately or connected). The groups' conversations were audio- and video-recorded during this activity. I then collected the group knowledge structure graphics.

Following the group knowledge structure graphic task, but prior to the implementation of the two treatment lessons, I interviewed each of the three groups representing the three cases: Group T, Group M, and Group C. The interviews were guided by the semi-structured interview protocol (Appendix D) with the group's knowledge structure graphic providing a major source of discussion. I asked the groups to explain their process in creating the graphic representing their collective knowledge and how they decided what concepts to include and exclude. I asked them about how the group knowledge structure graphic differed from their individual knowledge lists they created beforehand. These interviews were audio- and video-recorded and transcribed.

Treatment Phase

Dr. Pepper implemented the argumentative discourse lessons with the goals of increasing, clarifying, and reinforcing the participants' accurate conceptual understanding of photosynthesis and cellular respiration. I wrote the lessons in consultation with Dr. Pepper. The two lessons followed a similar format. Each consisted of a series of group tasks and took a little less than two hours to enact. The class period was 125 minutes long, but some time (approximately 20 minutes) was taken up by breaks, announcements, and other non-instructional tasks. The photosynthesis lesson was taught on Monday, April 13, 2015. The cellular respiration lesson was taught the next time the class met, which was Wednesday, April 15, 2015.

It was not feasible for participants to be engaged in argumentative discourse exclusively throughout the entire lesson time. Thus, other instructional tasks were employed. The participants worked in small groups throughout the lessons. The chief tasks undertaken were reading and interpreting information, sharing and synthesizing evidence, developing a model, choosing a claim, creating a written argument, critiquing others' arguments, and defending and revising their own arguments. These tasks were all essential to engaging in scientific argumentation from evidence. The instructional tasks were designed to encourage collaborative peer discourse and specifically to promote opportunities for argumentative discourse. A description of what occurred during each lesson is provided in the upcoming paragraphs. Additional details are found in Appendix G and Appendix J.

Lesson one: Photosynthesis. This lesson encouraged participants to engage in argumentative discourse to develop and establish an accurate understanding of the basics of the process of photosynthesis. The lesson had two main learning goals. The first goal was for participants to model the photosynthesis equation and provide evidence and reasoning to support it. The second goal, an application of the first goal, was for participants to accurately identify the major source of a plant's biomass and be able to explain why. This lesson also provided an opportunity for learners to develop and evaluate scientific arguments using the CER argument framework (McNeill & Krajcik, 2012). A description of what occurred during the photosynthesis lesson follows. Additional details about the lesson as it was enacted is found in Appendix G.

Task 1: Introduction of the guiding question (5 minutes). The lesson began with Dr. Pepper showing the class a small seed and a cross-section of a large tree trunk. She asked the participants to answer the question, "From where does a plant get its biomass?" and directed them to each write their initial answer on a sticky note.

Task 2: Selecting a claim (5 minutes). Next, Dr. Pepper provided the class with a concept cartoon. The cartoon provided four options for where the biomass of a plant mainly originates. Only one of the options was correct (from the air). Dr. Pepper asked the PSTs to discuss the four claims and select the one their group agreed was the most accurate. This provided the first opportunity for participants to engage in argumentative discourse based on their existing background knowledge.

Task 3: Modeling the photosynthesis equation (5 minutes). Then Dr. Pepper distributed a set of equation component cards to each group. These were components of the photosynthesis and cellular respiration equations written individually on small cards, including some distractors (e.g., CO_2, H_2O, $C_6H_{12}O_6$, O_2, ATP Energy, Light Energy, Soil, Heat, +,→). Dr. Pepper asked the groups to work together to lay out the cards and model the equation for photosynthesis. She had them record their group prediction on their individual equation sheets and provide some evidence and reasoning for the choice. This was another occasion for argumentative discourse as the participants planned and negotiated with their group members based on their background knowledge and reasoning.

Task 4: Gathering and sharing evidence within the group (25 minutes). Dr. Pepper then asked the small groups of PSTs to send members to each of the nine evidence stations posted around the room. The evidence stations (see Appendix H for an example) were information sheets that provided relevant data and descriptions of scientific investigations that revealed details regarding the process of photosynthesis. Student evidence sheets were provided (see Appendix I for an example), which included guiding questions to help participants identify the key ideas necessary from each evidence station. The participants studied their assigned evidence station(s) and then returned to their small groups to share and synthesize what they had all learned. Dr. Pepper explained that the evidence might also lead them to choose a different claim and/or adjust their model of photosynthesis.

Task 5: Developing an argument to support the claim (15 minutes). Dr. Pepper briefly reviewed the CER Framework (McNeill & Krajcik, 2012). She then asked the small groups to write their chosen claim, along with evidence they had gathered that supported the claim. She instructed them not to write their reasoning yet. This task provided the first opportunity for participants to engage in argumentative discourse using the evidence they had gathered from the evidence stations.

Task 6: Rotations for presenting, critiquing, and defending arguments (20 minutes). Next, Dr. Pepper directed the groups to choose one participant (termed *presenter*) to remain at their table to present their group's argument to those visiting from other groups. The other participants (termed *reviewers*) dispersed to visit other groups' tables and hear their arguments. Presenters explained and defended (as appropriate) their arguments, while reviewers evaluated the other group's argument and expanded their own understanding through the discourse that occurred. Dr. Pepper posted suggested actions and prompts to help guide the presenters and reviewers in their discussions. This was a deliberately planned opportunity to engage in argumentative discourse with those from other groups who had different epistemic beliefs. Once the discussions slowed, Dr. Pepper had the reviewers move to a new table to hear another group's argument and again evaluate, critique, and defend the arguments as appropriate.

Task 7: Changing, revising, and expanding the argument (10 minutes). Following the two rotations, Dr. Pepper had everyone return to their original groups and discuss what they had learned from the other groups' arguments and the previous discourse. Groups were instructed to revise their arguments and/or photosynthesis models as necessary. At this time, Dr. Pepper asked the groups to add the reasoning piece to their arguments. Participants had the opportunity to engage in additional argumentative discourse with their original small groups to revise, improve, and augment their written arguments.

Task 8: More rotations for presenting, critiquing, and defending arguments (15 minutes). The groups were instructed to do the same rotation process as before, leaving the presenter at their own table and going to visit the same group they had earlier. The presenters were asked to again explain their group's revised and augmented argument to the visiting reviewers. The reviewers were again required to evaluate and discuss the arguments. This was another opportunity for argumentative discourse with others who had different arguments and held different epistemic beliefs. After some time, Dr. Pepper had the participants rotate again so that everyone visited the same two groups that they had during the first rotations earlier. Since class time was limited, this final rotation was short. Then participants were asked to return to their original small groups.

Task 9: Final argument revision (5 minutes). A few minutes were provided for the small groups to make any final revisions or additions to their arguments based on anything they had learned from the previous discussions during the rotations. This was the last opportunity in the lesson for peer discussions and any final argumentation.

Task 10: Teacher explanation and questioning (15 minutes). For the last portion of the lesson, Dr. Pepper facilitated a whole class discussion regarding photosynthesis. She directed a participant from Group M to write their photosynthesis equation model on the board at the front of the room. Using this accurate example, Dr. Pepper questioned and scaffolded the class in a discussion that outlined the process of photosynthesis. This part included some lecturing in which Dr. Pepper expanded on the concepts. Most participants took notes.

Dr. Pepper asked the class to explain which was the correct claim for the source of most of a plant's biomass. No one volunteered an answer. Dr. Pepper answered her own question and provided more information in an attempt to clarify the participants' understanding. The time for the lesson period was over, and Dr. Pepper dismissed the class.

Lesson two: Cellular respiration. Like the photosynthesis lesson, this lesson engaged learners in developing and evaluating scientific arguments using the CER argument framework (McNeill & Krajcik, 2012). It also provided many opportunities for collaborative discourse, including argumentative discourse. One goal of the cellular respiration lesson was for the participants to gain an understanding of the cellular respiration equation and be able to model the process. Another goal of the cellular respiration lesson was for the participants to link the process of photosynthesis to cellular respiration and understand what happens to the products of photosynthesis, (i.e. how they are used by the plant to engage in cellular respiration). A description of each part of the cellular respiration lesson follows. More details about the lesson as it was enacted are found in Appendix J.

Photosynthesis lesson reviewed (15 minutes). The cellular respiration class session began with Dr. Pepper showing some examples of plants and seeds (i.e., ivy plant, avocado pit) to generate interest. She then conducted a review of the photosynthesis lesson from the previous class session by first having the participants individually write the photosynthesis equation from memory. Next, she asked them to work together (in the same homogeneous epistemic beliefs groups as the previous lesson) to model it using the equation component cards. Dr. Pepper concluded the review with some whole class questioning and lecturing to emphasize the main points from the previous lesson.

Task 1: Introduction of the guiding question (5 minutes). The first cellular respiration-focused lesson task began with Dr. Pepper providing the guiding question, “How and when does a plant use the food it makes to sustain life?” Dr. Pepper reminded the participants that during the previous lesson that she had asked them to choose a claim and then gather evidence. During this lesson, however, she explained that she would instead have them collect some evidence first, before seeking to make a claim to answer the guiding question.

Task 2: Gathering and sharing evidence within the group (25 minutes). Next, Dr. Pepper directed the participants to gather evidence regarding the process of cellular respiration. This was the same procedure as they had done in the previous lesson, although now the evidence stations (see Appendix K for an example) were focused on information pertinent to cellular respiration. As before, the PSTs were provided with student evidence sheets (see Appendix L for an example) with questions intended to help them identify the important information from each station.

Dr. Pepper gave the class some time to study the evidence stations. She then directed them to return to their small groups. Once together again, the group members reported on what they had learned so everyone in the small group heard and understood the information from all the evidence stations.

Task 3: Modeling the cellular respiration equation (15 minutes). Dr. Pepper next asked the small groups to create a model of the cellular respiration equation using the set of equation component cards. She explained that they might or might not use all of the cards, and they could also add their own words or symbols to the blank card if desired. Dr. Pepper directed the participants to think about the evidence from the evidence stations that supported the way they decided to model the cellular respiration equation. This was the first occasion for argumentative discourse to occur regarding cellular respiration. Participants were able to reference evidence they had just gathered to support their arguments regarding the correct cellular respiration equation.

Task 4: Compiling evidence and developing a claim (15 minutes). For the next task, Dr. Pepper asked the groups to work together to compile the evidence they thought seemed relevant to helping them answer the guiding question "How and when does a plant use the food it makes to sustain life?" She reminded the participants of the CER framework (McNeill & Krajcik, 2012) and provided a large sheet of paper for groups to record their evidence. She also explained they would be adding the claim and reasoning later. Unlike the photosynthesis class, this time Dr. Pepper explicitly asked the participants to reference the specific evidence station where they had obtained each piece of information.

Next, Dr. Pepper asked the groups to each make a claim that answered the guiding question. She reminded them that the claim should be based on the evidence they had been discussing and recording. Groups had the opportunity to engage in more argumentative discourse with their homogeneous epistemic beliefs group members throughout the development of their claim, evidence, and reasoning.

Task 5: Rotations for presenting, critiquing, and defending arguments (25 minutes). After the PSTs had finished listing pertinent evidence and developing their claim, Dr. Pepper asked the groups to separate to present, evaluate, and defend the arguments. This process was the same as had occurred during the photosynthesis lesson. Dr. Pepper had each group choose a presenter to stay at their table and present their argument to the visiting reviewers from other tables. Those not presenting were required to disperse to other tables to hear the presentation of that group's argument. This part of the lesson was intended to stimulate the participants' critical thinking, introduce new claims and/or previously unconsidered evidence, and require that all participants practice critiquing and defending the validity of the arguments as necessary. The participants had the opportunity to engage in argumentative discourse with those from other small groups who held different levels of epistemic beliefs and had different ideas regarding the claims, evidence, and reasoning in the arguments.

To support the generation of relevant discourse, Dr. Pepper posted suggested actions and prompts that the presenters and reviewers should engage in during this part of the lesson. Once the discussions slowed, Dr. Pepper had the reviewers move to a new table to hear another group's argument. This gave the PSTs another chance to engage in argumentative discourse with a new grouping of participants.

Task 6: Changing, revising and expanding the argument (5 minutes). Next, Dr. Pepper instructed the PSTs to return to their original groups to share what they had learned. She then asked them to revise and add to their claims and evidence based on any new insights they had obtained from the previous presentations and discussions with other class members. After a few minutes, Dr. Pepper instructed the groups to add their reasoning/justification section to their arguments. She provided some suggested sentence starters to give the PSTs some guidance for getting started on that section. She explicitly reminded them to think about underlying scientific concepts and models that they could use to help explain their evidence and justify their claim. This was the last opportunity in this lesson for participants to engage in argumentative discourse.

Task 7: Teacher explanation and questioning (15 minutes). After providing some time for the groups to finalize their arguments, Dr. Pepper began questioning the whole class. She asked scaffolding questions and explained concepts related to the process of cellular respiration. She emphasized the correct conceptions that answered the guiding question. Finally, Dr. Pepper highlighted the cyclical connection between photosynthesis and cellular respiration. She closed the lesson by emphasizing the dependence of humans on plants. The time for the class period was up, and Dr. Pepper dismissed the participants.

Researcher observations. During both of the lessons, I made observations and took field notes. I sat in the back left of the classroom, which happened to be nearest to Group C. Periodically I circulated the room and observed and listened to the other groups directly. Later, I listened to the audio recordings, prepared transcripts of the dialogue, and viewed the videos of each the three groups.

Post-Treatment Phase

During the next class period, two days after completing the cellular respiration lesson, the participants completed the modified Photosynthesis and Respiration in Plants Diagnostic Instrument (Appendix B) (Haslam & Treagust, 1987). They once again created individual knowledge lists and a group knowledge structure graphic using the same procedures as before (Appendix C).

Following that class period, I conducted the final group interviews. I based the post-treatment semi-structured interviews on the same questions I had asked at pre-treatment (Appendix D). I focused on encouraging the groups to explain their post-treatment group knowledge structure graphic, the process they used to create them, their individual understandings and alternative conceptions, and their experiences during the argumentative discourse lessons. In a few cases, the interviews took an unexpected turn as the participants requested I explain certain concepts about which they still felt confusion. Being a teacher myself, I could not deny their requests, so I did do some limited explaining of photosynthesis and cellular respiration during some of the post-treatment interviews.

Delayed Post-Treatment Phase

Following the conclusion of the study and data collection in her class, Dr. Pepper returned to teaching the course using her own instructional methods and curriculum plan. Photosynthesis and cellular respiration were not discussed further, other than incidentally as they pertained to subsequent content covered in the course. Participants were encouraged to study the topics, though, as there would be exam questions about them in about two weeks. The exam questions were not part of my study.

On the last day of the semester, participants took the Photosynthesis and Respiration in Plants Diagnostic Instrument (Haslam & Treagust, 1987) a third and final time. By having the participants take the survey a third time after allowing some time to pass, I aimed to see whether any lasting conceptual changes had occurred. Since the study had been conducted late in the semester, the delayed post-treatment survey had to occur only 17 days after the post-treatment survey was taken. The time of nearly 2.5 weeks was sufficient for participants' short-term memory to begin to fade and their long-term conceptual knowledge be discernable.

Data Analysis

The collected data were analyzed to answer the two descriptive research questions. They were:

1. How were life science alternative conceptions of PSTs influenced, if at all, by participation in two lessons incorporating argumentative discourse?
2. What, if any, influence did the participants' epistemic beliefs about science have on their conceptual change outcomes following the two lessons incorporating argumentative discourse?

The research questions were aligned with the basic propositions of this study. The first proposition was that argumentative discourse, when implemented with fidelity, can support conceptual change in learners. The second proposition was that the epistemic beliefs of the participants can influence the effectiveness of argumentative discourse in promoting conceptual change.

Analyzing qualitative data can be a complex and daunting undertaking for even experienced researchers. In this study, approximately 800 pages of transcriptions were analyzed, not to mention all the other data sources such as the alternative conceptions survey and the individual and group knowledge lists. Parsing and synthesizing such large amounts of complex narratives, knowledge representations, and surveys to identify relevant themes is not a smooth or linear process. I continually revised themes and categories, going back and forth between data sources in a constant iterative process. This was especially true in relation to the identification and tabulation of the alternative conceptions.

To initiate the analysis process, I compiled a case study database. The case study database consisted of an organized and digitized arrangement of the raw data collected throughout the study (Yin, 2014). I was particularly careful to store all my digital data in two separate cloud storage sites and on an external hard drive, in addition to my personal computer. My audio recordings were transcribed and the transcriptions added to the case study database. I also watched all the videos of the actions of the three groups to become familiar with the content of their discussions and their body language cues.

The focus of the analysis was to determine what changes occurred in the participants' alternative conceptions before, during, immediately after, and two weeks after the treatment lessons. An additional focus of analysis was concerned with the argumentation quality that occurred in the three groups The next two sections will provide more details concerning both of these analysis foci and what data sources were used for each.

Analyzing Changes in Alternative Conceptions

My first research question asked how the participants' alternative conceptions were influenced, if at all, by the argumentative discourse-based lessons. My second question asked how the epistemic beliefs of the participants influenced, if at all, their conceptual outcomes after engaging in the treatment lessons. Thus, it was first critical to identify the appearance of all alternative conceptions before, during, immediately after, and two weeks after the treatment lessons. Therefore, I began my analysis with the purpose of identifying all the alternative conceptions that had been revealed in each of the data sources at those four stages of the study. I analyzed the shifts in alternative conceptions at two levels: the individual level (embedded cases), and the group level (cases). The upcoming paragraphs will provide details about how I identified, organized, and tabulated the alternative conceptions by data source.

Alternative conceptions survey analysis. I scored the pre-, post-, and delayed post-treatment alternative conceptions surveys to gain a picture of how the individual participants' conceptions changed over time. I identified the items that were completely correct or completely wrong on each individual's pre-, post-, and delayed post-treatment survey responses. To count an item as correct, both parts of the two-tier items had to have been answered correctly. This helped ensure that the individual's actual knowledge was appropriately represented rather than being obscured by random guessing on the multiple-choice questions.

I calculated individual averages and reported them as percentages. One of the study participants, Tia, did not answer both parts of the two-tiered questions once on the post-treatment survey and once on the delayed post-treatment survey. Thus, the entirety of question number seven on the post-treatment survey and question number 13 on the delayed post-treatment survey were not included in the calculation of her averages. I also combined the scores of the members of each group to obtain a case level percentage.

I carefully reviewed all the items and answer options on the survey and determined what specific alternative conceptions they represented. Haslam and Treagust's survey (1987) was helpful in diagnosing 21 alternative conceptions that could be identified depending on the participants' answers to the tier one level questions and the reasons they chose for their answers in the tier two part. I used those alternative conceptions to begin a master list of all the alternative conceptions identified in all the data sources collected. As more alternative conceptions were identified, I added them to the master list. The complete list is found in Appendix M.

Artifact analysis. I critically examined all the participant-created artifacts to identify alternative conceptions present at both the individual level and at the collective group level. The artifacts from which I gleaned individual alternative conceptions were the participants' individual knowledge lists. The artifacts from which I identified collective group alternative conceptions were from the pre- and post-treatment group knowledge structure graphics and the photosynthesis and cellular respiration equation models the groups developed during the lessons.

I developed lists of every discrete accurate and alternative conception present on each individual's pre- and post-treatment individual knowledge list. I also examined the pre- and post-treatment group knowledge structure graphics and listed all the discrete accurate and alternative conceptions that were apparent in the collective group. Omissions were not considered alternative conceptions. I added all the alternative conceptions I identified from these artifacts to my master list of alternative conceptions found in the study participants (Appendix M).

The number of alternative conceptions present at each time period was compared and contrasted to help answer the research question regarding how alternative conceptions were impacted, if at all, by the argumentative discourse-based lessons. An evaluation comparing the outcomes for the three different epistemic beliefs groups (i.e., traditionalists, moderates, and constructivists) helped answer the second research question. That research question asked how the epistemic beliefs of the participants influenced, if at all, the conceptual change outcomes resulting from the argumentative discourse lessons.

Transcript analysis. The transcripts were arguably the most important and certainly the most time-consuming data sources to analyze. I originally planned to use qualitative software to help me in organizing and coding the transcripts. I tried that initially, but found the learning curve on the software to be steeper than expected and decided that the benefits did not outweigh the drawbacks. Therefore, I abandoned that in favor of more traditional means of organizing and coding data.

I printed all the transcripts and used colored highlighters to manually code three broad themes: any scientifically inaccurate statements, any noteworthy accurate statements, and anything that seemed relevant to group functioning or epistemic beliefs. I was hyper–sensitive to any inaccuracies mentioned by the participants at all, since I did not want to miss any appearances of alternative conceptions.

Beginning with Group T, I wrote an extensive narrative of all the incidences of alternative conceptions that met my initial criteria for selection. The narrative included example dialogue from the participants and was arranged in chronological order. Then I utilized the same process for Group M and Group C. These long narratives became the initial draft of my case study report. The case study report (Yin, 2014), also called a case description (Stake, 1995), is an organized written composition that brings together the collected data into a comprehensive narrative.

Because my study was a multiple case study with embedded cases, the case study report was organized into three sections, one for each of my three group case studies. The experiences of each of the three small groups were reported using a chronological structure (Yin, 2014), with the understanding that the cases occurred simultaneously within the larger context of the whole class. This case study report draft was used as the foundation for Chapter 4 of this document.

Finalizing the list of alternative conceptions. A master list of the individual and group-level alternative conceptions was generated (Appendix M) from all the data sources. This master list was constantly revised throughout my analysis in an iterative process. This occurred because of my evolving understanding and subsequent narrowing definition of what should be considered an alternative conception. It also occurred because as I analyzed the multiple data sources, I sometimes found information that led me to realize something I had categorized earlier as an alternative conception was in reality a lack of information or simply a careless mistake on the part of the participant. An individual's conception of a given scientific concept can be thought of as a continuum between novice and expert ideas. Deciding where on that continuum an explanation of an idea crosses from accurate to alternative can be problematic. It is not a simple binary distinction of right and wrong, since one of the characteristics of an alternative conception is that it contains some truth.

The criteria I eventually adopted for considering something to be a group alternative conception is as follows. Inaccurate concepts were included if they were accepted by the entire group at least once. If an alternative conception was introduced but then rejected and never discussed again, it was not included as a group-level alternative conception. I also did not include alternative conceptions that I deemed would not noticeably impact the participants' understanding of the main processes of photosynthesis and cellular respiration or a correct understanding of the lessons' guiding questions. Errors of omission were not generally included, since participants failing to talk about a certain concept did not prove they held an alternative conception about it.

In the end, I retained two alternative conceptions revealed on the alternative conceptions survey that technically were omissions. They were such fundamental omissions and were a clear rejection of the correct answers that I decided it represented an alternative conception. These two conceptions were: 1) failing to recognize sugar was a reactant in cellular respiration, and 2) failing to recognize that energy was a product in cellular respiration. Both of these are fundamental components in the process of cellular respiration. If a participant did not choose an answer showing that sugar (stored energy) is broken down and converted to adenosine triphosphate (ATP) (usable energy), then I felt they held an alternative conception as to the purpose and process of cellular respiration. I only counted this as an alternative conception from the survey data source. For example, if a participant or group did not put sugar as a reactant and/or ATP energy as a product on their individual knowledge list or their group knowledge structure graphic, I considered that representative of an omission and did not count it. However, on the survey, the correct reactants and products were there in front of them and if they failed to choose it, then they must have thought the other reactants/products were correct and thus that would represent an alternative conception.

As I generated the master list of all the alternative conceptions revealed, I also compiled them into a large matrix on a spreadsheet. This matrix listed the fundamental alternative conceptions identified. It also showed each individual, as well as the group collectively, at five points in time: immediately prior to the treatment (pre-treatment), during the photosynthesis lesson, during the cellular respiration lesson, immediately following the treatment lessons (post-treatment), and two weeks later (delayed post-treatment). On the matrix, I indicated every occurrence of the alternative conception, the source of the idea (i.e., the specific individual or the group collectively), and the data source that revealed it. This matrix helped me keep track of all the important alternative conceptions, when they were identified, and if they were retained. I used this matrix to guide the development of all the figures in Chapter 4 of this document.

Analyzing Argumentation Quality

My research question explored how the alternative conceptions were influenced by the argumentative discourse-based treatment lessons. I answered that question by identifying the alternative conceptions that were held by participants at various points throughout the study. To gain insight as to factors that may influence the effectiveness of the experience for promoting conceptual change, I also examined the quality of the argumentation that occurred in each group. The data sources and analysis methods used to determine findings related to those themes are explained in the upcoming paragraphs.

Observation protocol analysis. I analyzed the three group transcripts from the photosynthesis lesson and completed the observation protocol for each. I chose to analyze the argumentation quality of the photosynthesis lesson only as I was most interested in their initial argumentation skills. The photosynthesis lesson provided multiple opportunities for argumentation, thus influencing the quality of the argumentation in the cellular respiration lesson. Although a comparison of changes in argumentation skill quality from the photosynthesis lesson to the cellular respiration lesson would be valuable, it was outside the scope of this study.

To analyze the groups' argumentation quality, I first familiarized myself with all the items on the ASAC observation protocol (Sampson et al., 2012). I highlighted key terms and did additional background research as necessary until I felt sufficiently versed in what the typical evidence would be for the existence of each characteristic in the groups' dialogue. Then I carefully read through the first photosynthesis lesson transcript looking for evidence of each of the items. Whenever I found a statement or dialogue excerpt that I felt was representative of that characteristic, I copied and pasted it into a digital version of the protocol. I copied evidence, if any, that supported each aspect. I also copied anything that was clearly in opposition to any of the aspects. I felt that it was important to gather evidence that clearly did not support the aspect too, rather than only looking for evidence that was supportive. Then I did this same procedure for the photosynthesis lesson transcript of the other two groups. It was not uncommon to return to groups previously done and make revisions after something in another transcript prompted me to deepen my own understanding of that aspect and what evidence supported or opposed it.

Having reviewed all three transcripts carefully and consistently, I determined the score for each aspect on the survey. I based the score on the amount of evidence I had copied down. No evidence or only opposing evidence received a score of zero. One or two strong instances of supporting evidence resulted in a score of one. Three strong instances of supporting evidence were given a score of two. Finally, four or more strong instances of supporting evidence were given the highest score possible, a three. The amount of opposing evidence was considered when assigning scores as well. For instance, if there was one piece of supporting evidence, but multiple instances of strong opposing evidence, the group may receive a zero after considering the strength of all the pieces of evidence together.

Once the protocols were scored, I next developed tables to display the groups' answers on each item, sub-scores on each of the three parts of the protocol, and their total score. I converted both their sub-scores and total scores to percentages of the possible scores. Group scores on each sub-section were compared with one another, looking for any noteworthy differences.

Cross–Case Synthesis

Next, I employed cross-case synthesis (Yin, 2014) to compare and contrast the three group cases. I had employed the technique of time-series analysis (Yin, 2014) to trace the changes, if any, which occurred in the groups during the argumentative discourse treatment. Then for the cross-case synthesis, I used the analytic technique of pattern-matching (Yin, 2014) to relate those findings to my original propositions that there would be a difference observed in the conceptual change results due to the groups' differing epistemic beliefs about science.

Trustworthiness

Qualitative research is distinguished by its emphasis on describing a situation in great detail (Tracy, 2010). This "thick, rich description (p. 126)" is a necessary component that imparts credibility to the findings (Creswell & Miller, 2000). In keeping with that requirement, this investigation employed multiple data sources to generate a detailed description of the experience of the PSTs as they participated in argumentative discourse-based lessons. Trustworthiness of the results was also supported through the triangulation of data, in which themes and results from one data source corroborated those from another data source (Merriam, 1988; Tracy, 2010).

Limitations

In any study, no matter how well planned and executed, there are limitations that should be considered when interpreting the results. These are conditions outside of the researcher's control. In this study, there were some unavoidable constraints due to timing and scheduling. For example, the delayed post-treatment survey was originally planned to be given about two months after the completion of the treatment lessons. However, due to scheduling issues, the delayed post-treatment survey had to occur only about two weeks later. Thus, the delayed post-treatment results may not be indicative of what information was truly retained by the participants in the long term.

Another scheduling issue prevented Group C from being interviewed as a complete group at both the pre- and post-treatment interview times. For their interviews, I had to interview two participants together, and then the other participant separately. This was not ideal, as it was inconsistent with how I did the interviews with the other groups.

It did open up an opportunity for the Group C participants to speak much more freely about group dynamics and their personality clashes in their group. This circumstance also highlighted the unanticipated limitation of the impact of such strong personality clashes and ineffective social dynamics on the instructional experience and resulting conceptual change outcomes.

Finally, it became apparent following the treatment lessons that not all of the participants engaged thoughtfully in the entire process. There was a distinct lack of commitment to many of the lesson tasks, revealed by the prevalence of off-task talk and behavior. Many participants spent noticeable amounts of time complaining about the instructional experiences and being dismissive and haphazard in their approaches to the individual and group tasks. This was a limitation to be considered in examining the alternative conception changes that resulted from the treatment lesson experiences.

Delimitations

The study was also constrained by delimitations related to the design of the study which was under my control. One delimitation was that the data collection procedures such as the alternative conception survey and the group knowledge structure task may have had a significant influence on the participants' alternative conceptions. Thus, the act of engaging in the pre-, post-, and delayed post-treatment activities may have influenced the conceptual change results in addition to the impact of the argumentative discourse lessons themselves.

Concerning the enacting of the treatment lessons, it was not feasible for participants to be engaged in argumentative discourse exclusively during the entire four hours of lesson time. Instructional strategies were planned that would encourage extensive collaborative student discourse, and specifically promote episodes of argumentative discourse. These tasks were all related to processes involved in appropriate scientific argumentation such as examination of evidence, explanation building, and collaborative discourse. During the lessons, embedded episodes of argumentative discourse occurred, but it was only a part of the more extensive collaborative discourse that took place among the participants. Thus, any claims related to the results are based on the combination of argumentative discourse with collaborative discourse, rather than argumentative discourse exclusively.

Chapter Summary

The preceding chapter presented the data sources and outlined the methods used to conduct this study. This qualitative case study used multiple data sources to support the trustworthiness of the findings. The research context, participants, data collection instruments, and procedures were explained in detail so that the reader may evaluate the findings in light of an in-depth understanding of how the study was conducted, and how the data were collected and analyzed.

The next chapter will present the results of the study. It will describe the findings that provide insight into answering the research question and supporting or refuting the study propositions. The findings from each of the three cases will be presented in narrative form to provide evidence into how the participants experienced the argumentative discourse instruction, whether it influenced their conceptual understanding, and the possible influence of their underlying epistemic beliefs about science.

CHAPTER IV: RESULTS

Introduction

The focus of this study was to explore how the alternative conceptions of elementary PSTs might be influenced, if at all, by engagement in two lessons designed to encourage argumentative discourse. Arguing from evidence is considered a key scientific practice that encourages the development of deeper understanding and greater scientific proficiency (Driver et al., 2000). This approach to learning science may encourage conceptual change as learners are forced to confront their own prior alternative conceptions while evaluating and negotiating more accurate conceptions within a sociocultural learning environment (Nussbaum & Sinatra, 2003; Posner et al., 1982; Vygotsky, 1978).

An additional research question examined whether participants' epistemic beliefs about science influenced, if at all, their conceptual change outcomes following the two lessons incorporating argumentative discourse. One of the propositions of the study was that participants with more sophisticated epistemic beliefs about science might have more positive conceptual change outcomes from this type of experience. This may be because they are more open to the constructivist approach, more comfortable with ambiguity and subjectivity, and better able to apply scientific ways of thinking to the challenging tasks in the lessons. It is possible that participants with more traditional, less sophisticated epistemic beliefs may struggle more with this approach to learning and thus have less positive outcomes on their conceptual advancement. To explore this, three homogenous groups were formed and examined in detail. Each of these groups had similar epistemic beliefs, with one group holding more traditional beliefs (Group T), one group with moderate beliefs (Group M), and one group with the most strongly held constructivist beliefs (Group C).

This chapter will present the narrative and results of the participants before, during, and after their engagement in the inquiry-based lessons that encouraged the generation of argumentative discourse. The participants worked in small groups to complete collaborative tasks designed to encourage critical thinking, generate extensive peer discussions, promote the use of evidence to support conclusions, and ultimately to deepen their understanding of the processes of photosynthesis and cellular respiration in plants.

The results from each of the three cases will be presented in the chapter ahead: first Group T, then Group M, and finally Group C. Within each case, results will be grouped in time order of pre-treatment, during treatment, and post-treatment. Each of the time-based sections will begin by reporting on the individual alternative conceptions results of each embedded case in that group at that point in the study. Then I will report on the collective group-level alternative conceptions identified at that point in the study.

Following the detailed results regarding the alternative conceptions present in the individuals and in the groups as a whole, there will be a report of the quality of the group’s argumentation, specifically related to cognitive and epistemic aspects. Finally, a brief summary of each case is provided.

Following the three cases, there will be a cross–case analysis. This section will present a summary of the results of each case in comparison and contrast to the others. Finally, an overall summary will conclude this chapter.

Alternative Conceptions Identified

Many alternative conceptions about photosynthesis and cellular respiration were held by the participants. After careful analysis of the data sources, I identified 53 separate alternative conceptions held by the participants. Many of these had been identified in previous studies (e.g., Alparslan et al., 2003; Cakiroglu & Boone, 2002; Çokadar, 2012; Haslam & Treagust, 1987; Köse, 2008; Krall et al., 2009; Kuech, et al., 2003; Lumpe & Staver, 1995; Svandova, 2012; Özay & Öztaş, 2003). A comprehensive list of all the alternative conceptions that were identified can be found in Appendix M. Specific alternative conceptions held by each participant and by each group collectively at various times throughout the study are presented within the upcoming detailed results.

The Case of Group T

The group with the most traditional epistemic beliefs of the class, Group T, was composed of three study participants: Tia, Tory, and Tess. It is important to note that their views, as measured by the Hofer (2000) epistemic survey, were not strongly traditionalist. All of the study participants' beliefs skewed toward the constructivist end of the beliefs scale as measured by the survey. These three PSTs' beliefs could most accurately be described as being the least constructivist of the class. They were chosen to form the group with the least sophisticated and most traditional beliefs about science to satisfy the planned design of the study.

The results of Group T will be presented in the upcoming sections. The first main section will detail the conceptual changes that occurred over the course of the study, determined based on the identified alternative conceptions in each of the individuals as well as collectively as a group over time. These are arranged in three chronological sections: alternative conceptions present *before* the treatment lessons (individual-level and group-level), alternative conceptions present *during* the treatment lessons (group-level only), and alternative conceptions present *after* the treatment lessons (individual-level and group-level). Note that results from after the treatment lessons are subdivided into results from two different time periods: immediately after the treatment lessons (post-treatment) and two weeks after the treatment lessons (delayed post-treatment).

After the conceptual change results are presented, an additional section reports the results of Group T's argumentation quality. This is divided into two parts: conceptual and cognitive aspects of argumentation, and epistemic aspects of argumentation. A brief summary concludes Group T's results.

Conceptual Changes in Group T

The upcoming section will present a case study report of the conceptual changes that appeared over the course of the study. Both individual and collective group alternative conceptions will be discussed. These will be presented in three chronological parts. The first part will present the individual and collective group alternative conceptions that were identified prior to the treatment lessons. The second part will provide a detailed account of any alternative conceptions that were revealed during the treatment lessons. These were inaccurate ideas that were initially accepted by the group and discussed more than once. Finally, the last part will present the individual and collective group alternative conceptions that remained following the treatment lessons.

Pre-treatment conceptions (individual- and group-level). It was critical to elicit the individual participants' alternative conceptions that were present before the group members began working together at all. These baseline alternative conceptions were identified from two data sources: the pre-treatment individual knowledge lists and the pre-treatment alternative conceptions survey. These data sources were individually generated and not influenced by peers.

In addition, Group T's collectively agreed upon group alternative conceptions were important to identify prior to their engagement in the treatment lessons. These initial group alternative conceptions were gleaned from three data sources: the pre-treatment group knowledge structure graphic, the discussion the group engaged in while creating the pre-treatment group knowledge structure graphic, and the participants' comments during the pre-treatment interview. Alternative conceptions that arose and were not refuted by the other group members were considered group-level ones.

The upcoming section presents these beginning alternative conceptions. Each individual's alternative conceptions are presented first in the order of Tess, Tory, and then Tia. Their baseline understanding of photosynthesis and cellular respiration are explained, and their clearly identified alternative conceptions are listed. That is followed by a section that presents the collectively agreed upon Group T alternative conceptions.

Tess (individual-level). Tess's initial understanding of photosynthesis and cellular respiration was relatively developed in comparison to some of the other participants. Tess scored a 64% on the pre-treatment alternative conceptions survey, tied with Cady from Group C for the highest pre-treatment score in the class. However, this score did not represent a very high score, and she clearly held a number of alternative conceptions. A summary of the alternative conceptions apparent in Tess prior to the treatment lessons is shown in Figure 4.1 and then discussed more in the paragraphs that follow.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P biomass: originates in water
P equation: gas exchange is O_2 in, CO_2 out
P equation: turns light directly into sugar
P equation: chlorophyll is a reactant
P oxygen is a waste product, ignoring its importance as a reactant for CR
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR purpose: to produce sugar
Total: 8

P = Photosynthesis, CR = Cellular Respiration

Figure 4.1. Tess's pre-treatment alternative conceptions.

Photosynthesis. Tess wrote four facts on her pre-treatment individual knowledge list about photosynthesis. Two of those facts were vague, but correct, and spoke to the importance of the sun. Her two more detailed facts contained alternative conceptions. First, she included the erroneous idea that plants convert the sun's energy directly into food. The information on her knowledge list also revealed her lack of understanding regarding the reactants and products of the process, as well as missing the overall purpose. Tess wrote, “The plant gives off O_2, converts H_2O into glucose or CO_2” (Tess, Pre-Treatment Individual Knowledge List, 4/10/15).

Tess responded correctly to many of the photosynthesis items on the pre-treatment alternative conceptions survey. Tess’s understanding of photosynthesis, while mostly accurate according to her answers, also included the alternative conception that a plant forms carbon dioxide from water during the process. Tess’s knowledge of photosynthesis aligned quite well with accepted scientific thought, other than her belief that chlorophyll combined with carbon dioxide during the process. Tess also indicated incorrectly that water was the main source of a plant’s biomass.

Cellular respiration. Tess’s individual knowledge list about cellular respiration was short. It also revealed her lack of confidence in her understanding of the process. She wrote only the following, “IDK [I don’t know], something to do w/o [*sic*] going to/thru the cells in the body and something about mitochondria” (Tess, Pre-Treatment Individual Knowledge List, 4/10/15). It is likely her knowledge of mitochondria came from information learned earlier in the semester. Tess said later, “And Dr. Pepper always was, like, the mighty mitochondria, cellular respiration, so I remember that” (Pre-Treatment Interview, 4/10/15).

On the alternative conceptions survey, Tess answered many cellular respiration questions correctly. For instance, she accurately responded that cellular respiration occurs in all plant cells as well as in all animal cells. As for the inaccuracies in her understanding, Tess did not select the appropriate equation for the process of cellular respiration. Like her group mates, she also incorrectly believed that carbon dioxide was absorbed and oxygen released during cellular respiration, the opposite of the correct exchange of gases.

Tory (individual-level). The information Tory provided on her individual knowledge lists contained some accurate information as well as revealed some alternative conceptions. Tory's responses on the pre-treatment alternative conceptions survey also showed that she lacked a scientifically accurate understanding of both photosynthesis and cellular respiration. She scored 36% on the pre-treatment survey, the lowest pre-treatment score of Group T. Figure 4.2 provides a list of all the identified alternative conceptions held by Tory. The following paragraphs provide additional details.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P biomass: originates in water
P equation: turns light directly into sugar
P equation: unspecified energy is a reactant
P oxygen is a waste product, ignoring its importance as a reactant for CR
P purpose: main benefit to the plant is to remove CO_2 from air
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR equation: do not recognize energy is a product
CR timing: only occurs in light/day
CR timing: only occurs in dark/night
CR timing: only occurs when P is not happening
CR purpose: to produce sugar
CR requires chlorophyll
CR location: occurs only in leaf cells
CR only leaves have pores/stomata
Total: 15

P = Photosynthesis, CR = Cellular Respiration

Figure 4.2. Tory's pre-treatment alternative conceptions.

Photosynthesis. Tory included a mix of accurate and alternative conceptual understanding of photosynthesis in the facts she wrote on her pre-treatment individual knowledge list. Although she accurately mentioned that during photosynthesis plants take in carbon dioxide and release oxygen, she did not link that to the process of creating the sugar. Instead, she stated that plants “take in the sunlight and turn it into sugar” and “plants turn sunlight to sugars” (Tory, Pre-Treatment Individual Knowledge List, 4/10/15). These statements indicated that Tory did not recognize the need for carbon dioxide molecules and believed that the sugar was created directly from the light.

On the pre-treatment alternative conceptions survey, Tory revealed limited understanding of the process of photosynthesis. For example, she failed to identify the correct depiction of the equation. She also answered that the most important benefit of photosynthesis to plants was that it removed carbon dioxide from the air. This is arguably a benefit from the perspective of humans, but is irrelevant as a benefit to plants, especially when compared to the accurate multiple-choice option that stated the purpose was to convert light energy to chemical energy (Haslam & Treagust, 1987). Tory also believed that water was the main source of a plant’s biomass, which indicated her misunderstanding of the fundamental meaning of the term biomass.

Cellular respiration. On her individual knowledge list about cellular respiration, Tory said, “Cellular respiration occurs when plants take in energy and their cells produce sugar” (Tory, Pre-Treatment Individual Knowledge List, 4/10/15). This statement described the process of photosynthesis more accurately than it did cellular respiration. It revealed that Tory did not understand the fundamental purpose or process of cellular respiration and how it differed from photosynthesis.

Tory's ideas about cellular respiration were also inaccurate based on her answers on the alternative conceptions survey. Her responses revealed confusion about the purpose of cellular respiration. She indicated it was a process in which plants manufacture food from water and carbon dioxide. Tory chose the photosynthesis equation when asked to choose the cellular respiration equation, further conflating the two processes. Consistent with that inaccurate understanding, she answered that carbon dioxide was absorbed and oxygen released when there was no light present. Tory showed inconsistency in her answers regarding when cellular respiration occurs. For one question she chose a response that said it occurs only during daylight, while an answer she chose on a different item actually indicated the opposite. Tory also believed that cellular respiration only occurs in leaf cells.

Tia (individual-level). Tia's responses on the pre-treatment individual knowledge lists and the pre-treatment alternative conceptions survey showed that she too lacked an accurate understanding of the processes of both photosynthesis and cellular respiration. It appeared that her understanding of photosynthesis was more developed than that of cellular respiration. Tia scored 50% on the pre-treatment alternative conceptions survey. Figure 4.3 summarizes Tia's alternative conceptions held prior to the treatment lessons.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P biomass: originates in water
P timing: only occurs in the dark
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR equation: do not recognize energy is a product
CR timing: only occurs in light/day
CR timing: only occurs in dark/night
CR timing: only occurs when P is not happening
CR purpose: to provide energy when P is not occurring or has not made enough energy
CR purpose: to produce sugar
CR requires chlorophyll
CR animals do CR because they cannot do P
Total: 12

P = Photosynthesis, CR = Cellular Respiration

Figure 4.3. Tia's pre-treatment alternative conceptions.

Photosynthesis. Tia's pre-treatment individual knowledge list regarding photosynthesis included the following sentence only. She wrote, "Plants go through the process of photosynthesis in order to make food. They need water, sun, and chlorophyll for this to happen" (Tia, Pre-Treatment Individual Knowledge List, 4/10/15). She included a drawing of a plant, a sun, and rain. Notably, this response showed no acknowledgement of the critical role of carbon dioxide in photosynthesis.

On the alternative conception survey, Tia demonstrated more accurate conceptions of photosynthesis than she did of cellular respiration. However, she incorrectly indicated that plants could perform photosynthesis without the presence of light energy. In addition, Tia did not recognize the connection between the building block molecules of carbon dioxide and oxygen in the air and the resulting plant body and structures. She believed that water was the main source of a plant's biomass (dry weight), which exposed her misunderstanding of the term biomass.

Cellular respiration. Tia's individual knowledge list about cellular respiration contained only one sentence, just as her photosynthesis one had. She wrote, "All living things use the process of cellular respiration" (Tia, Pre-Treatment Individual Knowledge List, 4/10/15). This is factual, but the lack of more information indicated that Tia's knowledge of cellular respiration was likely limited.

Tia's answers on the alternative conception survey provided more clear evidence that her conceptions of cellular respiration were fundamentally flawed. She believed that carbon dioxide was absorbed and oxygen released during cellular respiration, the opposite of the actual gas exchange. She did not identify the correct equation for the process of cellular respiration. Tia answered that the main purpose of cellular respiration was to provide an alternative source of energy for plants to use when there was no light present. This revealed a critical misunderstanding regarding the function of both cellular respiration and photosynthesis. Tia did not show evidence of understanding that the two processes work in tandem: photosynthesis creates chemical energy while cellular respiration converts that to ATP energy, a usable form of energy for the plant. Tia believed that respiration occurred in plants only when there was no light energy available.

Group T (group-level). Following the individual tasks of completing the alternative conceptions survey and creating their individual knowledge lists, the members of the traditionalist group, Group T, collaborated to create a group knowledge structure graphic that represented their combined knowledge of both photosynthesis and cellular respiration (Figure 4.4). The graphic itself and the discourse that occurred while creating it was intended to reveal the alternative conceptions of the group prior to the treatment lessons. In addition, other alternative conceptions were revealed during the group's pre-treatment interview when I probed for more details about their current understanding of photosynthesis and cellular respiration.

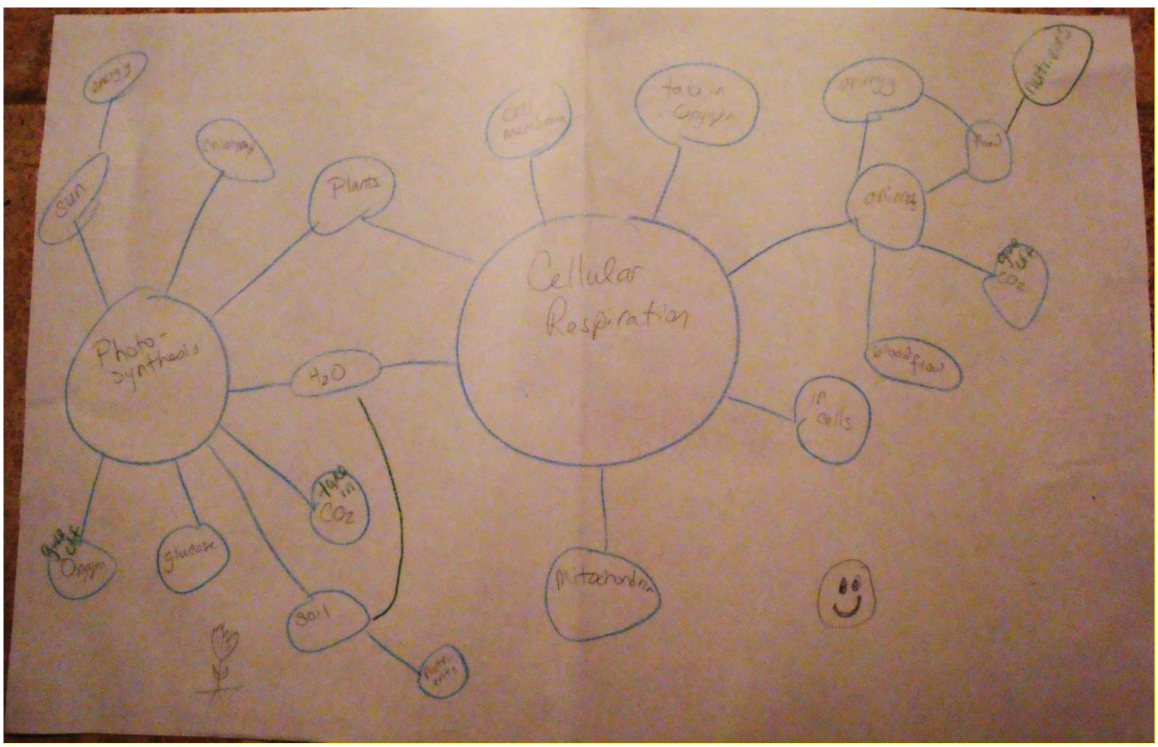

Figure 4.4. Group T's pre-treatment knowledge structure graphic.

Five alternative conceptions were suggested and agreed upon by the group prior to the start of the lessons. If an alternative conception was suggested but then immediately refuted by others in the group, it was not included. In addition, if an alternative conception was suggested but there was no obvious agreement from the others, then it was also not included as a collective group alternative conception. The five alternative conceptions identified were: a) plants “eat” soil; b) nutrients for plants come only from soil; c) photosynthesis turns light directly into sugar; d) cellular respiration is the same process as physical respiration in animals; and e) cellular respiration is associated with blood flow. A list of the collectively agreed upon alternative conceptions present in Group T prior to the treatment lessons is shown in Figure 4.5. The following paragraphs provide details about when and how the alternative conceptions were revealed, discussed, and accepted by the group. Note that the first two alternative conceptions (i.e., that plants eat soil and nutrients for plants come only from soil) are two closely related alternative conceptions. Thus, they will be discussed together in the upcoming paragraphs. Likewise, the last two on the list (i.e., the conceptions that cellular respiration is the same as physical respiration and that it is strongly associated with blood flow) are also connected ideas and will be discussed together.

Pre-Treatment Alternative Conceptions
Identified from pre-treatment group knowledge structure, pre-treatment discussion, and pre-treatment interview
P plants “eat” soil
P biomass: nutrients for plants come only from soil
P equation: turns light directly into sugar
CR similar to physical respiration in animals; plants do CR, but animals breathe
CR associated with blood flow
Total: 5

P = Photosynthesis, CR = Cellular Respiration

Figure 4.5. Group T’s pre-treatment alternative conceptions.

Plants "eat" soil and nutrients for plants come only from soil. On their pre-treatment group knowledge structure graphic, Group T included the word *nutrients* connected to the word *soil* and then connected to *photosynthesis*. During their discussion, the group subtly implied that plants absorb nutrients from the soil to obtain energy, analogous to the way animals consume food to gain energy. That dialogue is recorded below.

Tory: Well, what about food?

Tess: Food for?

Tia: Animals.

Tory: The animals take in food.

Tess: Right.

Tory: I don't know.

Tess: I don't either.

Tia: Because that's where they get the energy from to (trails off). With this process of growing.

Tess: Yeah.

Tory: Maybe soil?

Tia: Soil, we could put soil and then put nutrients.

Tory: Oh.

Tess: All right.

Tia: And then we can put a few nutrients. It's coming along great (laughter).

(Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15)

This concept of the importance of nutrients from the soil being integral for photosynthesis appeared during the pre-treatment interview as well. I had asked the group members to explain what they meant by including *nutrients*, connected to *soil*, which was then connected to *photosynthesis* on their pre-treatment group knowledge survey. The following exchange occurred.

Researcher: Um, what does that say?

Tess: Nutrients.

Researcher: Okay, tell me about that one.

Tess: From the soil. And from photosynthesis. Yeah, we were going to add that before.

Researcher: Oh, okay.

Tess: But that's just part of the process with photosynthesis.

Tia: Yeah.

Researcher: Would, can you elaborate on that? What do you mean it's part of the process of photosynthesis?

Tess: Well [plants] get some of their nutrients from the soil, so (trails off).

(Pre-Treatment Interview, 4/10/15)

This alternative conception surrounding the role and importance of soil and of unspecified nutrients located in the soil being necessary for photosynthesis became a conceptual obstacle for this group as well as others later in the lesson. At pre-treatment, it seemed that all Group T members agreed without question that nutrients of some sort in the soil must be absorbed by the plant in order for it to grow. The conception that nutrients (e.g., O_2, CO_2) were absorbed from the air to enable plant photosynthesis and subsequently growth was not mentioned by the group.

Photosynthesis turns light directly into sugar. Logically in conflict with the previous alternative conception, Group T also indicated correctly that photosynthesis was integral in producing necessary food energy for plants. However, their understanding of that process was limited. They held a common alternative conception that light generated food or sugar directly in the plant, discounting the reality that the light energy actually powers the recombination of absorbed molecules into sugar molecules. The group included the word *energy* attached to the word *sun*, and then attached to *photosynthesis*. I asked them to discuss this further during the interview. The resulting dialogue follows.

Researcher: Okay, um, let’s see, so you’ve got energy here and energy here [on your knowledge structure graphic].

Group: Mm-hmm.

Researcher: Talk to me about both of those.

Tia: We said, so animals, we would get our energy from food, and we talked during the day about how the plants get their energy from the sun.

Researcher: Okay, all right. Now is energy connected to photosynthesis at all, or is energy connected to cellular respiration at all?

Tory: I think in cellular respiration it helps [plants] make energy, right? Like it helps them produce energy, but in photosynthesis, they just, they get energy from the sun. It’s different.

Researcher: Gotcha.

Tia: I want to say with photosynthesis, [plants] might have to have [energy]? So that photosynthesis will be complete. But I’m not sure.

(Pre-Treatment Group Interview, 4/10/15)

In the above dialogue, Tia stated that plants get their energy from the sun and likened it to how animals get their energy from food. Also in the discussion above, it is clear that the group in general was confused about how photosynthesis and cellular respiration both are involved with energy production for the plant. This confusion became more evident during the treatment lessons.

Cellular respiration is similar to physical respiration in animals and is associated with blood flow. These two alternative conceptions were proposed during the discussion around the creation of the knowledge structure graphic and during the interview. They indicated that the group conflated cellular respiration with the process of physical respiration in animals. The first appearance of this idea occurred right at the beginning of Group T’s discussion as they started forming their pre-treatment knowledge structure graphic.

Tess: Okay, I'll put that on here. Um I thought [cellular respiration] was with, like, humans too? Because doesn't it have to do with oxygen going into the cells or something?

Tia: I think.

Tess: Because, like, respiration is breathing, or oxygen.

Tory: Isn't it in plants and animals, right?

Tess: I think so.

Tia: Yeah.

Tory: So, like, they make energy?

(Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15)

In the above discussion, Tess stated that respiration means breathing. This is correct, assuming she is speaking only of physical respiration. However, she did not appear to distinguish physical respiration from the topic at hand, cellular respiration. Tory recognized the illogic of cellular respiration only having to do with breathing, since plants do not breathe. She correctly suggested that cellular respiration had to do with the production of energy. However, her group mates did not recognize the importance of that idea and instead changed the subject.

Later, Tess suggested that cellular respiration had to do with blood flow. This idea was closely related to her earlier alternative conception that cellular respiration is the same as physical respiration. Both Tia and Tory were hesitant about the idea, and even Tess qualified her suggestion with an "I don't know" (Pre-Treatment Group Knowledge

Structure Graphic Discussion, 4/10/15). However, she then proceeded to include it on the knowledge structure graphic and the others did not object. The dialogue follows.

Tess: Did it help with, like, blood production or anything?

Tia: You think so?

Tory: I don't know.

Tess: Or blood flow? I don't know.

(Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15)

Later, this alternative idea was again discussed during the pre-treatment interview. I asked Group T to explain more about their knowledge graphic, particularly why they had included the term *blood flow* in a bubble connected to *animals*, which was then connected to *cellular respiration.* Tess explained:

> I'm not real sure, we thought maybe [cellular respiration] had to do something with how your blood flows but I mean, we weren't super sure, but we knew animals had it, or animals had blood, not plants, so that kind of thing. (Group T, Pre-Treatment Interview, 4/10/15)

Tia added,

> I was just going to say it's kind of, like, you know when you're breathing in, like you have to breathe in that oxygen, like, to get through your veins and all of that stuff. So it's kind of like that. So I thought, I figured, like, with respiration it has something to do with it. I'm not sure. (Group T, Pre-Treatment Interview, 4/10/15)

Tory did not contribute to these explanations, but she nodded while the others spoke, indicating her agreement with their ideas. Thus, it was evident that this group had an alternative conception regarding the purpose and process of cellular respiration. They were trying to associate it with the act of physical breathing and the process of oxygen being spread through an animal's body by blood flow. It was unclear what they understood cellular respiration to be in plants, which obviously do not breathe or have blood. Tess mentioned that fact, but she did not elaborate on her understanding of the discrepancy.

The next section will examine what occurred with the group's collective alternative conceptions as they worked through the argumentative discourse lessons on photosynthesis and cellular respiration. During the lessons, participants were provided evidence to use to develop and support their assertions regarding the scientific processes of photosynthesis and cellular respiration. They were asked to make claims and defend them using the evidence provided.

During treatment conceptions (group-level). The members of Group T engaged in extensive dialogue during the course of the two treatment lessons. Through their collaborative and argumentative discourse, alternative conceptions were revealed and accepted by the group. Any alternative conception that was accepted by the group and mentioned more than incidentally was counted as a group-level alternative conception. It should be noted that many of these alternative conceptions changed at some point during the treatment lessons (i.e., the group might not have continued to exhibit the alternative conception by the end of the lesson). No individual-level alternative conception results were collected during the treatment lessons since the participants were collaborating and negotiating understanding dynamically.

The group-level alternative conceptions that were identified in Group T during the photosynthesis and cellular respiration treatment lessons are listed in Figure 4.6. The upcoming section will provide more details about the occurrence and acceptance of these alternative conceptions through narrative and quoted dialogue. The alternative conceptions that occurred during the photosynthesis lesson will be discussed first, followed by those from the cellular respiration lesson.

During Photosynthesis Lesson	**During Cellular Respiration Lesson**
P biomass: originates from soil	
P equation: ATP energy is a product	
	CR and P equations: exact reverse/opposite of each other
	CR equation: gas exchange is CO_2 in, O_2 out
	CR purpose: to produce sugar
	CR purpose: to store sugar
	CR ATP energy is absorbed
	CR similar to physical respiration in animals; plants do CR, but animals breathe
	CR sugar made during CR is stored in stoma
Total: 2	**Total: 7**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.6. Group T's alternative conceptions during the treatment.

Photosynthesis lesson. During the photosynthesis lesson (Appendix G), two main alternative conceptions were identified as foundational ideas that impeded the group members' understanding: a plant's biomass mainly comes from nutrients in the soil and

ATP is a direct product of the process of photosynthesis. These had been expressed by at least one individual member of the group previously. These two concepts were also discussed at some length during the treatment lesson, rather than simply being mentioned in passing like some other inaccurate ideas. The first of these ideas was partially corrected during group tasks before the end of the lesson, but the other was not. They were not the only inaccuracies expressed, but they seemed to be the most extensive and detrimental to an accurate understanding of the lesson. Each of these will be discussed in detail in the following sections.

Biomass mainly comes from nutrients in the soil. At the start of the lesson, Dr. Pepper posed the guiding question, “From where does a plant get its biomass?” (Photosynthesis Lesson, 4/13/15). She clarified that biomass was the dry weight of a plant. Tess immediately offered a suggestion, saying, “From the roots?” (Photosynthesis Lesson, 4/13/15). Tia then asked, “What do they mean by ‘dry weight’? What does she mean by that?” (Photosynthesis Lesson, 4/13/15). The group proceeded to spend the next two minutes wrestling with the meaning of dry weight and biomass. Tory read the definition from her biology notebook to the group even though they had been asked not to use outside sources during the lesson. They then expressed their disinterest in the question altogether. The following exchange is illustrative of this eventual attitude toward the topic.

Tia: I don’t even know.

Tess: I don’t know. Is it really that important?

Tia: I will not use biomass to pay my bills. I just need the degree before anything.

Tess: I just need to pass this class. After I finish this final exam, I will not think about any type of life science ever again.

Tia: Me too.

(Photosynthesis Lesson, 4/13/15)

Then Dr. Pepper provided the class with four possible answers and asked the groups to choose the claim they agreed with the most. The following discussion occurred among the members of Group T.

Tia: Maybe it's the [nutrients in the soil] or the [water taken up by roots]?

Tory: Yeah, I think it's [nutrients in the soil]. I thought it could be all of them. Maybe just the first one [nutrients in the soil].

Tess: I don't know.

Tory: Because, I like, barely remember [Dr. Pepper] saying something about the roots and stuff.

Tess: Well, since it's science, it's a trick question, so (trails off).

Tia: Um, I don't think it could be the second one because that's water, so there wouldn't be dry weight, would it?

Tory: Oh yeah. Could we say [comes directly from the sun's energy]?

Tess: I don't know. You want to say [nutrients from the soil]?

Tia: Yeah.

Tory: Mm-hmm.

(Photosynthesis Lesson, 4/13/15)

In the above exchange, the group decided that *nutrients from the soil* were the main source of a plant's biomass. They considered and rejected the option that it came from water due to Tia's reasoning. No one endorsed sunlight as a source, so that option was not chosen. The correct answer, it comes from air molecules, was not mentioned at this time.

The class was then instructed to use the equation component cards to model the photosynthesis equation (Appendix G, Task 3). Through some discussion and without much confidence, Group T settled on a model (Figure 4.7). Their model was generally correct except they included chlorophyll, chloroplasts, and mitochondria as reactants. Interestingly, they did not include soil or nutrients, even though they had earlier been discussing those components as necessary.

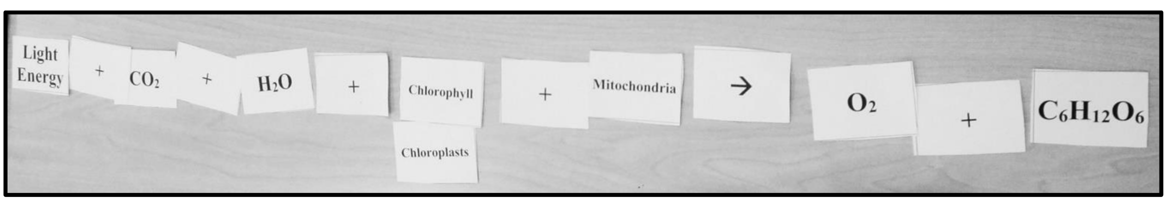

Figure 4.7. Group T's first photosynthesis equation model.

Next, the group members visited the evidence stations to gather more information regarding the process of photosynthesis. As instructed, they divided up the stations and were each responsible for sharing what they learned with the rest of their group when they returned to their table. Questions on a worksheet were provided to help focus them on the important ideas from each station.

After about 10 minutes of studying the evidence stations, all three members returned to their table and shared the information they learned (Appendix G, Task 4). In general, Group T struggled to make sense of the information they had gathered and were confused about how to apply it usefully to either adjust their photosynthesis equation or support their biomass claim with evidence. Tess was extremely outspoken in her frustration regarding the activity. She did most of the talking during the sharing time. The following excerpt is illustrative of the flavor of Tess's comments during the process of sharing evidence station information.

Tess: I learned nothing. And the information that was provided had nothing to do with the questions that were given.

Tory: Yeah. Me too. Um, it was different (trails off). I don't know.

Tess: I mean this [station] was talking about, this [expletive removed] was growing a plant, or a tree for five years. The tree started out five pounds, the soil was 200 pounds. After five years the tree grew and was 169 pounds, and the soil. And then his conclusion was that almost all the biomass must come from the water because it did not come from the soil.

Tory: Hm.

Following a few minutes of similar talk by Tory and Tess, Tia returned from studying her assigned evidence stations. She said, I have no clue what is going on and I was not going to stand there and keep doing it because (trails off). So, [the answers are] probably all wrong, but I tried, I did try on this one. It was the easiest one, but this other stuff I was like, whatever. These are all wrong. So (trails off). (Photosynthesis Lesson, 4/13/15)

Tia did not have an opportunity to discuss the content of her evidence stations in a meaningful way as next Tory briefly shared what she had learned. Then Tess monopolized the rest of the evidence sharing time. The group's conclusion was that everything was too disconnected and the evidence was not helpful in aiding their understanding of the biomass question or the photosynthesis equation. Tess summarized the group's frame of mind, saying, "More confusion than answers" (Photosynthesis Lesson, 4/13/15).

Dr. Pepper instructed the class to edit their photosynthesis equations as necessary, based on information they had learned from the evidence stations. She also encouraged them to change their claim about biomass if they felt that the new information warranted it. The following discussion occurred in Group T and resulted in a revision of their photosynthesis model (Figure 4.8).

Dr. Pepper: Do you want to change your claim in any way? Feel free to do that.

Tia: To *what*?

Tory: It's, like, we would if we knew what to write.

Tia: Yeah.

Tess: So take [mitochondria] out.

Tory: Maybe (trails off). Hm. I don't know.

Tia: I guess we could take [chloroplasts] out. That's like another [plant] part.

Tory: Yeah, because [chlorophyll] is in [chloroplasts].

Tess: I don't know, I really don't know.

Tory: We can ask [Dr. Pepper] to check it. I mean (trails off).

Tia: Check what?

Tory: That [equation].

Tia: We should've looked it up and then we wouldn't have to. But I didn't think about it.

Tory: I want to know what the right answer is.

(Photosynthesis Lesson, 4/13/15)

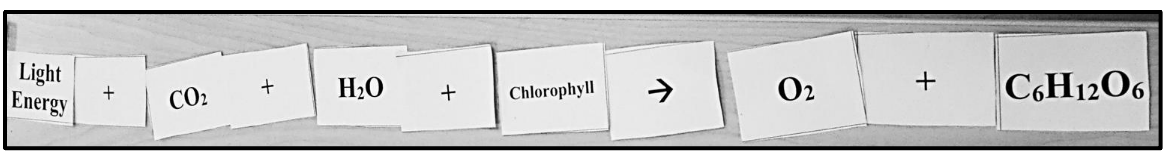

Figure 4.8. Group T's second photosynthesis equation model.

The next excerpt illustrated Group T's lack of ability to connect and apply the evidence. This occurred after Dr. Pepper asked the group to write their claim and evidence for their chosen claim regarding the biomass question.

Tess: So we're writing a claim about this?

Tia: Um, I think. From where do plants get its biomass? And we wrote "nutrients in the soil taken up by the plant's roots."

Tory: The one we picked.

Tess: Okay, so this doesn't have anything to do with what we're doing [modeling the photosynthesis equation]?

Tory: I don't think so.

Tia: I don't know.

(Photosynthesis Lesson, 4/13/15)

Tory wrote down the group's claim that the biomass of a plant mainly came from the soil. Dr. Pepper walked by and reminded the group to focus only on their claim and their evidence. After some silence, the following exchange occurred.

Tess: All right, so we can say that (trails off, sighs).

Tia: Um.

Tory: Do we have to use this (indicating information sheets from the stations)?

Tess: Yeah.

Tory: Oh, my.

(Photosynthesis Lesson, 4/13/15)

This exchange occurred nearly an hour into the class period during which Dr. Pepper had repeatedly instructed the participants to make connections between the evidence provided on the evidence station sheets and their photosynthesis equation and subsequently the biomass question. Only at this point did the members of Group T begin discussing the evidence in light of how it might support the claim they had chosen. It was during the next dialogue sequence that the group decided to reject their original claim and instead adopt the accurate claim that biomass results from the air. Of the foundational alternative conceptions that were identified during the lesson, this was the only one that showed evidence of being changed during the course of the group tasks and discussions. This excerpt began with the group talking about what components are necessary for a plant to grow. Then Tia made a comment that shifted the whole group away from their previously chosen claim. The exchange follows.

Tess: Okay, let's see.

Tia: I know soil is oxygen, optional, but you need water and nutrients. You have to have that for the plant to grow, so (trails off).

Tory: Water and nutrients (trails off).

Tia: That makes me wonder about our claim then, since it says "nutrients in the soil," but that [station] said you don't need soil for the plant to grow.

Tess: Well, and then this [station], his conclusion was that most of the water is drawn off and conveyed through the pores of the leaves and exhaled into the atmosphere.

Tory: That's kind of what I had.

Tess: Yeah and then (trails off).

Tory: Like, sunlight entered the leaves, and then it entered the cells of the leaves. Maybe it's the third one [biomass comes from air molecules].

Tia: Where is this?

Tory: On the bottom of the first column.

Tia: Oh no, the first one on the bottom.

Tory: Maybe. You want to change it?

Tia: Yeah.

Tory: Want to change it to the third one maybe?

Tia: Yeah.

Tory: Because that one makes sense.

(Photosynthesis Lesson, 4/13/15)

During the next interaction, the group members continued to suggest ideas from their evidence stations that could support the claim that biomass comes from air rather than the soil. Their dialogue is recorded below.

Tory: I'm going to write [my evidence] down first. The sunlight can enter the leaves, the cells of the leaf. Does that sound right?

Tess: You said something about the leaves and then this [station] was talking about that it goes through the pores of leaves and the water is drawn off. And then let into the atmosphere.

Tory: Okay so (trails off).

Tia: My evidence is that a plant does not need soil in order to grow.

Tess: Very good, because this one only used two ounces of soil in five years, so okay.

Tory: "Much soil" or "in soil"?

Tess: They grew plants without any soil. Didn't they use hydroponics?

Tia: [Soil] was optional.

Tess: Okay.

Tory: Oh really?

Tess: Because you can grow plants without it, with hydroponics, which is just water. Water and nutrients. Oh my god I feel like [expletive removed].

Tory: And then?

Tess: I was up all weekend working on research and, ugh, and then I had to do a mountain of laundry.

Tia: Girl, I have not done that yet. I didn't wash this whole month that pile of clothes that's gotten that high. I used to do it every Saturday, but I just, that box, to do like all of that (trails off).

Tory: They can absorb water through the pores.

Tess: Yeah. And then, I guess the rest of it goes out as oxygen, and (trails off).

Tory: The excess water in the pores leaves as oxygen?

Tess: I think so. Because I don't think, whenever this guy did it, they knew what oxygen and all that stuff was yet.

Tory: Um, the cell wall allows things to be absorbed into it, I forgot about that one. I guess I'll write it.

Tess: Should we put in there that over five years of growth, only two ounces of soil was lost? And then that's, what this other one's? I don't know, let's not put [Woodward's experiment]. His doesn't make any sense. He grew a plant in 77 days and he used 76,000 grams of water. And it only gained one gram of weight. I don't know what his point was.

Tia: Sometimes I wonder why did these people even do this stuff, like, you know?

Tess: Mm-hmm. They were rich and didn't have anything else to do. I mean. Anything else, do you have anything else? I mean, you had the one that didn't even need soil.

Tia: And no, we don't want those [stations]. That one was kind of hard too, about the beakers. I just figured since (trails off).

Tess: Oh, is that talking about, like, absorbing a liquid and then it comes in? Put that in there, that it can absorb coloring through the water, through whatever part of the plant it (trails off). We used to like doing that with carnations because you could make really pretty blue carnations. That's a good reasoning [points to something Tia wrote on her station information sheet].

Tory: What about that [station's evidence]?

Tess: Works for me.

Tory: Okay.

Tess: (Laughs) That works for me.

(Photosynthesis Lesson, 4/13/15)

In the preceding interaction, the group members looked through the information they had gleaned from the stations and attempted to identify pieces of evidence that supported their new claim. They were able to identify evidence supporting why their previous claim did not make sense. They also decided to include other pieces of data that they felt made the claim that the plant's biomass came from absorbed air. It should be noted that not all of their ideas or specific statements were completely accurate (e.g., excess water in the pores leaves as oxygen). In addition, they went off topic periodically in their discussions. However, at this point in the photosynthesis lesson, they were clearly moving toward a more correct understanding of the foundational idea of the building blocks of plant mass.

During the next part of the class, Dr. Pepper asked the groups to engage in an activity in order to share and evaluate their ideas (Appendix G, Task 6). Tory stayed at Group T's table to present their claim and evidence to the visiting participants from other groups. Tess and Tia each went to different tables to hear and evaluate the work of those groups. After a few minutes, Dr. Pepper had them cycle again to a new group, with presenters continuing to stay at their own table.

Tory presented her group's claim to the first visitors who came to her table. Here is what she said,

> Um, for ours we just picked the third one. It said, "What if it comes from molecules in the air that come through holes in the plants' leaves?" Um, and then we just put, we say that because we thought the leaves can, like, they can absorb water through their pores and stuff. And honestly, we were kind of confused, so if

that doesn't sound right, you can tell me. And then, um, like the plant can absorb dye through the stem and the excess water in the pores leave as oxygen, and yeah, that's basically it. Does that sound like evidence or reasoning? Because we were kind of confused about that. (Photosynthesis Lesson, 4/13/15)

Tory's lack of confidence in her group's choice of a claim and her presentation of little evidence to support it did not appear to influence those at her table whose groups had chosen different claims. Her explanation here did not include all of the evidence that had been discussed in her group previously. During the second rotation, Nadine and Morgan (Morgan was from Group M, discussed later) disagreed and explained evidence as to why the claim that biomass mainly originated from the soil made more sense.

Morgan: The only reason I would say not [from the air] is because, like, um (trails off).

Nadine: You need the roots.

Morgan: What does it say? It says it comes from molecules in the air and so, like, molecules in the air. If you dehydrated a plant, would it be affected in the biomass? Is kind of what we said to like not put that one but I don't know if that's right.

Nadine: Because, like, are all nutrients in the air? Like nitrogen, carbon?

Tory: Yeah.

Nadine: Because like an air molecule or is just what, O_2? Like, it's just oxygen. So it'd just be, like, all the other molecules, I guess. But I don't know if, like, nitrogen and carbon and all the things a plant needs are just floating in the air.

(Photosynthesis Lesson, 4/13/15)

Above, Morgan's rebuttal revolved around the naïve conception that molecules of air do not have mass and thus would not contribute to a plant's dry mass. She essentially said that if you dehydrate a plant, the air molecules will leave the plant, just as water molecules leave a plant when it is dehydrated. Nadine was not convinced that the necessary nutrients for plants would be found "floating in the air." Camille, visiting from Group C (discussed later), then added her thoughts.

Camille: We did, like our claim was like nutrients, but we didn't necessarily say soil. We said, like in our evidence, we said soil was optional because of the hydroponic something.

Nadine: So, it's more nutrients?

Camille: So, we said something about nutrients, not necessarily the soil, not necessarily the air.

Nadine: Well it's just, like, yeah. Yeah. The nutrient rich water was the (trails off).

Camille: Well, that one, like, it grew because it had a whole lot of carbon dioxide, and then the other ones grew because of the light. It didn't grow because of the soil, so.

Morgan: Oh wait, that.

Camille: Yeah, carbon dioxide.

Tory: I don’t know.

(Photosynthesis Lesson, 4/13/15)

During this exchange, Camille highlighted the importance of carbon dioxide to the growth of a plant. However, the claim she was arguing for was incorrect. She and her group had decided to accept only part of the claim, that biomass came primarily from nutrients, and discarded the rest of that claim (from the soil) since they realized from the evidence stations that soil was not necessary for plant growth. Group C (discussed in more detail later) felt that the nutrients that added to a plant’s biomass could originate from a variety of locations including from water, soil, and air. Tory remained unconvinced.

When the rotations ended, Tess and Tia returned to their own table and the three members of Group T reported what they had learned from other groups during the sharing time. Tess felt she had gleaned some information that supported their own claim, even though the other groups were not in agreement with their chosen claim, that biomass mainly originated from air molecules.

Tess: Well, I got for extra [evidence], um, they did where it was the sun. It comes from the sun. So, um, and they agreed without the sun the plants can’t produce the glucose or starch. Um, but it can grow without soil. So we’re cool on that. And then the sun converts it to the ATP chemical energy, which comes from the holes in the plants.

Tory: Okay.

Tess: And then the other one, I think we had this one, the greater the CO_2 levels, the larger the plants, and since CO_2 is a gas, it has to be absorbed. And then the main components of plants' growth is nitrogen and water and they use the one where they squirted the nutrients onto it, so again it's absorbed, through the plant.

Tia: But again, they said plants can be grown with another form of light energy other than the sun, meaning like you can put them under a light bulb.

Tess: And again, it's absorbed.

Tia: Right. We rock.

Tess: (Laughs). All right, so yeah, uh, my only questions is back, were, I didn't really have any because the stuff I got from them kind of helps us. But yeah, then I found out that ATP.

Tia: It made me want to go back to our first claim, though.

Tess: Yeah but that was the one with the soil though, wasn't it?

Tia: Right.

Tory: Yeah, everybody said that one I think.

Tess: I didn't think that one was right though because you can grow a plant without soil but you got to have the nutrients. And in order for it to be absorbed into the plant, you got to have pores, or holes. All right.

Tory: One table said it can be any of [the biomass origin claims].

Tess: It probably is all of them, depending on where you grow it.

Tory: That's what I thought.

(Photosynthesis Lesson, 4/13/15)

The above exchange shows Group T choosing to stay with their claim that the biomass was from the air. Tess presented one of the clearest pieces of evidence from the stations that supported that claim, the idea that a plant grows larger when exposed to higher levels of CO_2 concentrations in the air. However, at the end of the discussion, they again mentioned the idea that perhaps a combination of all the claims was correct. This idea was prevalent among the groups and had been mentioned at various times during the photosynthesis treatment lesson. The following exchange during one of the sharing rotations is illustrative of this unwillingness of many of the groups to commit to only one claim.

Nell: I feel like you could almost manipulate the evidence because we obviously put [from the soil] too, and we felt like that's exactly what the evidence pointed to, you know what I mean. But, like she had a totally different one. But she also supported it with evidence.

Mari: I feel like you could manipulate it to support all four of the statements.

Tory: Yeah, I thought it was all of them at first.

Mari: Yeah, that's what we were thinking.

Tory: Then [Dr. Pepper] said pick one.

Mari: Yeah.

Tory: And then we totally guessed on [ours].

(Photosynthesis Lesson, 4/13/15)

Although Group T began with the incorrect claim and then changed to the correct one as they evaluated evidence, they never became truly confident in that choice. Their selected evidence was minimal, and their reasoning was not well articulated. They focused mainly on proving that plants absorb air. This idea, while useful in supporting their claim that biomass mainly originates from air molecules, distracted them from recognizing or articulating more foundational ideas and more clearly supportive pieces of evidence. Thus, they were easily swayed by the opinion of other groups. The following exchange that occurred after the first and second rotation illustrated this.

Tory: One table said it can be any of [the biomass origin claims].

Tess: It probably is all of them, depending on where you grow it.

Tory: That's what I thought.

(Photosynthesis Lesson, 4/13/15)

ATP energy is a direct product of the process of photosynthesis. The second foundational alternative conception that appeared during the photosynthesis lesson was the idea that ATP energy was a product of photosynthesis. This idea was introduced to Group T during the second rotation (Appendix G, Task 6) when Tory was sharing their argument regarding biomass origin with three members of other groups: Morgan (from Group M, discussed later), Camille (from Group C, discussed later) and Nadine (from a group not specifically under study). *ATP Energy* was written on one of the provided component cards, but originally Group T had set it to the side when developing their model of photosynthesis. Other groups had been perplexed by the ATP energy card and had engaged in discussion regarding its possible role or lack of role in photosynthesis. Dr. Pepper approached Tory and her visitors at Group T's table during the second rotation and asked about ATP energy. The following discussion ensued:

Dr. Pepper: So have y'all had a good conversation?

Group: Mm-hmm.

Dr. Pepper: At some of the tables I see ATP energy and at some of the tables I don't. Has that come up?

Group: No. Not at all.

Dr. Pepper: Shame, shame. If somebody has that at their table they need to visit about it (walks away).

Nadine: No, we have it at our table but I don't know what ATP is. I just know what it stands for.

Morgan: Why did y'all include chlorophyll up here?

Tory: Isn't that where the sugar is produced or something?

Nadine: We included it above the arrow.

Tory: Oh really?

Morgan: Yeah, because we didn't include it at all.

Nadine: Because I think if you reverse it, then, because, like, if you reverse it, it's cellular respiration. But you don't, like, give off chlorophyll.

Tory: Right.

Nadine: I think it just, like, happens. Like the arrow is kind of, like, within the chloroplast, but have chlorophyll.

Morgan: Yeah, I don't know what ATP energy is.

Nadine: I don't either. I know it, like, what it stands for, like the adenosine triphosphate, but then I feel like it has to do with DNA. And I don't know what that is so (trails off).

Camille: It might be the makeup of the leaf or something like that, like the (trails off).

Nadine: I don't know.

Camille: No, that's chlorophyll. I don't freaking know.

Morgan: I thought it had to do with cells.

Tory: I thought [Dr. Pepper] said something about it.

Nadine: Yeah. Because I think it has to do with the nucleus or something within the cell.

Camille: Right.

Morgan: See, I don't think that's, like, I don't know.

(Photosynthesis Lesson, 4/13/15)

Following this exchange, the conversation moved off topic until Dr. Pepper had everyone return to their original groups to report on what they had discussed and learned from visiting other groups. When Tess and Tia returned to Group T's table, Tess immediately brought up the topic of ATP energy, which had apparently also been discussed in the groups she attended during the rotations. She gave a jumbled and inherently incorrect explanation for what ATP was and why it should be included in their photosynthesis equation. Within this discussion, a number of other correct ideas and alternative conceptions were mentioned.

Tess: I got some more evidence for us.

Tory: Really?

Tess: To support our claim.

Tory: I got a little.

Tess: I got some other things to add to this. I found out what the ATP was (laughs). It's the chemical energy that the sun, it's the cells, the chlorophyll in the cells, and then the sun converts it to the ATP which is chemical energy, which I was, like, I don't know.

Tory: Oh.

Tess: All right, what was our claim?

Tia: Like, who knew that?

Tory: Yeah.

Tess: All I could think of was my little Math 1410 going, "I need to take ATP." That's from molecules in the air. Okay so what, did you have any critiques?

Tory: Yeah. Some people said that, um, they thought it was the first [suggested answer to the claim] because biomass is the dehydrated mass.

Tess: Mm-hmm. The first one had to do with the soil, though, didn't it?

Tory: Um, I don't think so. That's what they said, and then they said um for this one, if you dehydrated the plant, it was weird, the air molecules inside it wouldn't make a difference.

Tess: Well, I got for extra [evidence], um, they did where it was the sun, it comes from the sun. So, um, and they agreed with, uh, without the sun the plants can't produce the glucose or starch. Um, but it can, and it can grow without soil. So we're cool on that. And then the sun converts it to the ATP chemical energy, which comes from the holes in the plants.

Tory: Okay.

Tess: And then the other one, I think we had this one, the greater the CO_2 levels, the larger the plants, and since CO_2 is a gas, it has to be absorbed. And then the main components of plants' growth is nitrogen and water, and they use the one where they squirted the nutrients onto it, so again it's absorbed, but through the plant.

Tia: But again, they said plants can be grown with another form of light energy other than the sun, meaning like you can put them under light.

Tess: And again, it's absorbed.

Tia: Right.

Tess: We rock (laughs). All right so yeah, uh, my only questions back were (pause). I didn't really have any because the stuff I got from them kind of helps us. But yeah, then I found out that ATP.

Tia: It made me want to go back to our first claim, though.

Tess: Yeah but that was the one with the soil though, wasn't it?

Tia: Right.

Tory: Yeah, everybody said that one I think.

Tess: I didn't think that one was right though because you can grow a plant without soil but you got to have the nutrients. And in order for it to be absorbed into the plant, you got to have pores, or holes. All right.

Tory: One table said it can be any of [the biomass origin claims].

Tess: It probably is all of them, depending on where you grow it.

Tory: That's what I thought.

(Photosynthesis Lesson, 4/13/15)

At the end of the above discussion regarding the information learned during the rotations, Group T revisited the biomass origin question. They did not change their answer, that biomass originated from the air. However, Tess and Tory agreed that any of the options could be right. This illustrated their lack of confidence in their answer. As a result of the above exchange, Group T revised their photosynthesis model for the third and final time during the photosynthesis lesson, most notably including ATP energy as a product (Figure 4.9).

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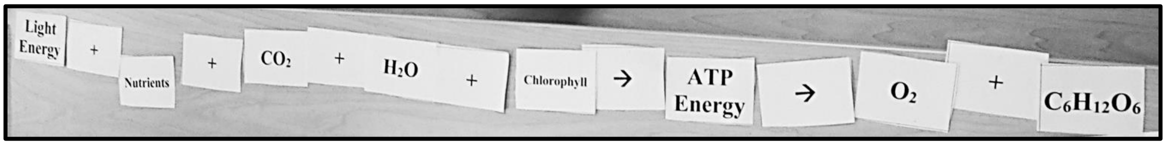

Figure 4.9. Group T's final photosynthesis equation model.

This final model was less accurate than either of their previous two models. The inclusion of ATP as a product revealed a foundational alternative conception regarding the purpose and results of photosynthesis. The discussion above did little to bring clarification or accuracy to the group. Group T did not originally include ATP. However, they were easily influenced by the alternative conceptions and incorrect suggestions of others during the visits to other groups. They did not discuss any clear evidence as to why ATP energy should be included as a product. They took other groups' explanation of ATP at face value and did not seek to confirm the accuracy of the idea by reasoning from the provided evidence.

During Dr. Pepper's concluding lecture and questioning session (Appendix G, Task 10), she asked what ideas the class would have liked more information and guidance about during the lesson. A number of participants, including Group T members, answered that they wanted more information about ATP. The class recognized their lack of knowledge regarding ATP. There was no evidence in the stations regarding ATP, primarily because ATP is not a part of the process of photosynthesis. However, the class in general, as well as Group T in particular, did not infer that this lack of evidence might indicate that ATP was not a relevant part of this lesson. Instead, they insisted on including ATP in the photosynthesis equation despite any direct evidence to support it.

As part of the conclusion to the lesson, Dr. Pepper asked Mari, a member of Group M, to come to the whiteboard and write down the photosynthesis equation their group had developed. She then asked the rest of the participants to evaluate its accuracy and proceeded to use that equation as a model as she talked through the reactants, basic process, and products of photosynthesis. When Mari wrote her group's accurate equation on the board, the following exchange quietly occurred within Group T.

Mari: We have H_2O plus CO_2 yields $C_6H_{12}O_6$ plus O_2.

Tess: See, that's what we started with. That's totally what we started with.

Tia and Tory: [Mumbled, mildly outraged agreement]

(Photosynthesis Lesson, 4/13/15)

During the wrap-up, Tess also said that she wanted direct information about photosynthesis. She was again voicing her personal desire, and the desire common in her group, to be provided with the right answers so she could then learn the right answers.

Dr. Pepper: The process of photosynthesis. You want somebody just to tell you?

Tess: Well, just to have something to go, to go and compare it to. (Quietly to her group) Yes, I do want someone to tell me the process, that way I can learn it.

(Photosynthesis Lesson, 4/13/15)

This theme of just wanting someone to tell them the answer so they could learn it came up often with this group, especially during the photosynthesis lesson. The next section presents the alternative conceptions that were evident in Group T during the cellular respiration lesson.

Summary. During this photosynthesis lesson, Group T worked together to build a model of photosynthesis using the equation component cards. They also chose a claim to answer the question from where the majority of a plant's biomass originates. They were required to support that claim through the evidence and the equation model. Group T found all the tasks relatively challenging and frustrating. They exhibited a poor ability to connect and apply the evidence to their chosen claim. Interestingly enough, they began with an incorrect claim regarding the biomass question, but eventually changed to a correct claim. However, their confidence in that answer was low. During the lesson, they also struggled with whether to include ATP energy as a product of their photosynthesis equation. They exhibited a lack of understanding of what ATP energy was and its role in plant functioning. More than a lack of understanding, this also spoke to a fundamental alternative conception regarding what exactly photosynthesis produces. Their initial model of the photosynthesis lesson was actually more accurate than their ending one.

Cellular respiration lesson. The next class period was devoted to the topic of cellular respiration (Appendix J). Group T expressed a number of inaccuracies regarding cellular respiration at various points throughout this treatment lesson. Seven main alternative conceptions were identified (Figure 4.6). These all came under discussion multiple times and were deemed to negatively affect an accurate conception of cellular respiration. These seven alternative conceptions were: a) Cellular respiration and photosynthesis are exact opposites of one another, b) gas exchange during cellular respiration consists of carbon dioxide in and oxygen out, c) the purpose of cellular respiration is to produce sugar, d) the purpose of cellular respiration is to store sugar, e) during cellular respiration ATP energy is absorbed, f) sugar made during cellular respiration is stored in stoma, and g) the conflation of cellular respiration with physical respiration.

The last of these, the conflation of cellular respiration and physical respiration, will be discussed first in the upcoming section. Then the other six will be discussed together under the overarching theme of melding photosynthetic processes and outcomes with cellular respiration. These will be discussed as a group since they were all closely related to one another and interwoven together throughout Group T's conversations with each other.

Conflating cellular respiration with physical respiration. The dialogue below occurred in Group T when they were first confronted with the idea of physical respiration in contrast to cellular respiration. One of the evidence stations directly addressed this concept since confusing the two is a common alternative conception among students of various levels, including PSTs (Brown & Schwartz, 2009; Lin & Hu, 2003; Seymour & Longden, 1991). Group T had returned to their table after examining their respective evidence sheets. They shared the information they had learned and tried to identify evidence to support an answer to the lesson's guiding question, "How and when does a plant use the food it makes to sustain life?" (Appendix J, Task 2).

Tess: Let's see, I had that physical respiration and cellular respiration [station], and for humans it said, what is the more common name for physical respiration? Breathing. Uh, what organs are involved in physical? Lungs. I can't think of any other organs. I don't think you can call your nose or your mouth an organ.

Tory: No.

Tia: Your heart?

Tess: Huh?

Tia: Is your heart?

Tess: Uh, it didn't have, well?

Tia: Did it?

Tess: It didn't have a picture, it just showed lungs, so.

Tia: Oh.

Tess: Maybe, I don't know. Do physical, do plants do physical respiration? No. They do the cellular respiration; they don't have lungs. Where does cellular respiration occur in animals? It said the mitochondria, so (trails off).

(Cellular Respiration Lesson, 4/15/15)

Group T then changed the subject. This discussion did not clarify how physical respiration was a different process than cellular respiration. The way Tess presented the information indicated she believed that cellular respiration was a process in plants that corresponded to physical respiration in humans. She did not mention the idea that humans also do cellular respiration.

Next, the group worked on constructing an equation model of the process of cellular respiration (Appendix J, Task 3). During that discussion, Tess said something that indicated her confusion regarding cellular respiration and physical respiration. The group was discussing which components were reactants and which were products. Tess said that water was given off as a product. To support that statement, she indicated that water could not be a reactant by explaining, “Well, we don’t take in water though, when we breathe unless we want to drown” (Cellular Respiration, 4/15/15). This reasoning was inappropriate for a few reasons; one being that showing water could not be a reactant does not actually support the idea that it has to be a product. Furthermore, in that sentence, Tess conflated the process of cellular respiration with the process of breathing in humans. She believed cellular respiration in plants was the equivalent of physical respiration in humans. Neither Tia nor Tory attempted to correct her, so it was presumed that they agreed.

More evidence that Tess was confusing cellular respiration with physical respiration occurred later in the class when she said, “Because the cellular respiration is breathing, but taking in oxygen. Because the water vapors come out” (Cellular Respiration Lesson, 4/15/15). As before, the other members of Group T did not dispute this statement.

Later, when Dr. Pepper questioned Tory and those visiting from other groups (Appendix J, Task 5), Meg introduced the idea that cellular respiration was the same as breathing. Dr. Pepper supplied a brief explanation that obtaining oxygen (breathing) is not the same process as using the oxygen at the cellular level to create energy (cellular respiration). This explanation did not noticeably influence Tory's alternative conception regarding physical and cellular respiration. She did not seek to clarify her own group's understanding on that point when they returned to her at the end of the rotation. Group T thus continued to conflate the two processes even until the end of the lesson. Evidence of this came at the conclusion of the class when Dr. Pepper asked some questions about when photosynthesis and cellular respiration occur. The following interaction happened quietly in Group T in response to one of her questions to the class.

Tia: In animals, there's no photosynthesis, right?

Tess: Right, yeah. So, respiration is all the time for plants, is all the time for animals. It's when you breathe.

Tia: It's when you breathe?

Tess; Yeah, well, we breathe all the time.

Tia: Oh.

(Cellular Respiration Lesson, 4/15/15)

It was clear that at the end of the lesson Tess still considered cellular respiration and physical respiration to be the same process. Tia accepted Tess's explanation with no reservations. Tory did not comment.

Melding photosynthetic processes and outcomes with cellular respiration. Throughout the cellular respiration lesson, Group T did not consistently identify the correct purpose or process of cellular respiration. As they attempted to create the cellular respiration model and answer the guiding question, they often misattributed processes and outcomes of photosynthesis with cellular respiration. As mentioned previously, six of the group's alternative conceptions were so interrelated and closely interwoven in the group's discussions that I have chosen not to explain them separately. I have grouped the following six related alternative conceptions under this one descriptor: melding photosynthesis processes and outcomes with cellular respiration.

1. CR and P equations: exact reverse/opposite of each other
2. CR equation: gas exchange is CO_2 in, O_2 out
3. CR purpose: to produce sugar
4. CR purpose: to store sugar
5. CR ATP energy is absorbed
6. CR sugar made during CR is stored in stoma

The following discussion ensued as Group T developed their initial model (Figure 4.10). No mention was made of the role of food or glucose in the process of cellular respiration. Tess began the discussion by describing information she had gathered from one of the evidence stations.

Tess: Dark went up in the atmosphere, carbon dioxide went up, and oxygen went down. Dark amount went up in the atmosphere, which prevents photosynthesis from occurring. Sunlight, oxygen, cellular respiration occurring. Even in the dark CO_2 is up. Yeah, I mean, that's what it sounds like to me. What gases are released during cellular respiration?

Tory: I think, wasn't oxygen released?

Tess: For a plant? Yeah, it must have been a plant, I think so.

Tory: Yeah.

Tess: And then gas is absorbed. Hmm, hmm, hmm okay. All right then.

(Pause for ten-minute class break. PSTs return and begin building the model)

Tia: O_2, plus water, and we know it's going to yield carbon dioxide.

Tess: Mm-hmm. Okay, so then, so it takes in oxygen.

Tory: So this is cellular respiration?

Tess: Yeah.

Tory: Because I was thinking (trails off).

Tess: So, take in oxygen, and it happens in the mitochondria.

Tory: They take in ATP. In cellular (trails off).

Tess: Mm-hmm. Mm-hmm. Okay, and then?

Tory: And then they release, what do they release?

Tia: Is it O_2 plus water?

Tess: Cellular respiration, use of oxygen, acceptor of hydrogen, allows energy to be released.

Tia: Because it's like photosynthesis backwards basically.

Tess: Yeah because it lets off carbon dioxide and water vapors.

Tory: And it takes in oxygen.

Tess: Yeah.

(Cellular Respiration Lesson, 4/15/15)

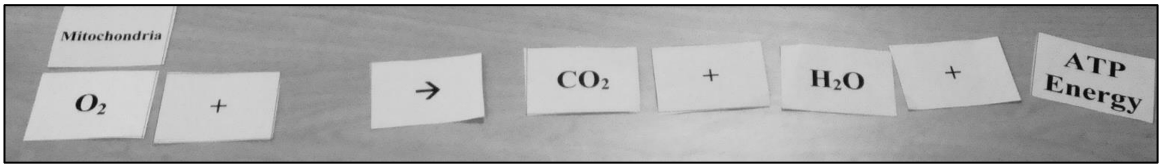

Figure 4.10. Group T's first cellular respiration model.

In the previous exchange, the group started with the alternative conception that oxygen was released during cellular respiration but concluded the discussion with the correct gas exchange. They also represented that part correctly in their initial model. As a group, the participants were able to correctly model the gas exchange that occurred during the process of cellular respiration (i.e., oxygen in, carbon dioxide out). However, following the treatment lessons, individuals reverted to their alternative conceptions regarding the exact process of cellular respiration, which is discussed in an upcoming section. Tia mentioned that cellular respiration was basically photosynthesis backwards. Although this is true regarding the gas exchange, it is untrue regarding the purpose and outcomes of the two processes. Photosynthesis and cellular respiration are not opposite processes.

As previously mentioned, food or glucose was not addressed at all as they formed their initial model. An empty space was left in their model where glucose should have been included. While this at first appeared to be a simple omission, as the class period continued it became clear that the group, in general, and Tory, in particular, were unclear on the role of food in cellular respiration. The following exchange illustrates this melding of photosynthesis and cellular respiration.

Tory: Is this for cellular respiration?

Tia: I don't know.

Tory: Like it uses the food to make sugar obviously.

Tia: But is the $C_6H_{12}O_6$, is that the food she's talking about?

Tory: Yes.

Tia: So is this saying how does it use that to sustain life?

Tory: Yeah, yeah. It eats it right?

Tia: I don't know. It eats the food.

Tory: Yeah.

Tia: It uses the nutrients in those, in that food to keep the process going.

Tory: Yeah, didn't somebody say like it um, something about.

Tia: The sun does. I made that up, but it sounds good.

Tory: Glucose is constantly being made and stored in the leaves.

Tia: So, I just don't understand, are we saying for photosynthesis or for cellular respiration.

Tory: Yeah, I don't know about that one.

Tory: I guess we just use this like last time.

Tia: Oh, um.

Tory: Um, we could put, um, the food is stored in the leaves for later processes. I don't know which processes, but um. It's stored in the leaves, or maybe just leading off.

Tia: Okay.

Tia: Even if the water is taken out of the plant, or even if water is taken out the food still remains, right?

Tory: Out of the plant?

Tia: Yeah because [Dr. Pepper] said, I don't know, I heard her say that the water is taken out the sugar is still left.

Tory: Probably.

Tia: Plants still have it.

Tory: Probably.

Tia: I don't know, I'll ask [Dr. Pepper] when she comes back.

(Cellular Respiration Lesson, 4/15/15).

The group members were confusing themselves as to whether they were trying to explain photosynthesis or cellular respiration. They knew that glucose and food were key parts, but they were struggling to understand that they were describing the same thing. They struggled to decide whether plants used or made sugar during cellular respiration. Tory settled on the idea that the sugar is stored during cellular respiration and shared this claim when visitors arrived at her table for the first rotation (Appendix J, Task 5).

Tory: Yeah, we changed this like twice, but we said plants use their food through cellular respiration and they store it in their stomata. Basically we said that plants can store their food in leaves, roots, stems, or they can use it. Like they don't have to constantly use it, they can store it basically. Yeah. Um, cellular respiration happens during the day and night. It makes the most food during the middle of the day, and the more light, the more growth it has. Yeah.

Nina: In, but that's in photosynthesis, that's not in cellular respiration.

Tory: No, in cellular respiration, it happens during day and night. But during the middle of the day when the sun's out the most, that's when it works the best. (long pause) Okay. (long pause) Get it? Does that sound right? (long pause). Then the last one was on photosynthesis. This one's on, feel free to correct me if it sounds bad or something.

Nina: I couldn't correct you if I knew.

Tory: Oh. Okay.

Nina: Because I'm confused.

Meg: Me neither.

Tory: Yeah. I'm kind of confused about it. But basically they, I, we just said it can store food in the stomata, and use it for later. And cellular respiration happens during the day and the night.

(Cellular Respiration Lesson, 4/15/15)

Tory's explanation above contained correct facts and minor inaccuracies, with her contention that plant food was made during cellular respiration being the most problematic. Even after a participant from another table, Nina, disagreed with her, she persisted in the alternative conception. Another alternative conception in Tory's comments was that the food was stored in the plant's stomata. It should be noted that throughout the treatment lesson, the members of Group T in general continually stated that the plant food was stored in the stomata. This revealed their lack of understanding regarding the role and function of plant stomata. To their credit, they also often talked about how the food was stored in the leaves and the stem, which is accurate.

It was during the second rotation (Appendix J, Task 5), that the visiting PSTs pointed out to Tory that her group's equation was missing glucose altogether. This time Tory's explanation was more accurate and did not include the part about food being made during cellular respiration.

Tory: We just said that, um, plants use their food through cellular respiration, and they store it in the stomata throughout the day and the night. Um, basically we said that they store their food in their leaves, the roots, and the stems so they don't have to like constantly make it.

Others: Mm-hmm.

Tory: Um, yeah, and they need food for energy to survive. That's basically it. Does that look right to y'all?

Morgan: The only thing is you don't have the food up here.

Noelle: Yeah where's the glucose?

Morgan: This would be above this, but you don't have your like, glucose.

Tory: Glucose, okay.

Noelle: Glucose goes there. And then (trails off).

Morgan: And then you also need enzymes right here because that's what breaks it down.

(Cellular Respiration Lesson, 4/15/15)

When Tess and Tia returned, the group discussed their cellular respiration model more and revised it (Figure 4.11). They accurately added glucose as a reactant. Group T also included some supplementary information by showing that this process occurs in the mitochondria and with the help of enzymes.

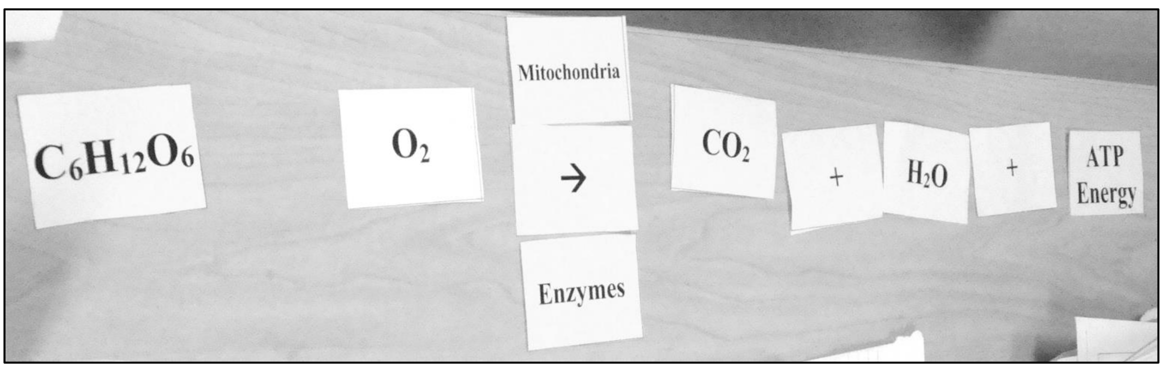

Figure 4.11. Group T's final cellular respiration model.

Summary. Throughout this lesson, Group T struggled to make connections between the guiding question (how and when do plants use the food produced during photosynthesis?), the cellular respiration equation they were asked to model, and the evidence provided at the stations. The evidence stations were intended to provide facts upon which to develop the equation model. Once the equation model was developed, then the answer to part of the guiding question would be revealed (i.e., how the plants use the products of photosynthesis). The following excerpt illustrates this group's continued difficulty in understanding this hierarchy and the connections within it.

Tia: Did she say the equation is part of our evidence [for our guiding question claim]?

Tess: I don't, that doesn't really have to do with. I mean (trails off).

Tory: I mean we could probably use it.

Tess: Mm-hmm.

(Cellular Respiration Lesson, 4/15/15)

The next section presents the alternative conceptions that were still held individually and collectively by the members of Group T following the completion of the two treatment lessons. The post-treatment results include data collected at two separate times: immediately after the treatment lessons (designated as *post-treatment*) and approximately two weeks later (designated as *delayed post-treatment*). The next section will present the individual-level results at both the post- and delayed post-treatment times. Then the group-level results will be presented. Note that group-level results were collected only at the post-treatment time.

Post-treatment conceptions (individual- and group-level). The members of Group T exhibited various individual alternative conceptions following the treatment lessons. These remaining alternative conceptions were identified and comparisons made between the participants' understanding prior to the treatment lessons. There were two distinct data collection time periods following the treatment. The post-treatment data collection occurred within a few days of the completion of the cellular respiration lesson and consisted of individual knowledge lists, alternative conceptions survey, group knowledge structures, and group interviews. The delayed post-treatment results were collected approximately two weeks later. These results consisted of the alternative conceptions survey, which participants took for the third and final time.

The upcoming sections are organized as follows. First, there will be a presentation of each member's individual alternative conception results at post-treatment, shortly after the treatment lessons ended. These results were taken from the participants' completed post-treatment individual knowledge lists and their responses on the post-treatment alternative conceptions survey. In addition to these post-treatment results, the delayed post-treatment results are shared. These individual-level results consisted of the survey score and alternative conceptions that were identified from the alternative conceptions survey given approximately two weeks after the treatment lessons concluded.

Once the individual-level results are shared for all the Group T members, the group-level results are provided. Foundational alternative conceptions that appeared and were agreed upon by the group will be presented. These collective group alternative conceptions were gleaned from the post-treatment group knowledge structure graphic, the group discussion that occurred during the construction of the knowledge structure graphic, and the post-treatment group interview. No group alternative conceptions were identified at the delayed post-treatment time.

Tess (individual-level). Tess's responses on the alternative conception surveys showed she began with more accurate knowledge than her group mates, but then demonstrated no consistent growth as a result of the treatment lessons. She scored the same, 64%, on both the pre- and the post-treatment survey. However, her answers were not all exactly the same. Some questions that she answered correctly on the pre-treatment survey, she answered incorrectly on the post-treatment and vice versa. Unlike her group mates, whose scores remained relatively consistent between the post- and the delayed post-treatment survey, Tess's score dropped markedly to 50% on her delayed post-treatment survey. Overall, this was the least amount of improvement on the survey shown by any of the participants in the three group cases.

The total number of individual alternative conceptions that were identified in Tess before, after, and two weeks after the treatment lessons showed an overall increase (Figure 4.12). The blue bar denotes the number of alternative conceptions that were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange on the middle bar indicates alternative conceptions that first appeared immediately after the treatment lessons. Orange on the last bar shows the number of those alternative conceptions that were retained two weeks after the treatment lessons. Gray indicates any alternative conceptions that were expressed for the first time at the last data collection point two weeks after the lessons ended.

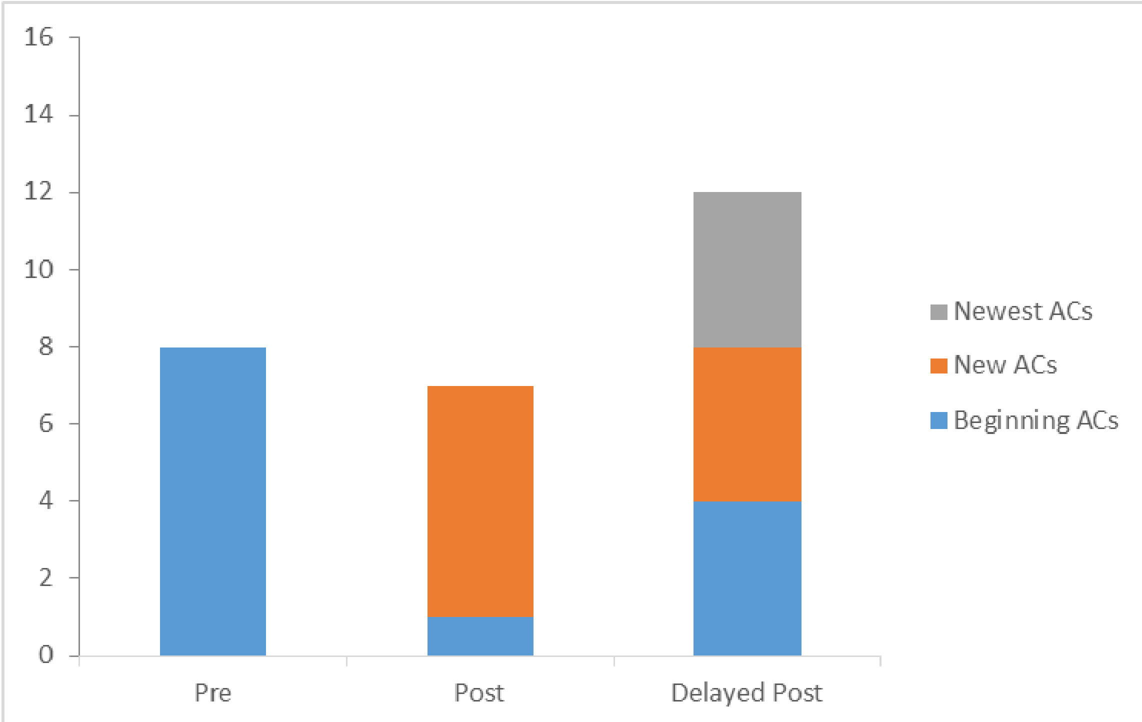

Figure 4.12. Tess's number of alternative conceptions identified at pre-, post-, and delayed post-treatment (ACs = alternative conceptions).

Tess's beginning alternative conceptions were reduced from pre- to post-treatment. However, she exhibited a number of new ones. Two weeks later, the results were even more concerning. At that time, she reverted back to some of her initial alternative conceptions, reiterated many of those identified at the post-treatment survey, and expressed additional ones. Figure 4.13 lists the specific alternative conceptions that Tess held before, after, and two weeks after the treatment lessons. The paragraphs that follow provide more specific information regarding Tess's conceptual understanding.

Pre-Treatment	Post-Treatment	Delayed Post-Treatment
Identified from pre-treatment alternative conceptions survey and pre-treatment individual knowledge list	**Identified from post-treatment alternative conceptions survey and post-treatment individual knowledge list**	**Identified from delayed post-treatment alternative conceptions survey**
P biomass: originates in water		
P equation: gas exchange is O_2 in, CO_2 out		P equation: gas exchange is O_2 in, CO_2 out
P equation: turns light directly into sugar		
P equation: chlorophyll is a reactant		
P oxygen is a waste product, ignoring its importance as a reactant for CR		P oxygen is a waste product, ignoring its importance as a reactant for CR
CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant		
CR purpose: to produce sugar		CR purpose: to produce sugar
	P equation: unspecified energy is a reactant	
	CR purpose: simply to exchange CO_2 and O_2	
	CR purpose: to provide energy when P is not occurring or has not made enough energy	CR purpose: to provide energy when P is not occurring or has not made enough energy
	CR timing: only occurs in dark/night	CR timing: only occurs in dark/night
	CR timing: only occurs when P is not happening	CR timing: only occurs when P is not happening
	CR animals do CR because they cannot do P	CR animals do CR because they cannot do P
		P biomass: originates from O_2
		P timing: only occurs in the dark
		P equation: sugar is a reactant
		P chlorophyll is not required
Total: 8	**Total: 7**	**Total: 12**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.13. Tess's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Tess's post-treatment individual knowledge list revealed a detailed understanding of the process of photosynthesis. She correctly reproduced the equation and added descriptive comments that illuminated the process, indicating a deep and correct understanding. In addition, Tess drew a picture showing a leaf releasing oxygen, a rabbit absorbing oxygen and then releasing carbon dioxide, and the leaf absorbing the carbon dioxide. Although this is an overly simplified view, it does indicate Tess conveying some understanding of the carbon cycle.

Tess's answers on the post-treatment survey regarding photosynthesis revealed a mix of accurate and alternative conceptions. Although Tess had accurately depicted the photosynthesis equation on her individual knowledge list, she inexplicably chose the wrong equation on her post-treatment survey. Her answer was the equation that incorrectly included energy as a product of photosynthesis. She correctly answered the question about biomass on the post-treatment survey.

Tess's delayed post-treatment survey contained more errors in responses related to photosynthesis than did either her pre- or post-treatment survey. The lack of consistency in her answers compared to the other two surveys was noticeable. Oddly, Tess often answered the first tier question correctly, and then chose an incorrect response from the second tier questions which were supposed to align as the reasoning for her first tier answer. For instance, Tess identified the correct photosynthesis equation. Then, she chose a second tier reasoning response that aligned with cellular respiration, rather than photosynthesis. On this delayed post-treatment survey, Tess also missed one question that she had not missed on any of the other surveys. She did not correctly identify which factor was most irrelevant to the process of photosynthesis (amount of oxygen) although she had answered it correctly every other time. On the positive side, Tess identified the most important contributor to a plant's biomass, carbon dioxide, on the delayed post-treatment survey.

Cellular respiration. Tess correctly reproduced the cellular respiration equation on her individual knowledge list. She also included some descriptive comments with the equation that were accurate and illuminated her depth of understanding about what the equation represented. There were no identifiable alternative conceptions included.

On the post-treatment survey, Tess chose the correct cellular respiration equation. However, she did not align many of her other answers correctly with the equation. For example, on a later survey item, Tess indicated that carbon dioxide was taken in and oxygen given off during the process of cellular respiration. She also incorrectly indicated that the purpose of cellular respiration was to exchange gases, rather than the correct answer of making energy from glucose. Many of the two-tier answers on her survey were internally inconsistent, with Tess correctly answering one of the tiers and incorrectly answering the other.

On the delayed post-treatment alternative conceptions survey, Tess's conceptual understanding of cellular respiration remained a mix of accurate and inaccurate ideas. For the first time on one of the surveys, Tess answered correctly that oxygen is taken in when there is no light present, thus during cellular respiration. Yet the response she chose for her second tier question, which provided the reason behind her answer of oxygen, was about photosynthesis. Tess was either not paying attention, or else she continued to hold alternative conceptions about the process of cellular respiration. This same pattern occurred on another question about cellular respiration. She answered the first tier response correctly and then chose an erroneous answer for the reasoning. Tess chose the correct cellular respiration, but then the response she chose for the reasoning did not align with the equation she chose.

Tory (individual-level). Tory's understanding of both photosynthesis and cellular respiration showed improvement from the pre- to the post-treatment alternative conceptions survey. Tory scored 35% on the pre-treatment survey and 57% on the post-treatment survey. She also scored 57% on the delayed post-treatment survey. It should be noted that although she scored the same percentage, her specific answers varied some between the post- and the delayed post-treatment survey. A summary of the number of alternative conceptions that were revealed before, during, and after the treatment lessons is presented in Figure 4.14. The blue bar denotes how many alternative conceptions were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present at that data collection time point. Orange indicates alternative conceptions that first appeared immediately after the treatment lessons. Orange on the last bar show the number of those alternative conceptions retained two weeks after the treatment lessons. Gray indicates any alternative conceptions that were expressed for the first time at the last data collection point two weeks after the lessons ended.

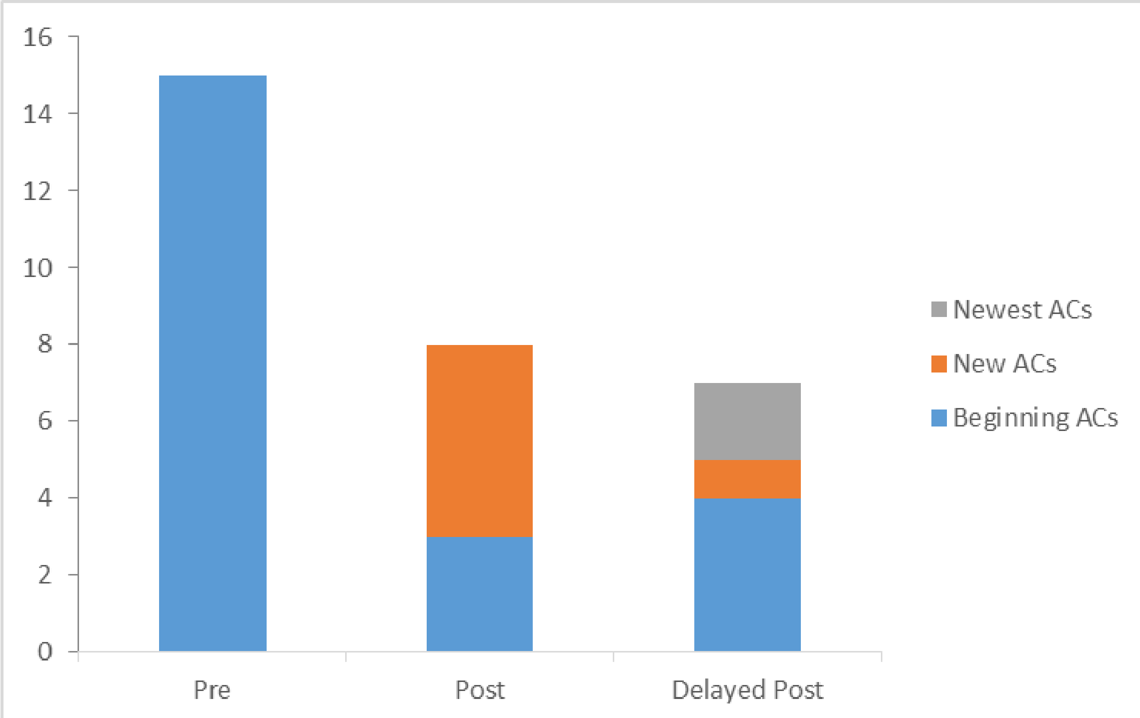

Figure 4.14. Tory's number of alternative conceptions at pre-, post-, and delayed post-treatment (ACs = alternative conceptions).

Tory began with a large number of alternative conceptions, but they were reduced noticeably following the treatment lessons. Her overall score on the delayed post-treatment continued that positive trend of fewer alternative conceptions. Tory showed a similar pattern to Tess in that many of her original alternative conceptions did not appear on the post-treatment survey, yet on the delayed post-treatment survey they had begun to increase again. Interestingly, Tory's newly identified alternative conceptions on the post-treatment survey had almost disappeared on the delayed post-treatment survey. Details regarding Tory's specific alternative conceptions are shown in Figure 4.15 and explained in greater detail in the paragraphs that follow.

Pre-Treatment	Post-Treatment	Delayed Post-Treatment
Identified from pre-treatment alternative conceptions survey and pre-treatment individual knowledge list	**Identified from post-treatment alternative conceptions survey and post-treatment individual knowledge list**	**Identified from delayed post-treatment alternative conceptions survey**
P equation: turns sunlight directly into sugar		
P equation: unspecified energy is a reactant		
P oxygen is a waste product, ignoring its importance as a reactant for CR		
P purpose: main benefit to the plant is to remove CO_2 from air		
CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant		
CR equation: do not recognize sugar is a reactant	CR equation: do not recognize sugar is a reactant	CR equation: do not recognize sugar is a reactant
CR equation: do not recognize energy is a product	CR equation: do not recognize energy is a product	CR equation: do not recognize energy is a product
CR timing: only occurs in light/day		
CR timing: only occurs in dark/night		
CR timing: only occurs when P is not happening		
CR purpose: to produce sugar		CR purpose: to produce sugar
CR requires chlorophyll		
CR location: occurs only in leaf cells		
CR only leaves have pores/stomata		
	P biomass: originates from O_2	P biomass: originates from O_2
	P sugar is stored in chloroplasts only	
	P produces energy directly	
	CR and P equations: exact reverse/opposite of each other	
	CR purpose: simply to exchange CO_2 and O_2	
		P timing: occurs all the time in plants
		P equation: chlorophyll is a reactant
Total: 15	**Total: 8**	**Total: 7**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.15. Tory’s alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Tory showed improvement in her understanding of photosynthesis following the treatment lessons. She accurately reproduced the photosynthesis equation on her individual knowledge list. She included a few descriptive comments about the equation as well. One inaccurate statement she included was that photosynthesis is the opposite of cellular respiration.

On the post-treatment survey, Tory appropriately identified the photosynthesis equation. However, she did not make a connection to it for the biomass source question. She also gave the incorrect purpose of photosynthesis, though the reasoning she chose actually aligned with the correct answer. In answer to the question about biomass, Tory incorrectly answered oxygen.

Tory's responses on the delayed post-treatment survey revealed more alternative conceptions she held regarding photosynthesis. Tory indicated that the amount of carbon dioxide is not an important factor in the process of photosynthesis. Then the reason she chose indicated that photosynthesis cannot take place without carbon dioxide, revealing another inconsistency in her answers and thus in her understanding. Tory again chose the same wrong response as on her post-treatment survey that biomass mainly originated from oxygen.

Cellular respiration. Tory's conceptual understanding of cellular respiration had advanced following the treatment lessons. On her post-treatment individual knowledge list, she included many more accurate facts than she had written prior to the treatment lessons. Notably, however, she did not include the cellular respiration equation. She also reiterated her alternative conception that cellular respiration and photosynthesis are exact opposites.

Although Tory had not written down the equation for cellular respiration on her individual knowledge list, she did choose the correct one on the post-treatment survey. She aligned some of her other answers on the survey with the equation, for instance correctly answering that oxygen was taken in during cellular respiration. However, she also indicated that oxygen was given off during respiration demonstrating her inconsistency in applying the equation appropriately.

On the post-treatment survey, Tory had not correctly identified the purpose of cellular respiration. She also demonstrated a naïve conception that cellular respiration is the exact opposite of photosynthesis. Although she recognized that respiration occurred at all times of the day and night, she said that it was greatest during the peak of sunlight at midday.

Tia (individual-level). Tia's responses on the post-treatment alternative conceptions survey showed an improvement in her overall understanding of the topics. Tia scored 50% before the treatment lessons and 62% immediately after, as well as 62% on the delayed post-treatment survey. Although she scored the same percentage on both the post- and the delayed post-treatment survey, it should be noted that her answers were not all exactly the same. An overview comparing the alternative conceptions that were identified before, after, and two weeks after the treatment lessons is provided in Figure 4.16. The blue bar denotes how many alternative conceptions were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange indicates alternative conceptions that first appeared after the treatment lessons. Orange on the last bar shows the number of those alternative conceptions that were retained two weeks after the treatment lessons. Gray indicates any alternative conceptions that were expressed for the first time at the last data collection point two weeks after the lessons ended.

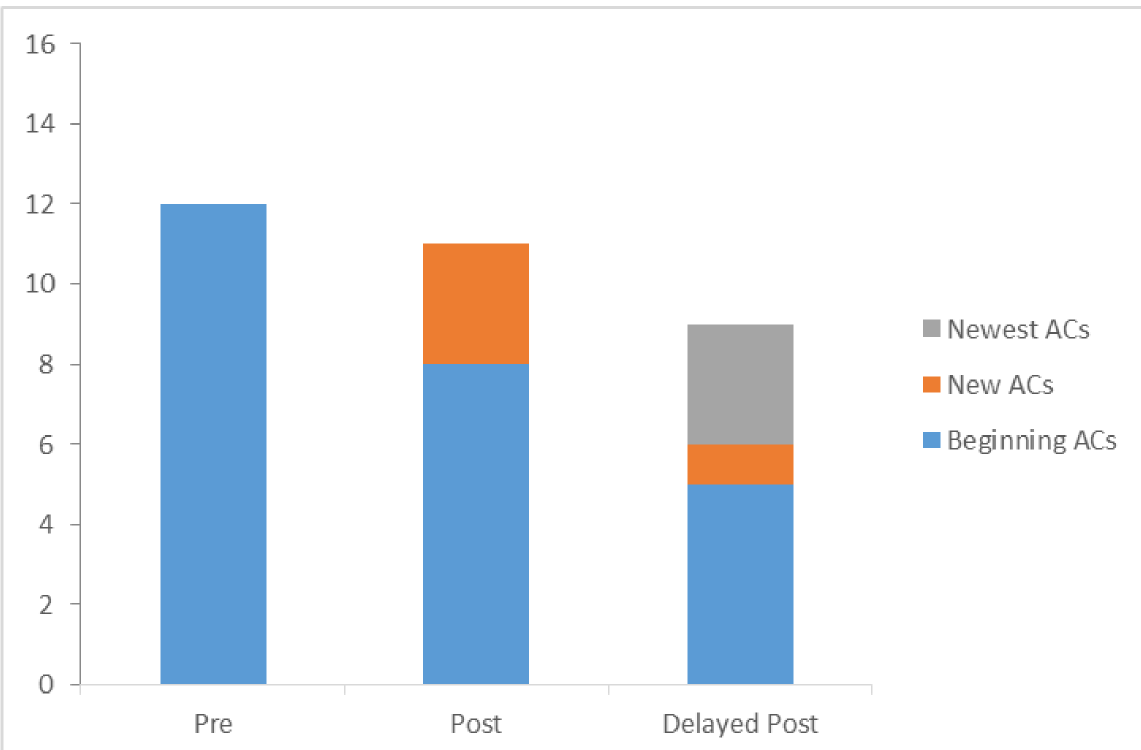

Figure 4.16. Tia's number of alternative conceptions at pre-, post-, and delayed post-treatment (ACs = alternative conceptions).

Tia, like Tory, began with quite a few alternative conceptions identified prior to the study. On the post-treatment survey, Tia's answers revealed that her original alternative conceptions had been reduced. A few newly expressed ones were identified. Two weeks later, Tia’s original alternative conceptions had further diminished and the ones from the post-treatment survey were also reduced. However, a few additional alternative conceptions were revealed at that time. Tia showed incremental improvement in her alternative conceptions over time. The specific alternative conceptions that were present in Tia before, after, and two weeks after the treatment lessons are listed in 4.17 and detailed in the upcoming paragraphs.

Pre-Treatment	Post-Treatment	Delayed Post-Treatment
Identified from pre-treatment alternative conceptions survey and pre-treatment individual knowledge list	**Identified from post-treatment alternative conceptions survey and post-treatment individual knowledge list**	**Identified from delayed post-treatment alternative conceptions survey**
P biomass: originates in water		
P timing: only occurs in the dark		
P equation: gas exchange is O_2 in, CO_2 out	P equation: gas exchange is O_2 in, CO_2 out	
CR equation: water is a reactant	CR equation: water is a reactant	
CR equation: do not recognize energy is a product	CR equation: do not recognize energy is a product	
CR timing: only occurs in light/day	CR timing: only occurs in light/day	
CR timing: only occurs in dark/night	CR timing: only occurs in dark/night	CR timing: only occurs in dark/night
CR timing: only occurs when P is not happening	CR timing: only occurs when P is not happening	CR timing: only occurs when P is not happening
CR purpose: to provide energy when P is not occurring or has not made enough energy	CR purpose: to provide energy when P is not occurring or has not made enough energy	CR purpose: to provide energy when P is not occurring or has not made enough energy
CR purpose: to produce sugar		CR purpose: to produce sugar
CR requires chlorophyll		
CR animals do CR because they cannot do P	CR animals do CR because they cannot do P	CR animals do CR because they cannot do P
	P timing: occurs all the time in plants	
	P produces energy directly	
	CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out
		P equation: chlorophyll is a reactant
		P equation: unspecified energy is a reactant
		P oxygen is a waste product, ignoring its importance as a reactant for CR
Total: 12	**Total: 11**	**Total: 9**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.17. Tia's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Tia's individual knowledge list and her responses on the post-treatment alternative conceptions survey showed growth in her understanding of some photosynthesis concepts immediately following the treatment lessons, as well as a regression in others. Tia included much more information on her individual knowledge list about photosynthesis than she did before the treatment lessons. She accurately reproduced the photosynthesis equation and indicated that it only occurs in the presence of light. However, she also wrote that photosynthesis could only happen during the day, ignoring the possibility of photosynthesis occurring at any time in the presence of artificial light.

Tia's post-treatment survey answers showed that she had regressed in her understanding of the purpose of photosynthesis. She answered that the main purpose of photosynthesis was to create energy instead of the more accurate response that its purpose is to convert light energy to chemical energy. On a positive note, Tia answered the biomass question correctly, showing that she now understood that carbon dioxide was the main source of a plant's biomass.

On Tia's delayed post-treatment survey, she also revealed more inconsistencies in her understanding of photosynthesis. For the first time, Tia did not identify the accurate photosynthesis equation. As before, she remained unable to reliably apply her mostly correct knowledge of the photosynthesis equation to specific questions regarding reactants and products.

Cellular respiration. Tia's conceptual understanding of cellular respiration improved following the treatment lessons, although she persisted in many of her previous alternative conceptions. Her individual knowledge list included much more information, both accurate and inaccurate, than did the one she completed prior to the treatment lessons. For example, Tia reproduced part of the cellular respiration equation, but included two notable errors: having water as a reactant and completely leaving out the production of ATP energy. Some inconsistencies were present in her included information as well. She wrote that cellular respiration takes place with or without sunlight and occurs in the day and the nighttime. Then, she immediately contradicted herself by writing that plants respire when there is no light energy available.

Her responses on the post-treatment survey were often contradictory. Although she was able to choose the correct cellular respiration equation on the post-treatment survey, she did not consistently align other answers on the survey with that accurate knowledge. For example, she sometimes responded that carbon dioxide is absorbed during cellular respiration but on another question responded that carbon dioxide is released. Another notable contradiction was her response that plants respire when they cannot get energy from light, implying that they do not respire at all in the presence of light, and another time indicating that light energy is necessary to the process of cellular respiration. Multiple inconsistencies like this in her responses made it difficult to be certain of her understanding on a number of foundational concepts.

Tia's responses on the delayed post-treatment survey revealed additional inconsistencies in her understanding of cellular respiration. Similar to her approach to photosynthesis, Tia struggled to correctly apply her knowledge of the cellular respiration equation to specific questions related to products and reactants. She also did not indicate that cellular respiration converted stored energy to usable energy, instead answering that it was a process that created food.

Group T (individual-level). The sections above explained in detail the identifiable alternative conceptions that persisted in each individual member of Group T following the treatment lessons. A summary of their individual scores on the pre-, post-, and delayed post-treatment alternative conceptions survey provides a helpful snapshot of their individual conceptual changes over the course of the study. Figure 4.18 shows the comparison of all of Group T members' scores.

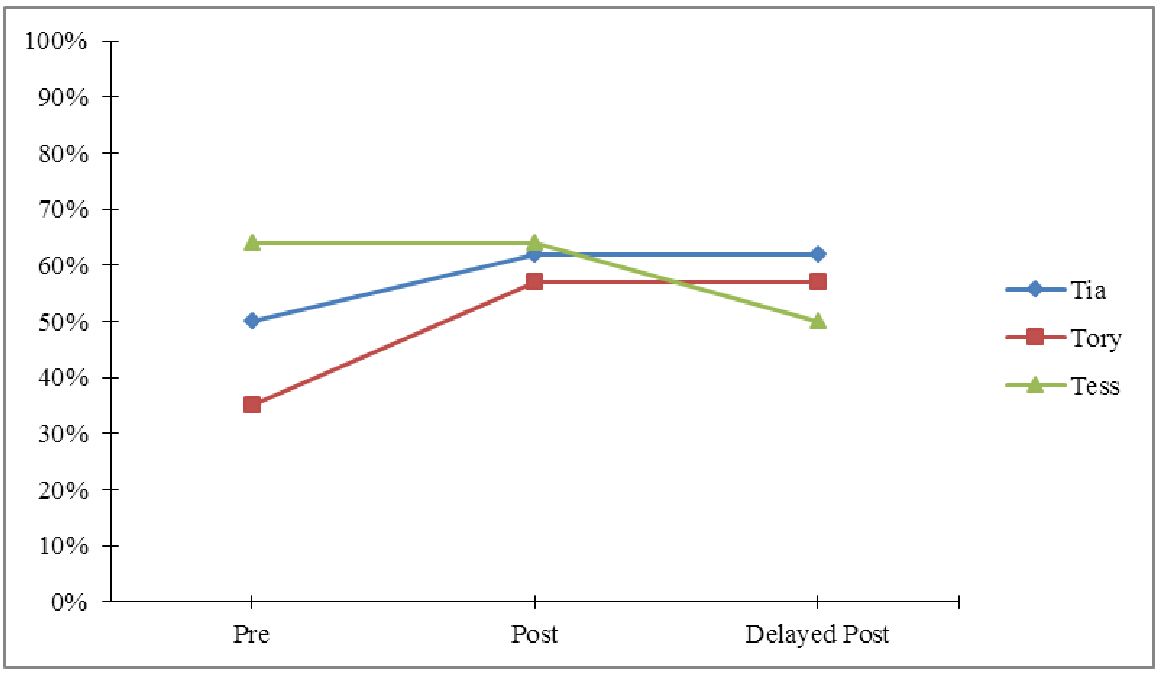

Figure 4.18: Comparison of Group T members' scores on alternative conceptions survey at pre-, post-, and delayed post-treatment. Higher scores indicated more accurate conceptual understanding.

The scores of each member of Group T changed over the course of the study. The scores of both Tory and Tia increased from the pre- to the post-treatment survey and that increase was maintained on the delayed post-treatment survey. In contrast, Tess scored the same on the pre- and post-treatment survey and then scored even lower on the delayed post-treatment survey. Tess began with the highest score on the pre-treatment survey, indicating her baseline knowledge was the most developed at the start of the treatment. No gains were made over the course of the treatment and, in fact, the accuracy of her conceptual understanding decreased rather than increased. It should be noted that the post-treatment survey was taken before the group did their post-treatment group knowledge structure graphic and discussed a unified vision for the concepts. The delayed post-treatment survey was taken approximately two weeks after the group created their group knowledge structure graphic.

Group T (group-level). In the upcoming section, the alternative conceptions evident in the group as a whole following the treatment lessons will be explained. Although individual members of the group held certain alternative conceptions as outlined in the previous paragraphs, they did not always appear within the group as a whole. Therefore, it was important to identify what alternative conceptions were persistent and prominent enough to be mentioned and accepted by the entire group. This picture of the group's collective knowledge following the treatment lessons has been developed from three data sources: the post-treatment group knowledge structure graphic, the group discussion that occurred while creating the knowledge structure graphic, and the post-treatment group interview.

Group T's post-treatment knowledge structure graphic (Figure 4.19) included many more correct facts than did their pre-treatment graphic. Their post-treatment knowledge structure graphic demonstrated a deeper and more detailed understanding of the concepts of photosynthesis and cellular respiration. However, there were incorrect details included on the post-treatment knowledge survey, indicating that the group still agreed on some alternative conceptions related to the topics.

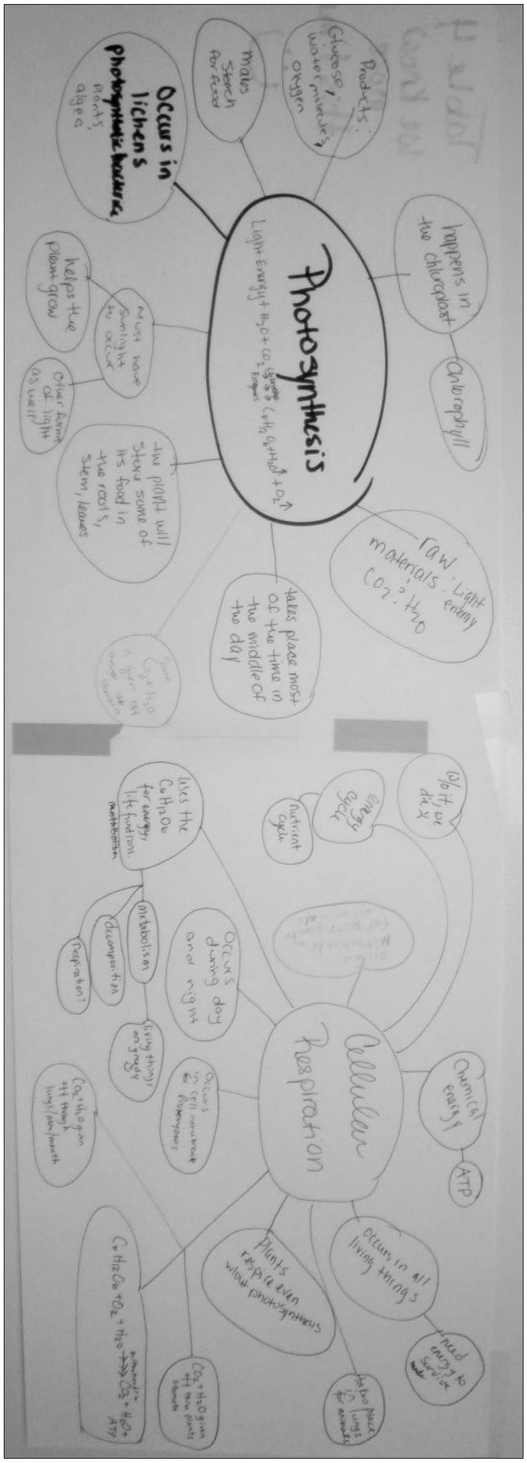

Figure 4.19. Group T's post-treatment knowledge structure graphic.

The collectively agreed upon alternative conceptions that were present before, during, and after the treatment lessons are shown in Figure 4.20. A detailed discussion of the two collective alternative conceptions identified after the treatment lessons is presented in the rest of this section. The two closely related alternative conceptions were conflating cellular respiration with physical respiration, and stating that cellular respiration occurs in the lungs (only). These will be discussed together since the second alternative conception essentially provides evidence for the first one.

Pre-Treatment	During	Post-Treatment
Identified from pre-treatment group knowledge structure, pre-treatment discussion, and pre-treatment interview	**Identified from photosynthesis and cellular respiration lesson discussions**	**Identified from post-treatment group knowledge structure, post-treatment discussion, and post-treatment interview**
P equation: gas exchange is O_2 in, CO_2 out		
P biomass: nutrients for plants come only from soil		
P equation: turns sunlight directly into sugar		
CR similar to physical respiration in animals; plants do CR, but animals breathe	CR similar to physical respiration in animals; plants do CR, but animals breathe	CR similar to physical respiration in animals; plants do CR, but animals breathe
CR associated with blood flow		
	P biomass: originates from soil	
	CR purpose: to produce sugar	
	P equation: ATP energy is a product	
	CR and P equations: exact reverse/opposite of each other	
	CR equation: gas exchange is CO_2 in, O_2 out	
	CR purpose: to store sugar	
	CR ATP energy is absorbed	
	CR sugar made during CR is stored in stoma	
		CR happens in lung organs only
Total: 5	**Total: 9**	**Total: 2**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.20. Group T's alternative conceptions at pre-, during, and post-treatment.

Conflating cellular respiration and physical respiration. This confusion in Group T again was revealed following the treatment lessons. Their knowledge structure graphic and responses during the post-treatment interview again indicated they believed that cellular respiration was an analogous process to breathing in animals. This was the only collective group alternative conception that was evident before, during, and after the treatment lessons.

On the post-treatment knowledge structure graphic, Tory wrote that cellular respiration occurred in the lungs. This is accurate, since cellular respiration occurs in every cell in an organism and the lungs are made of cells. However, by focusing only on lungs, the group revealed their continued difficulty in understanding how cellular respiration and physical respiration differ. No discussion among the other group members occurred when she included this fact during the construction of the graphic.

During the post-treatment interview, I pointed out the phrase on their knowledge structure graphic about cellular respiration occurring in the lungs of animals. I wanted to see if they realized their mistake. Their responses confirmed they were confused and had been conflating the processes of cellular respiration and physical respiration in animals. When I probed more, the group began to recognize their errors and adjust their thinking. An excerpt from the group interview follows.

Researcher: Okay is there anything else on either of these pages that you feel less confident about?

Tess: Is there like a specific name for like when humans and animals, I mean if the organ is the lungs, but is there like a specific thing to call it? How we do cellular respiration, because we take the oxygen in through our lungs, and our nose, and our mouth, I mean.

Tory: Would that be circulatory? Or is that something completely different?

Tess: I don’t know. I just know that it happens in your lungs. I don’t know if there’s like some scientific.

Researcher: So when you say "it," what do you mean? *What* happens in the lungs?

Tess: Breathing, the cellular respiration, the breathing. Well not the cellular, the breathing.

Tia: Like, you mean, like the taking in and giving off?

Tess: Mm-hmm.

Tia: Okay, like, what do we call that?

Tess: When you take in the oxygen.

Researcher: So there was a station about physical respiration and cellular respiration. Now are those, are they the same thing?

Tess: No.

Tia: No.

Researcher: Okay, so what is physical respiration?

Tess: When you breathe.

Researcher: Okay, and then what is cellular respiration?

Tess: When it makes its life functions.

Tory: When the cells, like, make energy.

Tia: Mm-hmm.

Tess: The only reason I'm asking is because you're taking in oxygen at the same time.

Researcher: Right, so that oxygen had to come from somewhere. And how, where did that oxygen come from in an animal? It came from the process of what you were talking about before.

Tess: So it's not talking about bringing in oxygen like through breathing? Or yes?

Researcher: So. Well. Okay, this is a confusing area. There's a lot of misconceptions about it because when people talk about cellular respiration, people's brains go automatically to breathing.

Group T: Mm-hmm.

(Post-Treatment Interview, 4/17/15)

I attempted to explain and clarify the two processes. By the end of my explanation, Tory and Tess had a clearer understanding as evidenced by their ability to correctly answer my questions. Tia remained silent so it is difficult to know exactly what she was thinking. Here is the conclusion of that mini–teaching session.

Researcher: Okay, so then, where's cellular respiration happening?

Tess: Everywhere.

Researcher: Everywhere. In every cell. So yeah, it's happening in your lungs, but it's also happening in every other body part. Every cell in your body.

Tory: So does that, give you, like, energy to breathe? Like it causes you to be able to breathe?

Researcher: That's, yeah, that's how you get energy for anything.

Tory: Oh, okay. Cellular respiration.

Researcher: That's the purpose of cellular respiration, to take that food energy and break it down into some, to create energy so you can keep doing everything that you do, like breathing.

Tory: I see. That makes sense.

(Post-Treatment Interview, 4/17/15)

No other opportunities to collect group alternative conceptions were included in the study after this point, so there was no way to confirm if all members of Group T adjusted their alternative conception regarding the differing, albeit connected, processes of cellular respiration and physical respiration. After this data collection event, only the delayed post-treatment alternative conceptions survey was left to do two weeks later. That survey did not include any questions related to lungs.

The previous sections have presented the detailed results of the alternative conceptions that were identified both individually and collectively in Group T members before, during, and after the treatment lessons. By providing these results, a picture of the participants' changes in conceptual understanding emerged. The next section will present the results of the group's argumentation quality during the photosynthesis lesson.

Argumentation Quality of Group T

It is important to understand the quality of Group T's argumentation. This was critical to evaluating the research question, even if it did not answer it directly. The conceptual changes that occurred, or did not occur, may have been influenced by the quality of the group's discourse around developing and defending arguments from evidence. It may have also depended on the quality of the group's level of epistemic thinking and speaking related to the discipline of science.

The presentation of these results is divided into two parts. The conceptual and cognitive aspects of the group's scientific argumentation will be discussed first, followed by their epistemic aspects. Evidence for the argumentation protocol was gathered only from the photosynthesis lesson.

Conceptual and cognitive aspects. This section of the observation protocol evaluated how effective the group was in negotiating meaning among themselves and developing their collective understanding. One of the main goals of quality scientific argumentation is to positively impact the participants' conceptual knowledge of the scientific content. The presence or absence of certain aspects of their discussions and argumentative discourse are posited to support the development of their knowledge and lead to more and better conceptual change. The scores of Group T on the conceptual and cognitive aspects of scientific argumentation are shown in Figure 4.21. Each item was scored from zero to three, with higher scores indicating better quality of argumentation and group performance that is more sophisticated. A total of 21 points was possible on the conceptual and cognitive aspects section.

Conceptual and Cognitive Items	Score
1. The talk of the group was focused on solving a problem or advancing understanding.	1
2. The participants sought out and discussed alternative claims or explanations.	2
3. The participants modified their explanation or claim when they noticed an inconsistency or discovered anomalous data.	2
4. The participants were skeptical of ideas and information.	1
5. The participants provided reasons when supporting or challenging an idea.	1
6. The participants based their decisions or ideas on inappropriate reasoning strategies (reverse scored).	1
7. The participants attempted to evaluate the merits of each alternative claim or explanation in a systematic manner.	3
Total	**11**
Percent	**52%**

Figure 4.21. Group T's scores on conceptual and cognitive aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

Group T had low to medium scores on their conceptual and cognitive aspects of scientific argumentation. They scored at least a one on every item, which meant they exhibited that behavior at least once or twice. Group T scored high on the seventh item since there was evidence that they often attempted to evaluate the merits of all the alternative claims in a systematic way. One example of this is found in the upcoming dialogue in which they talked through the various possible answers to the claim about where the biomass of a plant originated:

Tory: Yeah. Some people said that, um, they thought it was the first [suggested answer to the claim] because biomass is the dehydrated mass.

Tess: Mm-hmm. The first one had to do with the soil, though, didn't it?

Tory: Um, I don't think so. That's what they said, and then they said um for this one, if you dehydrated the plant, it was weird, the air molecules inside it wouldn't make a difference.

Tess: Well, I got for extra [evidence], um, they did where it was the sun, it comes from the sun. So, um, and they agreed with, uh, without the sun the plants can't produce the glucose or starch. Um, but it can, and it can grow without soil. So we're cool on that. And then the sun converts it to the ATP chemical energy, which comes from the holes in the plants.

Tory: Okay.

Tess: And then the other one, I think we had this one, the greater the CO_2 levels, the larger the plants, and since CO_2 is a gas, it has to be absorbed. And then the main components of plants' growth is nitrogen and water, and they use the one where they squirted the nutrients onto it, so again it's absorbed, but through the plant.

Tia: But again, they said plants can be grown with another form of light energy other than the sun, meaning like you can put them under light.

Tess: And again, it's absorbed.

Tia: Right.

Tess: We rock (laughs). All right so yeah, uh, my only questions back were (pause). I didn't really have any because the stuff I got from them kind of helps us. But yeah, then I found out that ATP.

Tia: It made me want to go back to our first claim, though.

Tess: Yeah but that was the one with the soil though, wasn't it?

Tia: Right.

Tory: Yeah, everybody said that one I think.

Tess: I didn't think that one was right though because you can grow a plant without soil but you got to have the nutrients. And in order for it to be absorbed into the plant, you got to have pores, or holes. All right.

Tory: One table said it can be any of [the biomass origin claims].

Tess: It probably is all of them, depending on where you grow it.

Tory: That's what I thought.

(Photosynthesis Lesson, 4/13/15)

Group T was also fairly good at seeking out and considering more than one claim. In addition, they were willing to adjust their explanations and claims, rather than always trying to explain anomalous data away to remain settled on their original answer. The following dialogue is illustrative of their willingness to make changes to their claim after discussing evidence that did not fully support it.

Tia: I know soil is oxygen, optional, but you need water and nutrients. You have to have that for the plant to grow, so (trails off).

Tory: Water and nutrients (trails off).

Tia: That makes me wonder about our claim then, since it says "nutrients in the soil," but that [station] said you don't need soil for the plant to grow.

Tess: Well, and then this [station], his conclusion was that most of the water is drawn off and conveyed through the pores of the leaves and exhaled into the atmosphere.

Tory: That's kind of what I had.

Tess: Yeah and then (trails off).

Tory: Like, sunlight entered the leaves, and then it entered the cells of the leaves. Maybe it's the third one [biomass comes from air molecules].

Tia: Where is this?

Tory: On the bottom of the first column.

Tia: Oh no, the first one on the bottom.

Tory: Maybe. You want to change it?

Tia: Yeah.

Tory: Want to change it to the third one maybe?

Tia: Yeah.

Tory: Because that one makes sense.

(Photosynthesis Lesson, 4/13/15)

There was less evidence of some of the other conceptual and cognitive aspects in their discourse, and there was even direct evidence to the contrary. For example, they exhibited a lack of commitment to solving the problem or advancing understanding. After the group had tried to talk through some of the options for the claims, Tess put an end to that by stating, “Well, since it’s science, it’s a trick question, so” (Photosynthesis Lesson, 4/13/15). This quote was illustrative of her negative responses and her attitude that it would be impossible to figure out the right answer anyway. There was not much evidence that Tia and Tory felt as strongly; however, they willingly went along with Tess’s pronouncements. They often did not pursue additional meaningful dialogue about the evidence after she made such comments.

Epistemic aspects. This part of the observation protocol helped identify how consistent the group’s discussions and arguments were with the culture and language of science during their discussions and argumentative discourse. Items in this section were concerned with aspects such as whether the group evaluated the relevance and quality of the evidence, how much they used the evidence to support their arguments, how they incorporated science terms in their discussions, and how well they applied broad scientific theories or models within their explanations. The observation protocol scores for Group T’s epistemic aspects of scientific argumentation follow (Figure 4.22).

Epistemic Items	Score
8. The participants relied on the "tools of rhetoric" to support or challenge ideas (reverse scored).	2
9. The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	1
10. The participants examined the relevance, coherence, and sufficiency of the evidence.	0
11. The participants evaluated how the available data was interpreted or the method used to gather the data.	1
12. The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	1
13. The participants made distinctions and connections between inferences and observations explicit to others.	0
14. The participants used the language of science to communicate ideas.	1
Total	**6**
Percent	**29%**

Figure 4.22. Group T's scores on epistemic aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

Group T scored lower on the epistemic aspects section than the other two group cases. This was expected, considering that this group was formed of participants with the most naïve and least sophisticated beliefs about science of the class, as measured by the Hofer (2000) epistemic beliefs survey given at the start of the study. This group struggled to appropriately evaluate evidence and use it in their explanations and argument development during the photosynthesis lesson. For example, this was Tory's response when providing a reason for her group's claim choice, "And then we totally guessed on that" (Photosynthesis Lesson, 4/13/15). Tess revealed her belief that science was inscrutable when she said, "Well, since it's science, it's a trick question, so" (Photosynthesis Lesson, 4/13/15). These participants also accepted the provided evidence at face value and did not seek to evaluate its quality or distinguish between actual data and inferences.

Case Summary

The case of Group T, the group with the most traditional and most naïve epistemic beliefs of the class, was presented in the preceding section. The members of this group began the study with a number of alternative conceptions about photosynthesis and cellular respiration. They also lacked confidence in their knowledge of science, with all feeling unprepared in the area of science. Unsurprisingly, this group struggled with many aspects of the argumentative discourse-based lessons. However, there was a decrease in the number of alternative conceptions held by all members of Group T from pre- to post-treatment (Figure 4.23). All reduced at least minimally. The results from the delayed post-treatment survey taken two weeks later showed that Tory and Tia retained their correct conceptions and even further improved by exhibiting fewer alternative conceptions than on their post-treatment survey.

Unfortunately, such an improvement was not seen in Tess. In fact, Tess's alternative conceptions increased notably from seven immediately after the treatment to 12 as measured two weeks later. This was even greater than the eight alternative conceptions she exhibited prior to the treatment lessons.

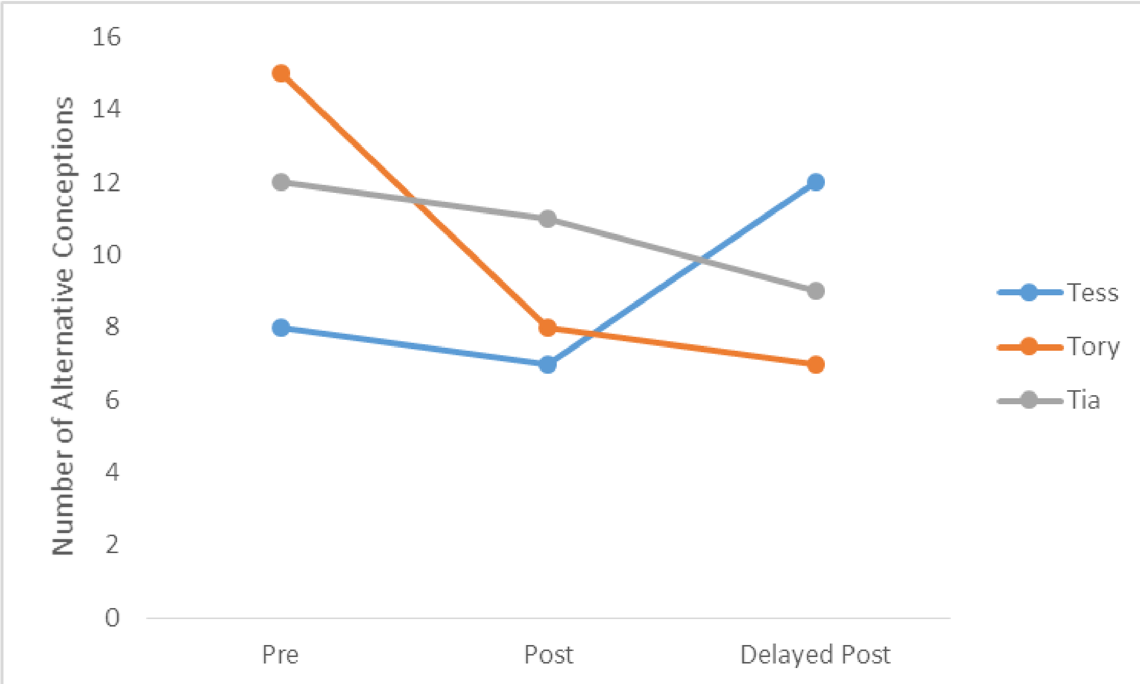

Figure 4.23. Comparison of Group T members' total number of alternative conceptions at pre-, post-, and delayed post-treatment.

The group, as a whole, improved on their collectively held alternative conceptions over the course of the study (Figure 4.24). They began with five, discussed nine more during the lessons, and ended with two. One alternative conception, that cellular respiration and breathing are analogous processes, was discussed and retained through all three time points. Otherwise, the group discussed different alternative conceptions each time.

Figure 4.24 shows the number of alternative conceptions that were identified before, during, and immediately following the treatment lessons. Also, the figure shows when and how many newly expressed group alternative conceptions were revealed during and after the lessons. The initial purple bar denotes how many alternative conceptions were identified before the treatment lessons. Additional purple on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Yellow indicates alternative conceptions that first appeared during the treatment lessons. Yellow on the last bar shows the number of those alternative conceptions retained immediately after the treatment lessons. Green indicates any collective alternative conceptions that were newly expressed following the treatment lessons.

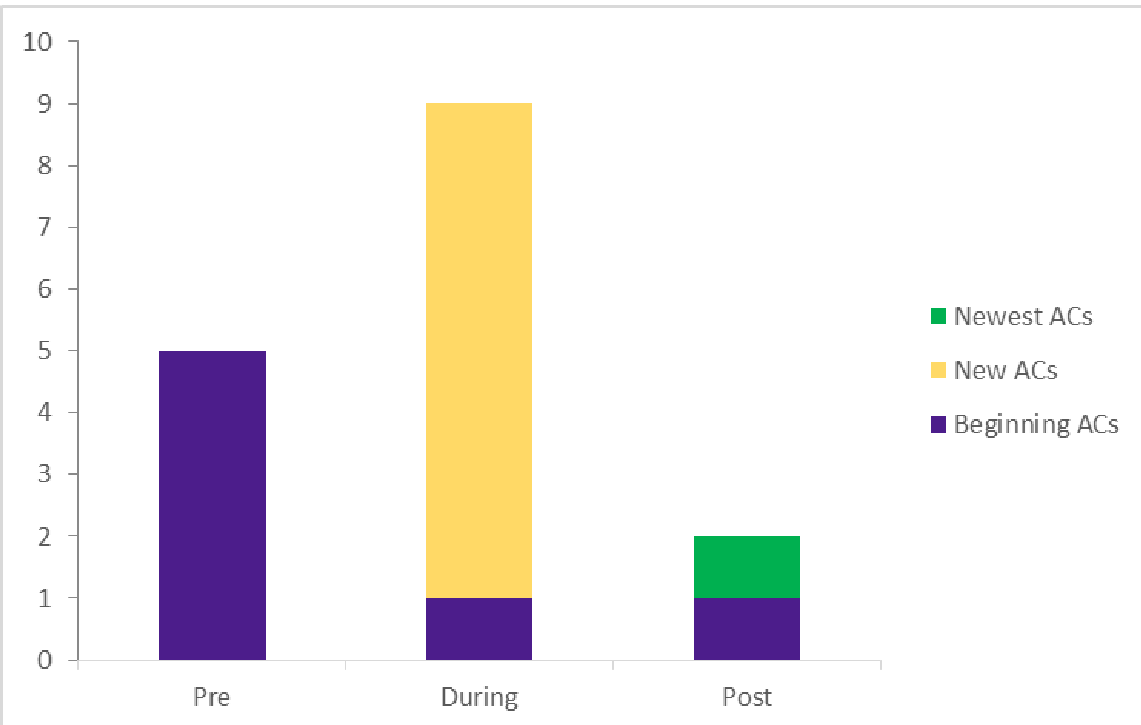

Figure 4.24. Group T’s number of alternative conceptions at pre-, during, and post-treatment (ACs = alternative conceptions).

The Case of Group M

The group with the most moderate epistemic beliefs, Group M, consisted of four female members: Mari, Morgan, Meg, and Macy. These PSTs were placed together based on their scores on the epistemic beliefs survey (Hofer, 2000). When all the study participants were ranked from most constructivist to least constructivist (i.e., traditionalist), these four PSTs ranked approximately in the middle between both extremes. Since the entire class held beliefs that skewed more toward the constructivist end of the spectrum, these PSTs designated as having moderate epistemic beliefs were rated with constructivist epistemic beliefs according to the survey. However, since they were not at either extremity of the class rankings on the survey, they were designated as the PSTs with moderate epistemic beliefs.

The results of Group M will be presented in the upcoming sections. The first main section will detail the conceptual changes that occurred over the course of the study, determined based on the identified alternative conceptions in each of the individuals as well as collectively as a group over time. These are arranged in three chronological sections: alternative conceptions present *before* the treatment lessons (individual-level and group-level), alternative conceptions present *during* the treatment lessons (group-level only), and alternative conceptions present *after* the treatment lessons (individual-level and group-level). Note that results from after the treatment lessons are subdivided into results from two different time periods: immediately after the treatment lessons (post-treatment) and two weeks after the treatment lessons (delayed post-treatment).

After the conceptual change results are presented, there is an additional section that reports the results of Group M's argumentation quality. This is divided into two parts: 1) conceptual and cognitive aspects of argumentation and 2) epistemic aspects of argumentation. A brief summary concludes the section on Group M's results.

Conceptual Changes in Group M

The upcoming section will present a case study report of the conceptual changes that occurred over the course of the study. Both individual and collectively accepted group alternative conceptions will be discussed. These will be presented in three chronological parts. The first part will present the individual and collective group alternative conceptions that were identified prior to the treatment lessons. The second part will provide a detailed account of any collective alternative conceptions that were accepted by the group during the treatment lessons. Finally, the individual and collective group alternative conceptions that remained following the treatment lessons will be presented.

Pre-treatment conceptions (individual- and group-level). Before the group members began working together, their initial alternative conceptions were elicited. These baseline alternative conceptions were identified from two data sources: the pre-treatment individual knowledge lists and the pre-treatment alternative conceptions survey. These data sources were individually generated and not influenced by peers.

In addition, Group M's collectively agreed upon group alternative conceptions were important to identify prior to their engagement in the treatment lessons. These initial group alternative conceptions were gleaned from three data sources: the pre-treatment group knowledge structure graphic, the discussion the group engaged in while creating the pre-treatment group knowledge structure graphic, and the participants' comments during the pre-treatment group interview. An alternative conception that arose was considered to be a group-level one if the group members all agreed with the idea when it was presented by either verbally agreeing or failing to express dissatisfaction or disagreement.

The upcoming section presents these beginning alternative conceptions. Each individual's alternative conceptions are first presented in the order of Mari, Morgan, Meg, and finally Macy. Their baseline understanding of photosynthesis and cellular respiration are explained, and their clearly identified alternative conceptions are listed. That is followed by a section that presents the collectively agreed upon Group M alternative conceptions that were present before the treatment lessons.

Mari (individual-level). Prior to the treatment lessons, Mari's understanding of photosynthesis and cellular respiration was a mix of accurate and alternative conceptions. A summary of her knowledge at the beginning of the study is provided in the following section. This summary is based on her pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey, on which she scored 57%. A summary of the alternative conceptions apparent in Mari prior to the treatment lessons is shown in Figure 4.25.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P timing: occurs all the time in plants
P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR equation: do not recognize energy is a product
CR timing: only occurs in light/day
CR purpose: to produce sugar
CR requires chlorophyll
Total: 9

P = Photosynthesis, CR = Cellular Respiration

Figure 4.25. Mari's pre-treatment alternative conceptions.

Photosynthesis. Mari's responses on her individual knowledge list about photosynthesis were more detailed and more factual than any of her group mates. She accurately explained the purpose of photosynthesis and also provided a description of most of the raw materials and byproducts of the process. Mari mentioned the role of light in photosynthesis. The only subtle alternative conceptions on her individual knowledge list were contained in the following sentence: "Photosynthesis is the process by which plants absorb the energy from light (the sun) in combination with carbon dioxide and process that energy through their chlorophyll (chloroplast) and energy is produced and stored" (Pre-Treatment Individual Knowledge List, 4/10/15). In the statement, Mari said that *energy was produced and stored*. This is an accurate statement. However, the lack of clarity regarding what type of energy was produced and stored (sugar) foreshadowed Mari's alternative conception related to the role of cellular respiration and its conversion of sugar into ATP energy.

Mari answered the majority of questions about photosynthesis correctly on the alternative conceptions survey. For example, she chose the correct equation for photosynthesis and accurately identified the correct gas exchange that occurs during that process. Although she was correct in answering that oxygen was released, Mari indicated that the oxygen was a total waste product. This was not the best answer, which included the concept that oxygen was used for cellular respiration, and then any extra was released. Mari correctly answered that the main benefit of photosynthesis to plants was to convert light energy to chemical energy. Her reason was incorrect, though, as she chose an answer that stated photosynthesis provides energy for plant growth instead of the more accurate answer that clarified that light energy was converted to glucose molecules.

Cellular respiration. The information Mari included on her pre-treatment knowledge list regarding cellular respiration was generally accurate. She included the correct ideas that cellular respiration occurs continuously and does not rely on the presence of light. She also wrote that it happens in the mitochondria of all cells. However, she was unclear about the idea of energy and its relationship to cellular respiration. One of her sentences said, “Plants use the absorbed and converted energy to grow, like functions, and reproduce” (Pre-Treatment Individual Knowledge List, 4/10/15). This statement did not explain the procedural steps necessary nor clarify the difference between stored energy in the form of glucose and ATP energy which is created from the glucose through the process of cellular respiration. Additional alternative conceptions on Mari’s individual knowledge list included the idea that oxygen is released during cellular respiration. This statement ended in a question mark, indicating that Mari was not completely confident in the idea.

On the alternative conceptions survey, Mari answered some cellular respiration questions correctly and some incorrectly. She was unable to identify the correct equation for cellular respiration. She also incorrectly answered that carbon dioxide was absorbed and oxygen released during the process. Mari correctly answered the questions indicating that it occurs in all cells and at all times, even without the presence of light.

Morgan (individual-level). Morgan's original conceptions of photosynthesis and cellular respiration were limited. Similar to the other participants, Morgan exhibited a mix of correct and incorrect conceptions on the pre-treatment alternative conceptions survey, scoring 36% overall. On her individual knowledge lists, however, the information she chose to include was essentially accurate. All the alternative conceptions that were identified in Morgan prior to engaging in any group discourse are shown in Figure 4.26.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P biomass: originates from soil
P timing: only occurs in the dark
P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR equation: do not recognize energy is a product
CR timing: only occurs in light/day
CR timing: only occurs in dark/night
CR timing: only occurs when P is not happening
CR purpose: simply to exchange CO_2 and O_2
CR purpose: to provide energy when P is not occurring or has not made enough energy
CR purpose: to produce sugar
CR requires chlorophyll
CR animals do CR because they cannot do P
Total: 15

P = Photosynthesis, CR = Cellular Respiration

Figure 4.26. Morgan’s pre-treatment alternative conceptions.

Photosynthesis. Morgan’s individual knowledge list regarding photosynthesis included three correct and important facts and nothing that indicated an alternative conception. She said that “only plants use photosynthesis” and that they use chlorophyll “to ‘capture’ the sun’s energy” (Pre-Treatment Individual Knowledge List, 4/10/15). It was unclear what she intended to convey by her use of single quotes around the word capture, but it may be surmised that she recognized that was not the most scientific way to describe the phenomenon. In addition to the above information, Morgan explained that plants use photosynthesis to produce food.

Morgan’s responses on the alternative conceptions survey about photosynthesis were largely correct, which was in line with her correct statements on her individual knowledge list. However, her responses on the survey revealed some subtle inaccuracies were present in her thinking. For the most part, Morgan correctly answered all the questions related to photosynthesis, but sometimes made errors in the second-tier questions that required her to select the appropriate reason for her response. For instance, although she correctly answered that carbon dioxide was absorbed and oxygen released during photosynthesis, she did not choose the correct reason why oxygen was released. Her response did not include the correct conception that some of the oxygen was reabsorbed for cellular respiration, and instead she had chosen the response that oxygen was a complete waste product. Similarly, her reason for indicating that carbon dioxide was absorbed during photosynthesis was the inaccurate idea that animals need carbon dioxide to respire. The only photosynthesis-based question that Morgan got completely incorrect was when she indicated that the majority of a plant’s biomass originates from the soil.

Cellular respiration. Morgan’s individual knowledge list about cellular respiration contained little specific information. The two facts that she included, however, were accurate. Morgan stated that “all living things use cellular respiration” and it was a “life–sustaining function of cells” (Individual Knowledge List, 4/10/15).

Morgan’s answers on the alternative conceptions survey provided evidence that her conceptual understanding of cellular respiration was less developed than that of photosynthesis. Morgan did not identify the correct equation representing cellular respiration, instead choosing an equation that more closely matched photosynthesis. She also was unable to identify the type of gas exchange that occurs during the absence of light, again choosing answers that aligned with gas exchange during photosynthesis (carbon dioxide absorbed, oxygen released). Additionally, Morgan did not identify the correct purpose of cellular respiration. She again chose an answer that focused on the idea of absorbing carbon dioxide and releasing oxygen instead. Morgan, however, was correct on her answers regarding when cellular respiration occurs and that it takes place in all plant and animal cells.

Meg (individual-level). Meg's baseline recall of information about photosynthesis and cellular respiration was minimal, as evidenced by the brief statements she included on her individual knowledge lists. However, her answers on the pre-treatment alternative conceptions survey indicated that her knowledge was more extensive and more accurate than her individual knowledge lists might have indicated. She scored 50% on the pre-treatment survey. Meg's responses showed that she held some correct conceptions of both photosynthesis and cellular respiration, as well as some notable alternative conceptions. Figure 4.27 summarizes the alternative conceptions that were identified in Meg prior to the study.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P timing: light not required
P equation: chlorophyll is a reactant
P equation: unspecified energy is a reactant
P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR purpose: to produce sugar
Total: 8

P = Photosynthesis, CR = Cellular Respiration

Figure 4.27. Meg's pre-treatment alternative conceptions.

Photosynthesis. Meg's individual knowledge list regarding photosynthesis, which she wrote prior to taking the alternative conceptions survey, consisted of one sentence. She wrote, "Plants use photosynthesis to produce food and energy" (Pre-Treatment Individual Knowledge List, 4/10/15). This statement was essentially correct, although there was no indication of her awareness of the intervening step of cellular respiration in which the food is converted to usable ATP energy.

Meg's answers on the alternative conceptions survey showed that she had some accurate knowledge of photosynthesis. For instance, she correctly identified the most important benefit that plants achieve from photosynthesis, the conversion of light energy to chemical energy. Meg was also among the few participants in the study to choose the correct source of a plant's biomass (carbon dioxide) on the pre-treatment alternative conceptions survey. Regarding gas exchange, Meg answered correctly that carbon dioxide was absorbed and oxygen released during periods of sunlight, thus during photosynthesis.

However, there were also alternative conceptions revealed in her survey answers. For example, she did not accurately identify the appropriate reason that oxygen was released during photosynthesis. Later in the survey, she selected the answer that indicated oxygen was a complete waste product, overlooking the better answer that indicated that most of the oxygen was used in subsequent processes (cellular respiration). Meg did not correctly identify the equation for photosynthesis. Additionally she indicated in another answer that light was not an important factor in photosynthesis.

Cellular respiration. Meg's individual knowledge list about cellular respiration included only one word. That word was "Mitochondria" (Pre-Treatment Individual Knowledge List, 4/10/15). No details were included to provide contextual information indicating how Meg viewed the relationship between cellular respiration and mitochondria. No other facts were included.

Meg's responses on the alternative conceptions survey about cellular respiration revealed that her knowledge of that process contained multiple alternative conceptions. She was unable to identify the correct equation for cellular respiration. Meg also responded incorrectly that carbon dioxide was absorbed and oxygen released during periods of darkness, when it is actually the opposite gas exchange that occurs during cellular respiration. Notably, she did not identify the accurate purpose of cellular respiration, instead indicating that its purpose was to manufacture food from water and carbon dioxide, which is the purpose of photosynthesis. However, Meg correctly indicated that cellular respiration occurs at all times during the day and night.

Macy (individual-level). Like her group mates, Macy held both alternative conceptions and accurate conceptions related to photosynthesis and cellular respiration. Macy's baseline memory of photosynthesis contained more specific details than other participants, as evidenced by the information included on her pre-treatment individual knowledge survey. However, she struggled to translate those specifics into an accurate conception of the processes as a whole. Macy scored 36% on the pre-treatment alternative conceptions survey, revealing that her conceptual understanding was limited. A summary of all the alternative conceptions identified in Macy at the start of the study is shown in Figure 4.28.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P timing: occurs all the time in plants
P equation: gas exchange is O_2 in, CO_2 out
P equation: turns sunlight directly into sugar
P equation: unspecified energy is a reactant
P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR purpose: to produce sugar
CR location: occurs only in leaf cells
CR only leaves have pores/stomata
CR related to exercising (in humans)
Total: 12

P = Photosynthesis, CR = Cellular Respiration

Figure 4.28. Macy's pre-treatment alternative conceptions.

Photosynthesis. Macy's individual knowledge list about photosynthesis indicated she held a generally correct conception of the process itself, although there were factual errors in the details. For instance, Macy correctly wrote, "Photosynthesis is the process that plants use to create food energy" (Pre-Treatment Individual Knowledge List, 4/10/15), but later called that food energy sucrose rather than glucose. Macy also included an equation for photosynthesis, one of the few participants in the study and the only member of Group M to do so on the pre-treatment individual knowledge list. Macy wrote, "Sun + O_6 + $H_2O \rightarrow C_6H_{12}O_6$ + C" (Pre-Treatment Individual Knowledge List, 4/10/15). This indicated Macy had memorized the balanced equation previously and tried to reproduce it here, but made errors in the details. Most notably, her equation did not show a source for the carbon molecules in the reactant (left) side of the equation. It also showed O_6, probably intended to mean oxygen (O_2), as a reactant rather than a product. As part of her explanation beneath the equation, Macy incorrectly stated that one of the products of photosynthesis was carbon monoxide.

On the alternative conceptions survey, Macy answered correctly that carbon dioxide was absorbed and oxygen released during photosynthesis. However, her selections for the reasoning for each of those facts were incorrect. Like many of her group mates, she indicated that oxygen was a complete waste product and ignored the better answer that included oxygen reabsorption for cellular respiration once it was produced in photosynthesis. Her reasoning for choosing carbon dioxide as a reactant was inaccurate as well, ignoring the correct answer that plants make their food from this gas.

Instead she selected the answer that suggested animals need the gas in order to respire, which is a false statement in addition to being illogically associated with the original question. Macy selected an equation for photosynthesis that was nearly correct, showing the correct gas exchange, but did not include water as a product and showed unspecified energy as a reactant. The better answer showed light energy above the arrow in the equation, indicating it activating the conversion of products to reactants. Macy did not correctly identify the most important benefit of photosynthesis to plants (conversion of light energy to chemical energy) and instead answered *production of energy*. This answer indicated she held a common and naïve conception regarding the purpose of photosynthesis and ignoring the role of cellular respiration. Macy was correct in recognizing that plants photosynthesize only in the presence of light. She also correctly answered that the biomass of a plant mainly originates from carbon dioxide.

Cellular respiration. Macy's individual knowledge list regarding cellular respiration contained little accurate information. She explained one correct fact saying, "Well, I know it takes place in the mitochondrea [*sic*] of the cell, but I think that's it" (Pre-Treatment Individual Knowledge List, 4/10/15). She included one other sentence: "In my head I compare it to a human working out and sweating for some reason" (Pre-Treatment Individual Knowledge List, 4/10/15). This statement did not clearly indicate any additional accurate conceptual knowledge related to cellular respiration. It could be surmised that it suggested a vague conceptual idea that cellular respiration and metabolism are linked, or perhaps pointed to a distant memory of aerobic and anaerobic respiration, which might have included exercising as an example.

Macy's answers on the alternative conceptions survey revealed a few correct conceptions about cellular respiration, as well as multiple alternative ones. Macy was unable to identify the correct equation for cellular respiration, instead choosing an equation that was more like photosynthesis. She also did not know the appropriate gas exchange that occurred during periods of darkness, thus during cellular respiration. On an item asking about the most accurate statement regarding cellular respiration, Macy chose an answer that described the purpose of photosynthesis. She also indicated that cellular respiration occurred only in the cells of the plant leaves. The two questions regarding this topic that she answered correctly indicated that Macy understood that cellular respiration occurred all the time as well as in plant and animal cells.

Group M (group-level). The members of Group M were tasked with creating a group knowledge structure graphic (Figure 4.29) that represented their collective knowledge of both photosynthesis and cellular respiration. This immediately followed the completion of their individual knowledge lists and alternative conceptions survey. After the knowledge structure graphic task, the group was interviewed to learn more about them individually and about their collective group knowledge of the topics of photosynthesis and cellular respiration. Although the purpose of the group knowledge structure graphic and interview was to develop a clearer picture of the group's baseline knowledge prior to the argumentative discourse lessons, it should be noted that these experiences also provided an opportunity for the group members to begin influencing each other's knowledge through discourse. The process of developing the group knowledge structure graphic and later discussing it during the interview allowed Group

M members to consider, accept, and reject one another's conceptual ideas before the treatment began.

Through discussions prompted by my questions during the pre-treatment group interview, which came later the same day, the members of Group M revealed additional collective conceptions of both photosynthesis and cellular respiration. I encouraged them to include the information on their knowledge structure graphic, since the concepts were original to them and thus was illustrative of group knowledge before the treatment lessons. The facts that were added to the knowledge structure graphic were generated solely by the group during the interview. Two of the cellular respiration facts (i.e., the use of energy and part of life necessities/life functions) and one of the photosynthesis facts (i.e., not all energy is used, some stored) were added, as well as connecting lines between the topics of cellular respiration and photosynthesis.

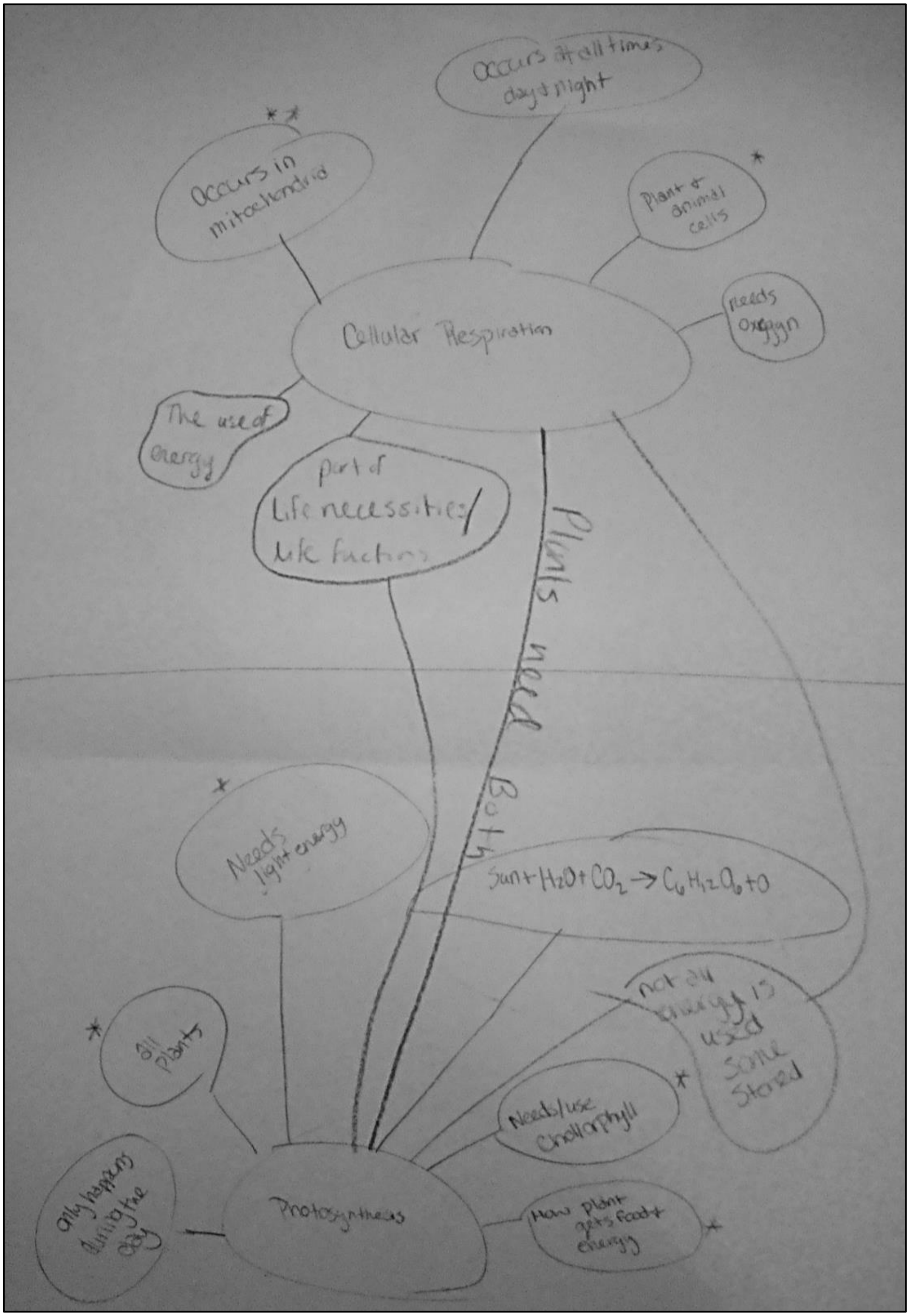

Figure 4.29. Group M’s pre-treatment knowledge structure graphic.

The one alternative conception that Group M held collectively prior to the treatment lessons was that photosynthesis produced energy directly (Figure 4.30). They exhibited a lack of understanding regarding the intervening process of cellular respiration. On their knowledge structure graphic, they wrote, “How a plant gets food and energy,” and connected that statement only to photosynthesis. During the pre-treatment group interview, the group added the concept, “The use of energy,” connected to cellular respiration.

Pre-Treatment Alternative Conceptions
Identified from pre-treatment group knowledge structure, pre-treatment discussion, and pre-treatment interview
P produces energy directly
Total: 1

P = Photosynthesis, CR = Cellular Respiration

Figure 4.30. Group M’s pre-treatment alternative conceptions.

At first glance, these seem to be accurate statements. However, they were actually indicative of a common alternative conception, that photosynthesis is the only process needed to provide energy to the plant. According to other data sources, most of the individual group members held this idea prior to the treatment. The reality is that photosynthesis itself does not create usable energy for the plant. This naïve conception fails to acknowledge the role of cellular respiration in converting the unusable energy of the stored glucose molecules, created during photosynthesis, into usable ATP energy, which drives life functions. Cellular respiration makes the energy usable to the plant.

Yes, it does use energy to complete cellular respiration, but stating that it is the "use of energy" (Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15) is incorrect.

During the pre-treatment interview, group discussion illuminated the confusion that the members of Group M had regarding this conception. Morgan first introduced the concept of energy. The group discussed how energy might be part of photosynthesis and cellular respiration. The following exchange is the beginning of that discussion.

Morgan: Like, they both, do they both produce energy? I could be totally wrong. Is it both some form of energy production?

Mari: Well, [photosynthesis] produces energy, but through [cellular respiration] you can use that energy. Yeah so they both have to do with energy, because for plants it's like a two-step process they have to you know take the energy and convert it through photosynthesis, then be able to use it for respiration. But animals, we eat it and it's you know converted in our stomachs, and then we get to use it through the respiratory process.

Researcher: Okay.

Macy: In order to, like, photosynthesize, do you have to have, like, have cellular respiration? I don't think it can, I know when we think of photosynthesis, we don't like, I just think of [photosynthesis] constantly, and I don't think of cellular respiration. But I'm pretty sure they have to go hand in hand in plants. And I think we all, like, agreed that this happens, cellular respiration happens in all cells and day and night just kind of constantly goes. And [photosynthesis] just happens during the day.

(Pre-Treatment Interview, 4/10/15)

In the above exchange, the group attempted to explain the purpose of cellular respiration. In general, they held the common naïve conception that photosynthesis is the only process necessary for a plant to generate and use energy, and yet they began to acknowledge that cellular respiration has a role to play as well. However, they struggled to identify what, precisely, was that role and purpose. Mari appeared to have an accurate conception, but her explanation did not appreciably influence her group mates' own understanding. Thus, the group settled on the general idea that photosynthesis creates and stores energy, and that cellular respiration is the process that uses the energy. Their discussion continued with them trying to understand how the concepts of metabolism and plant life functions fit with this conception of cellular respiration. The dialogue is recorded below.

Mari: Well, I mean [photosynthesis] you get, you know, the energy from the sun, which we have. But [cellular respiration], is, like, the stored energy, basically, isn't it? When you start using it? It was stored away.

Macy: [Morgan], you said something that sounded, like, awesome. When you said it was (trails off).

Morgan: Did I say production?

Macy: Now, like [photosynthesis] gets energy, and [cellular respiration] is, like, how we use it.

Mari: The use of energy and storage I guess. This is, does [cellular respiration] link to the whole life function? Like, with the metabolism because you have to have the respiration. Does that, like, link in to that?

Morgan: Metabolism can include cellular respiration.

Mari: So it’s a part of the life functions that [Dr. Pepper] was mentioning.

Macy: Yeah.

Mari: Which in turn, if it’s part of the life functions, makes that part of the, you know, the need for the photosynthesis in a way. Because that’s the life function of the plant being able to convert the (trails off). So, because it’s feeding.

Morgan: Right.

(Pre-Treatment Interview, 4/10/15)

Group M was close to exhibiting an accurate conception of the role of cellular respiration. Meg did not contribute to the discussion so it is impossible to know what she was thinking. Although the group’s conception was close to accurate, they never clearly explained that the purpose of cellular respiration is to transform the chemical energy into usable ATP energy, which is then used for life functions. Since the group did not understand the purpose of cellular respiration, they were unable to make accurate sense of how it related to other life functions that use energy in the plant. This inability to distinguish between the purpose of photosynthesis and the purpose of cellular respiration was apparent in this group prior to the treatment lessons.

The next section will examine what occurred with the group's collective alternative conceptions as they worked through the argumentative discourse lessons on photosynthesis and cellular respiration. During the lessons, they were provided evidence to use to develop and support their assertions regarding the scientific processes of photosynthesis and cellular respiration. They were asked to make claims and defend them using the evidence provided.

During treatment conceptions (group-level). The members of Group M engaged in extensive dialogue during the course of the two treatment lessons. Through their collaborative and argumentative discourse, alternative conceptions were revealed and agreed upon by the group. Any alternative conception that was accepted by the group and mentioned more than incidentally was counted as a group-level alternative conception. It should be noted that many of these alternative conceptions changed at some point during the treatment lessons (i.e., the group might not have continued to exhibit the alternative conception by the end of the lesson). No individual-level alternative conception results were collected during the treatment lessons since the participants were collaborating and negotiating understanding dynamically.

The group-level alternative conceptions that were identified in Group M during the photosynthesis and cellular respiration treatment lessons are listed in Figure 4.31. The upcoming section will provide more details about the occurrence and acceptance of these alternative conceptions through narrative and quoted dialogue. The alternative conceptions that occurred during the photosynthesis lesson will be discussed first, followed by those from the cellular respiration lesson.

During Photosynthesis Lesson	During Cellular Respiration Lesson
P biomass: originates from multiple sources (e.g., soil, water, air, sun)	
P biomass: originates from soil	
	CR and P equations: exact reverse/opposite of each other
	CR purpose: simply to exchange CO_2 and O_2
	CR purpose: to provide energy when P is not occurring or has not made enough energy
	CR purpose: to store sugar
	CR ATP energy is a type of stored energy
Total: 2	**Total: 5**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.31. Group M’s alternative conceptions during the treatment.

Photosynthesis lesson. During the photosynthesis lesson (Appendix G), there were two alternative conceptions that the members of Group M discussed at length. The one discussed most extensively was the idea that the main source of a plant’s biomass originates from nutrients in the soil. An additional closely related alternative conception was mentioned briefly. It was the idea that the majority of a plant’s biomass originates from a variety of sources (i.e., soil, air, and water). This alternative conception was often framed around the assumption that Dr. Pepper’s request for them to choose and defend just one of the claims was actually a purposeful misdirection.

An inability to accurately identify where a plant mainly obtains the molecules to create biomass represented more than a simple omission. Instead, it was indicative of a foundational alternative conception regarding what occurs during photosynthesis. Group M returned to the idea that a plant's biomass originated from nutrients in the soil multiple times during their discourse. There were moments of clarity and various levels of correct understanding apparent in individuals along the way. However, collectively the group was loathe to reject their alternative conception entirely, even after accepting evidence that clearly showed it was incorrect. The comments related to the conception that the biomass came from all the sources were so intermingled with the discussions about the first alternative conception that I will discuss them together in the upcoming section. This upcoming narrative will detail the discourse that occurred around Group M's two alternative conceptions about the source of a plant's biomass.

A plant's biomass comes mainly from nutrients in the soil, and a plant's biomass comes from many combined sources. The guiding question, given at the beginning of the lesson, prompted the group to choose a claim about the source of a plant's biomass based on the provided evidence. Interestingly, all the group members except Morgan had answered the biomass question correctly on the pre-treatment alternative conceptions survey taken immediately before the treatment lesson on photosynthesis. Thus, three members had correctly indicated that the main source of a plant's biomass was carbon dioxide, while only Morgan chose soil. Despite this, a completely accurate understanding of the concept was not evident in Group M's discourse during much of the photosynthesis lesson. Multiple layers of confusion were revealed. An exposition of Group M's discussions regarding the biomass source follows.

At the start of the photosynthesis lesson, the participants were asked to generate their own answer to the query regarding the main source of a plant's biomass (Appendix G, Task 1). The four members of Group M began talking quietly together immediately following Dr. Pepper's question, rather than thinking to themselves as directed. No one in the group provided an immediate answer. Morgan expressed her lack of understanding related to the term *biomass*, and Mari provided an accurate definition. The following exchange occurred.

Macy: Tough question. From where does a plant get its biomass? Okay, interesting.

Morgan: Where does it get its biomass?

Macy: I don't know, I don't know how to answer that.

Morgan: I don't think I understand what the biomass is. I feel like it's supposed to be related.

Mari: The biomass, remember, is, like, if you were to put something in a dehydrator and take out the water, like, how much it would weigh.

Morgan: Oh, okay.

Mari: And that's how we take the biomass. I feel like [the trophic pyramid] is going to be something, since [Dr. Pepper's] reiterating the whole nutrients thing is somehow related.

Macy: Yeah, we're all stuck.

(Photosynthesis Lesson, 4/13/15)

Next, Dr. Pepper asked the members of the groups to explain their proposed answers to each other. The following exchange occurred, which revealed the first appearance of Group M members' pervasive alternative conception that the biomass comes from *nutrients*, a term that they did not attempt to define or clarify at this time. This was also the first appearance of their idea that the answer will be a "combination of, like, three or four things" (Photosynthesis Lesson, 4/13/15). Meg did not contribute to the discussion.

Macy: My answer is so dumb. I just put, "From its bark, question mark," and then I said, "Everything without the water," because that's what biomass is, and I put, "All the nutrients a plant soaks up probably adds to the weight." I don't really know.

Mari: I just put, like, nutrients.

Macy: Go ahead and put *mass* and *dehydrate*.

Morgan: It sprouts from a seed, but that wouldn't be left if you put it in the (trails off).

Mari: Well, see, the seed is going to have a different biomass because if you were to dehydrate the water that's in the seed, but I mean it accounts to it eventually.

Morgan: I don't know.

Mari: I feel like [the source of a plant's biomass] is going to be a combination of, like, three or four things.

(Photosynthesis Lesson, 4/13/15)

The next instructional task required the participants to choose the best answer from four provided answers (Appendix G, Task 2). Macy immediately suggested the first claim that stated the main source of biomass was from *nutrients in the soil*. Mari agreed, but also suggested that more than one answer might be correct. She said, "Yeah, I would think nutrients. I feel like [Dr. Pepper's] going to be like, 'It's a combination, guys. I tricked you, ha-ha!' I really don't know though. That seems like something she'd say" (Photosynthesis Lesson, 4/13/15). Mari then asked the rest of the group for input, and both Macy and Morgan agreed that the *nutrients in the soil* claim was the best one. Meg did not offer any comments, and the group did not ask for her input.

During the next task (Appendix G, Task 3), Group M modeled the photosynthesis equation (Figure 4.32) using the provided equation component cards. Their original model was correct except they did not include water as one of the products. After modeling the equation, Mari questioned whether the nutrients card should also be included somewhere in the equation. The following dialogue occurred.

Mari: Should we have the nutrients card out since these (gesturing at the equation) are technically nutrients?

Morgan: I guess they have the stuff, just like above it on that?

Mari: I mean they are nutrients technically, but (trails off).

Macy: I don't know. This is the equation, but all that stuff comes into play.

Morgan: Yeah.

Mari: They still have everything out over there (looking at nearby group).

Macy: Model the equation for photosynthesis that best supports your claim. Yeah, since we agree that nutrients is what makes it happen we do need— (interrupted)

Dr. Pepper: Your table's ready to go, or you're not ready?

Morgan: No, we're changing stuff.

Mari: We're redoing stuff.

(Photosynthesis Lesson, 4/13/15)

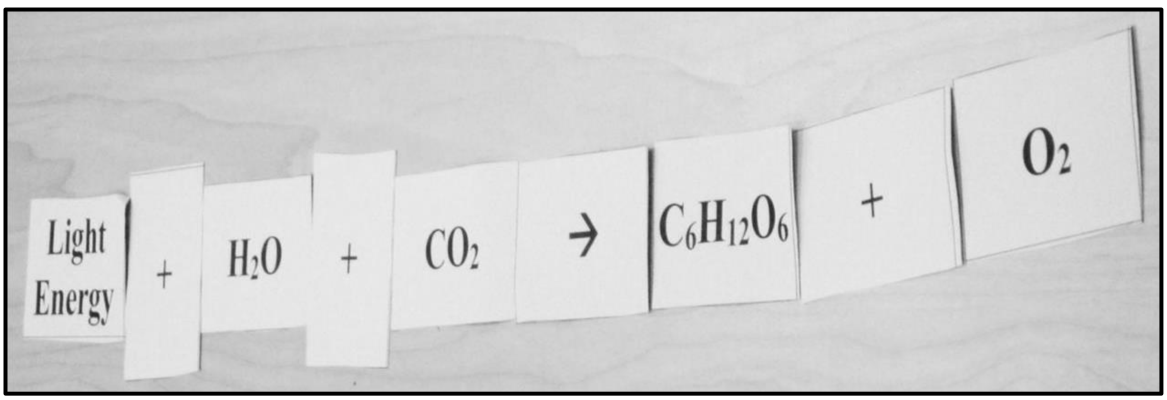

Figure 4.32. Group M's first photosynthesis equation model.

During the above discussion, the group determined that the *nutrients* card was necessary in their equation since they had chosen *nutrients in the soil* as the source of a plant's biomass. They also erroneously included fats and minerals in their revised equation (Figure 4.33). To their credit, Group M tried to logically connect the photosynthesis equation to the biomass guiding question, which was the intended goal of the lesson. In addition to discussing nutrients, the above exchange included the first mention of ATP by Group M. ATP was on one of the provided equation component cards. There was little discussion about it at this time, other than statements by Mari and Morgan expressing their lack of knowledge. Then Dr. Pepper announced the next task, and no more discourse about the equation occurred at this time. Meg again had not contributed verbally nor manipulated the cards.

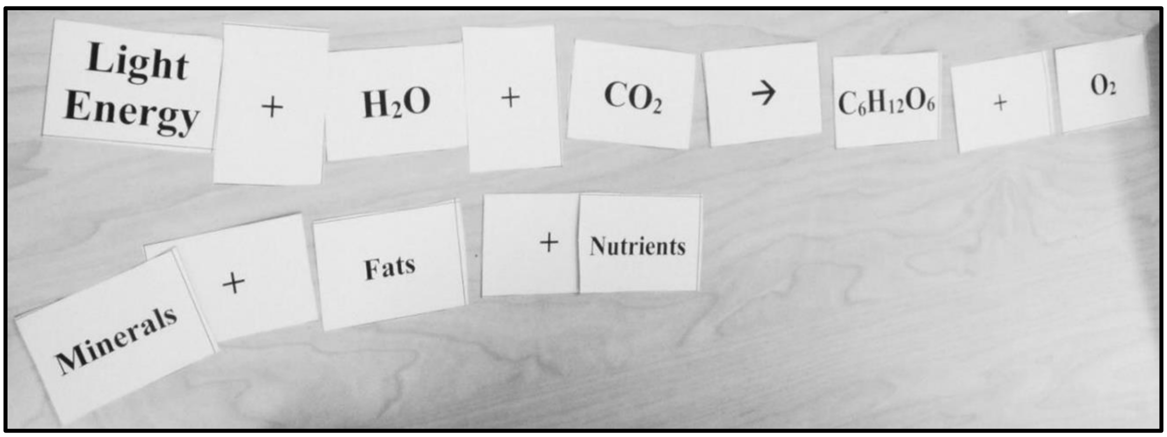

Figure 4.33. Group M’s second photosynthesis equation model.

The next instructional task (Appendix G, Task 4) required the participants to gather evidence from information stations around the room to help them revise their equations as well as their answer to the biomass guiding question. Macy gathered evidence from a station explaining van Helmont’s famous 17th century investigation (Krikorian & Steward, 1968). In this investigation, van Helmont grew a tree in a pot of soil weighing 200 pounds. At the conclusion of five years, the tree had gained approximately 164 pounds, but the soil had only lost approximately two ounces. From this, he concluded that the mass of a tree did not come from soil and, thus, must come from water since that was the only thing he added during the five-year period (Krikorian & Steward, 1968). When Macy explained this to the group, she said,

> I said his conclusion wasn't valid. Uh, this was the only thing that this investigation proved. I said, well, since biomass excludes, like, water weight, I don't really know why he decided to accredit it to water. But it just proves that some is taken from the soil since the soil was lighter. So I think some biomass is taken from the soil. (Photosynthesis Lesson, 4/13/15)

Her reasoning was valid in recognizing that water could not be contributing to biomass, since biomass itself is the dried weight. However, she persisted in the belief that the biomass must have come from the soil. The fact that logically 164 pounds of tree could not come directly from two ounces of soil did not dissuade her from that alternative conception. She did not appear to consider that measurement error or other factors could easily have accounted for such a small change in the amount of soil loss. The other group members accepted her report without comment, and they continued presenting what each had learned.

Next, Morgan explained what she learned from evidence stations three, four, and five. She correctly gathered from station three's experimental data that typically a tree grown in an atmosphere with a higher concentration of carbon dioxide would be larger than one grown in an atmosphere with less carbon dioxide. She explained, "So what I took from it was that the more carbon dioxide a plant got, the bigger it grew" (Photosynthesis Lesson, 4/13/15). This evidence was probably the most obvious indicator among the evidence provided that carbon dioxide was the key component required for increasing the biomass of a plant. However, no one in the group noted or responded to Morgan's evidence regarding the importance of carbon dioxide.

Then Mari presented the evidence she had gathered. Her evidence conflicted directly with Macy's earlier conclusion. Mari had learned about hydroponic gardening, in which plants are grown completely without soil. She stated, "So ultimately, they gathered that nutrients are essential and, you know, like, water, carbon, and nitrogen and things like that, and they need energy of some sort, but soil is 100% optional" (Photosynthesis Lesson, 4/13/15). She maintained the idea that nutrients are necessary, but recognized that soil is not. No further discussion occurred at that time that dealt with, or even acknowledged, the conflicting conclusions drawn from the evidence stations regarding whether soil can be the main source of a plant's biomass.

Then it was Meg's turn to share her evidence. For the first time, more than 30 minutes into the group discussion part of the lesson, Meg began speaking. Meg's general explanation of what both her stations included was unclear and disjointed. However, she drew sound conclusions from both of her evidence stations, though she stopped short of explicitly connecting the ideas to the guiding question. From one station, she concluded, "I said the plant soaked up the CO_2. And what happened to the carbon dioxide? It was absorbed by the plant" (Photosynthesis Lesson, 4/13/15). She also stated that the other evidence station was "about the weight of air and carbon dioxide" (Photosynthesis Lesson, 4/13/15). Both of these ideas were key pieces of information supporting the correct conception that carbon dioxide in the air has mass, which is then incorporated into the plant's biomass. Meg did not attempt to apply any of the information to the photosynthesis equation nor the guiding question about biomass. The group did not ask any follow-up questions, and the only response was a noncommittal "hmm" (Photosynthesis Lesson, 4/13/15) from Macy.

Next, Dr. Pepper asked the class to edit their photosynthesis equations based on any new evidence they had gathered. She also told them they were free to change their choice of claim as to where the majority of a plant's biomass originated from, if desired. She then asked them to develop an argument to support their claim about the guiding question (Appendix G, Task 5).

While Macy wrote, Mari and Morgan contributed ideas. As before, Meg did not contribute. Morgan reiterated that the group had agreed that most of the biomass of a plant came directly from nutrients in the soil taken up by the plant's roots. Seemingly talking more to herself than the group, she proceeded to verbally list and then reject each of the other claim options. Morgan said, "It can't be water, because it would come out" (Photosynthesis Lesson, 4/13/15). This revealed she had an understanding that biomass was the dry weight of a plant; therefore, the water held in the plant would not contribute to its biomass. She went on to reject the sun's energy as contributing to a plant's biomass because "you can't measure that" (Photosynthesis Lesson, 4/13/15). This may indicate that Morgan understood that the sun's energy is not matter and does not have mass. Finally, Morgan rejected the correct claim, which was that the majority of biomass originates from air molecules. She mused, "No. Air would be taken out. So, yeah, let's go with [nutrients in the soil]" (Photosynthesis Lesson, 4/13/15). This statement revealed that Morgan may not have understood that air is matter and has mass, which becomes incorporated into the mass of the plant. She assumed that any air that had entered the plant would disappear or somehow be "taken out" and therefore not count toward the biomass of a plant.

Mari contributed evidence by reminding the group that soil was optional to plant growth. Morgan also reminded the group that carbon dioxide was important in increasing the biomass of a plant. The following exchange occurred.

Mari: [The hydroponics evidence station] kind of goes in with that. Like, it was saying soil is optional, but it proved that carbon dioxide, like air, water, and nitrogen, nutrients were essential for plant growth. Because it had to have, that, they grew better with it, and faster, and, you know, lots of energy.

Morgan: Mm-hmm. Yeah, they all affect the growth, so.

Macy: Yeah.

Mari: But it just steals the nutrients from the soil; it doesn't actually need the soil itself.

Morgan: Right.

Mari: Because the fish food was kind of, you know, another form of soil replacement with the nutrients.

Macy: So really this is all a plant needs: light energy, water, and CO_2 to produce sucrose and oxygen.

Morgan: Yeah, if you want to say something about, because I had the one that had carbon dioxide and then it was, like, you needed carbon dioxide to increase, like, the growth, so that would affect the biomass of the plant.

Mari: Yeah.

Morgan: Eventually.

Macy: Yeah.

Morgan: Would you just say added CO_2 affects growth overall?

Macy: Yeah, okay.

(Photosynthesis Lesson, 4/13/15)

Toward the end of the above dialogue, Macy succinctly summarized the photosynthesis equation almost in its entirety and did not include *nutrients* or *soil* in her statement. She also acknowledged that the role of soil was optional for plant growth. Group M’s final and correct photosynthesis model is shown in Figure 4.34. Following this exchange, it was surprising that the group did not seek to reject their original choice that a plant’s biomass comes from the soil and choose a different claim. They recognized that carbon dioxide was an important nutrient that affected plant biomass, yet they did not consider that the main source of that critical nutrient was the air. They remained convinced that the claim that contained the word *nutrients* had to be the correct one.

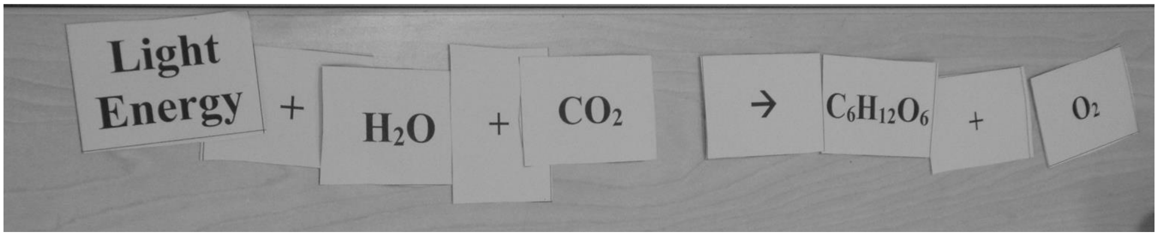

Figure 4.34. Group M's final photosynthesis model.

Dr. Pepper then introduced the next instructional task, which required the participants to rotate to different group tables to present, critique, and defend the various written arguments (Appendix G, Task 6). Macy stayed at Group M's table to present and defend their written argument to the visitors from other table groups. Mari, Morgan, and Meg separated and each went to another group's table to hear and critique their written arguments. During this part, Macy continued to emphasize the conception that the main source of a plant's biomass was nutrients, but she was less emphatic regarding the fact that the nutrients came from the soil. The following dialogue occurred when Macy presented Group M's written argument to Nasima and Nadine, each visiting from other small groups.

Macy: Just us? Good deal. So I'm just presenting to you guys I suppose? Well, we picked the first option. We all, uh, we believe this plant's biomass comes from the nutrients. I don't know why I put that there. Wait, no, I know why I put that there. From nutrients from the soil, and the tree just kind of soaks it up, yeah. Um, we know that light energy plus H_2O plus CO_2 yields sucrose and oxygen. But, we kept, like, fat and minerals and nutrients because those things, like, help, but they're not necessary. All they really need is CO_2, light, and water. I don't know what else to say. I used, like, evidence from these guys (points to evidence stations). Like, I don't know which ones you all had, but I'm sure they only corroborated.

Nasima: So did you think soil was a part of that, or?

Macy: A little part, just because, uh, that guy did the study on it and, just like, only like, one ounce of the soil was, like, missing after five years of the plant growing, so.

Others: Mm-hmm.

Nadine: But it could be without the soil.

Macy: Yeah.

Nasima: Because, I think, hydroponics said you don't need soil, it's not necessary.

Macy: Yeah, as long as you provide, like, CO_2 plus water plus light, it's all good. Soil just helps a little.

Nasima: Right. Yeah, it just gives off nutrients.

Macy: So what did you all pick then?

Nadine: The first one [nutrients in the soil].

Nasima: The first one [nutrients in the soil].

Macy: Sweet. Uh, I'm trying to think, the critiques of our argument. Do you all have anything I can put down?

Nadine: I don't know. Like, the main thing we put was that, um, it doesn't matter if it's like, like, we kind of put parentheses around the *in the soil* part.

Macy: Okay.

Nadine: Because that could be in, like, it could just, it just has to have a provider of nutrients basically. And, in that case the soil is, and in the other case it's, like, the nutrient rich water.

Macy: Oh yeah.

Nadine: So the soil part, like, leaves.

Macy: Because it's not necessary. Okay, ways to improve our argument, uh, formulated better.

Nadine: But I mean, that's the exact same we wrote it. We just wrote parentheses.

Macy: It's smarter. Okay (adds parentheses). All right.

(Photosynthesis Lesson, 4/13/15)

The above dialogue revealed that at least two other groups in the classroom also agreed on the choice that a plant's main source of biomass was *nutrients in the soil*. However, both participants from two separate groups acknowledged that soil was not necessary for plant growth. They resolved this conflict by putting parentheses around the part of the answer choice that indicated it came from soil. Thus, they felt the biomass came from various nutrients that could come from soil, but did not *have* to come from soil. Macy quickly agreed with their conclusion and modified Group M's argument by adding similar parentheses to their statement.

Dr. Pepper called for another rotation and three new participants arrived at Macy's table. Macy explained her group's argument again, this time with the newly added clarification that the nutrients did not have to come from the soil. She gave credit to Nadine as the source of the idea for putting part of the statement in parentheses. Norah and Natalie both agreed with little comment. The conversation turned to off-task topics.

Next, Dr. Pepper asked the participants to return to their original groups and all to share what had been learned during the rotations (Appendix G, Task 7). She encouraged them to change or revise their claims and evidence as needed. The upcoming exchange about the biomass question occurred, opening with Mari explaining another group's claim about the sun being the main source of biomass.

Mari: Because [the other group] did the, um, the energy from the sun, and they did the, um, absorption through the leaves because they remembered reading that. And their reasoning was, like, stems can absorb and leaves can by the food and stuff. But, you know, that they talked about how they didn't choose what we did because the whole word *soil*. That it wasn't necessary. But I told them we chose what we did mainly because nutrients are necessary. And they come from soil.

Macy: I changed our claim a little. I just added parentheses, like nutrients, quote, in the soil, like.

Morgan: Right.

Mari: Yeah, and so.

Macy: We can take that out.

Mari: Because what she said, she said that their thing would only work if nutrients were provided. Otherwise, such as in the hydroponic gardening, where they sprayed it on there and stuff. So that, you know, like, they were realizing that the nutrients had to be there.

Morgan: Right. And they come from, that was the one that said, they said it comes through the leaves, and I was, like, but nutrients don't come through the air, only through the roots. The air only has like whatever the air has in it.

(Photosynthesis Lesson, 4/13/15)

The members of Group M correctly rejected the other group's suggestion that the sun was the main source of biomass. However, they persisted in their erroneous claim that it originated from nutrients in the soil. They acknowledged, somewhat accurately, that the soil was not the important part, instead, that the *nutrients* were the critical component that created the biomass. Morgan's last statement made it clear that she had no conception of necessary nutrients that have mass existing in the air and being absorbed into the plant. The dialogue continued as members of Group M proceeded to wrestle more with the concept of nutrients and how the plant might obtain them.

Mari: Well, the nutrients of carbon dioxide would [come through the air], but the other, like, the other, nitrogen could as well.

Morgan: Right.

Mari: But nitrogen is also very rich in soil and de-comp, like, decomposed matter.

Morgan: But, as far as, like, sucrose and all that?

Mari: Sucrose is produced in the plant.

Morgan: Oh, okay.

Mari: Sucrose is sugar. Glucose is sugar, like, it's different kinds. Um, but, like, there are certain things that they would get more out of soil, or soil-like substances, like, but you, it has, the majority of it is absorbed through the roots. Unless it's an air molecule, then it's absorbed through the leaves.

Macy: How's it sound so far? (Reading aloud) "Since plants can survive without soil, only needing CO_2 and nutrients from water to grow." Uh, the, that sentence needs more in it. "Therefore, biomass must come from nutrients, not soil, and definitely not water." Okay, what else can I put?

Morgan: I guess we could just put (trails off).

Mari: Water itself is a nutrient because it has hydrogen and oxygen, though.

Macy: Isn't or is?

Mari: It is.

Macy: Well, I put nutrients from water.

Mari: Okay, because you said, not water.

Macy: I put, “the biomass doesn’t count.”

Mari: I’m sorry.

Macy: You’re good. I said, “Therefore, biomass must have nutrients, not soil and definitely not water.”

Mari: Yeah, I just missed that little key word.

Macy: Good things come from the water, but that can’t, doesn’t, can’t affect the biomass.

Morgan: It wouldn’t affect the overall biomass.

Macy: Everyone else okay with that? I feel like it should be longer.

Mari: Yeah, um, it’s supposed to be like two sentences I think. This, and then we restate stuff. Um, I think we need to reiterate that nutrients, like, water, consists of hydrogen and oxygen, and carbon dioxide consists of carbon and oxygen. And, like, break down what the formula is, maybe? And prove that those are all nutrients. But I feel like [Dr. Pepper’s] going to, like turn around and be, like, “Oh it’s all four of them combined, you guys.” That’s what both, or should I, in the other group we were, like, yeah that might be. But I’m wondering if that’s right on the whole ATP thing because we started thinking about it because there has to be some way for the plant to continue with stored energy. It keeps getting like cold and then hot and then cold and then hot in here.

Morgan: Yeah, there's a vent over there on the right side.

Mari: I feel like this is more confusing than it should be.

(Photosynthesis Lesson, 4/13/15)

The above dialogue provided evidence of Mari recognizing that carbon dioxide is a key nutrient and that it is absorbed from the air into the plant leaves. Macy and Morgan appeared to agree with her comments; Meg did not contribute. Although Mari clearly understood that carbon dioxide comes from the air, she was unwilling to actually give up on the nutrients in the soil claim. She also returned to her earlier suggestion that in reality it was probably a combination of all four claims provided.

For the next task (Appendix G, Task 8), Dr. Pepper asked the participants to return to the tables they had visited during the first rotation in order to re-evaluate the revised arguments. During this third rotation, Macy indicated that her group had not revised their argument from before, but simply added reasoning. She mentioned that carbon dioxide was necessary, but did not link it to being the main source of the plant's biomass. The following dialogue occurred.

Nadine: Did you all change anything really?

Macy: Nah, we just made our reasoning. Some plants can survive without soil, they only need CO_2, and nutrients from water, and sun to grow, and therefore biomass.

Nadine: I don't think they need sun.

Macy: Okay, well, light energy.

Nadine: I think they need light energy, yeah, because I think they can also grow.

Macy: That's why fluorescence can.

Nadine: Yeah.

Nasima: Yeah.

Macy: But, therefore, biomass must come from nutrients, not soil, and definitely not water, the specific nutrients from water and CO_2 are hydrogen, oxygen and carbon, which adds mass to plants.

Nadine: Yeah, we said, the only thing like, we said that, uh, because it has, like, nutrients I guess we decided were like the majority of the biomass, they can't be all because if you take all the water out of the leaves, there's still a leaf. Like, there's still a biomass. So that's biomass, and the majority's going to be nutrients.

Macy: Yeah.

Nadine: And CO_2 and water are all nutrients then.

Macy: Yeah.

(Photosynthesis Lesson, 4/13/15)

No on-task dialogue occurred during the fourth rotation (Appendix G, Task 8) until Dr. Pepper approached with a question regarding the position of light energy in their photosynthesis equation. Group M returned to their table and revised their argument again (Appendix G, Task 9). However, no more discussion of the biomass occurred among the Group M participants.

At the end of the lesson, Dr. Pepper explained to the whole class that the source of the biomass was mainly from the carbon dioxide molecules absorbed from the air. She asked if that made sense. No one replied to her directly. Within groups, however, some participants spoke quietly to each other. This exchange occurred in Group M.

Morgan: That doesn't make sense.

Mari: I feel like that's not entirely right.

Morgan: It doesn't make sense.

(Photosynthesis Lesson, 4/13/15)

This reaction to the pronouncement of the correct answer was met with disbelief. This occurred even though Mari had said the exact same thing during the lesson, and the others had agreed with her. The end of the class period arrived, and Dr. Pepper dismissed them.

Summary. Group M spent the majority of the lesson trying to make sense of how and from whence a plant gains its biomass. Although three of the four correctly answered this question prior to the lesson, and they continually accurately stated and agreed that carbon dioxide was an important nutrient for biomass and was sourced from the air, the group struggled to choose the correct claim. Even after being told that the correct answer was from the air, they were largely unable to permanently incorporate it into their conceptual understanding.

Cellular respiration lesson. The cellular respiration lesson (Appendix J) occurred the next time the class met, two days following the photosynthesis lesson. The cellular respiration lesson was designed and enacted the same way as the photosynthesis lesson.

Participants were asked to gather evidence from stations to make a claim regarding their guiding questions and the cellular respiration equation. Five alternative conceptions were expressed and discussed at length by the members of Group M (Figure 4.31). They were: a) the purpose of cellular respiration is to store sugar, b) the purpose of cellular respiration is to provide energy when photosynthesis is not occurring, c) the purpose of cellular respiration is simply to exchange gases, d) ATP energy is a type of stored energy, and e) cellular respiration is the exact reverse of photosynthesis. The upcoming paragraphs will provide narrative and quoted dialogue that occurred related to the alternative conceptions. The first three of these alternative conceptions all pertain to an incorrect understanding of the purpose of cellular respiration; thus, they will be grouped together.

The purpose of cellular respiration is to store sugar, provide energy when photosynthesis is not occurring, or simply to exchange gases. An undeveloped and incorrect understanding of the purpose of cellular respiration was threaded throughout much of Group M's discussions during the lesson. The group understood that the purpose of photosynthesis was to make and store food. They also understood that the plant used that food to live. However, at the start of the cellular respiration lesson, they did not understand cellular respiration's purpose in converting the stored food to usable ATP energy, which then could drive the plant's metabolic processes. This disconnect first appeared when Morgan explained the evidence she had gathered from her station to the rest of the group. She spoke about how a plant will "use up all of its stored nutrients and energy and die" (Cellular Respiration Lesson, 4/15/15) when it is not doing photosynthesis. She did not link this idea to the process of cellular respiration. Instead, a few comments later she incorrectly stated that carbohydrates are stored during the process of cellular respiration. She said, “And what does the graph show happens to carbohydrates in plants during cellular respiration? They are being stored” (Cellular Respiration Lesson, 4/15/15). Macy agreed, saying “Yeah, they’re just chilling at the bottom [of the graph]” (Cellular Respiration Lesson, 4/15/15). Both Morgan and Macy misinterpreted the graph, which actually showed that carbohydrate consumption occurs at a steady rate both day and night. This graph was intended to provide evidence that cellular respiration occurs continuously and is not dependent on light.

The purpose of cellular respiration was next discussed peripherally when Mari presented the evidence she had gathered. She tried to understand and explain why seeds germinate and grow in the dark and why oxygen levels decrease during that process. The following exchange occurred.

Mari: Well, the germinating seeds aren’t mature plants yet, so that means they’re not photosynthesizing and cellular respiration uses oxygen. So pretty much what I figured, is that it’s using the stored energy to, like, grow. So maybe through cellular respiration it might be taking in oxygen, because, you know, it doesn’t have photosynthesis to use carbon dioxide yet. And, then what, uh, process might be, might the germinating seeds be doing, that is using up oxygen in the atmosphere? Cellular respiration is the answer to the question.

Macy: Okay.

Mari: Because that's all that really makes sense to me of why it would be doing that. Because, like, you can grow bean seeds in the dark and they'll start sprouting. They don't need light. So, you know, it's using stored energy.

Macy: So that's actually, like, cellular respiration then? It's growing in the lack of sunlight.

Mari: Well, I think it would be, probably, be, because it's using stored energy and growing in the lack of sunlight, so obviously, like, it's not using photosynthesis.

Macy: Yeah.

(Cellular Respiration Lesson, 4/15/15)

Mari exhibited a clearer understanding of the process and purpose of cellular respiration than did Morgan and Macy. She stated, "It's using stored energy" (Cellular Respiration Lesson, 4/15/15) when explaining what occurs during cellular respiration and repeated it when seeking to clarify and correct Macy's statement that cellular respiration was "growing in the lack of sunlight" (Cellular Respiration Lesson, 4/15/15). Macy agreed with her; Morgan and Meg said nothing. While partly correct, Mari's explanation was incomplete and did not explain that the purpose of cellular respiration is to convert the stored energy into usable ATP energy. Mari herself did not hold a fully developed conception of the purpose of cellular respiration as was revealed in later conversations.

Additionally, her explanation was not effective in remedying the others' alternative conceptions regarding the purpose of cellular respiration.

Group M continued to wrestle with correctly modeling the cellular respiration equation. They did not include ATP as one of the products in their first cellular respiration model (Figure 4.35). ATP is the most important product of cellular respiration, the generation of which could be considered the purpose of cellular respiration.

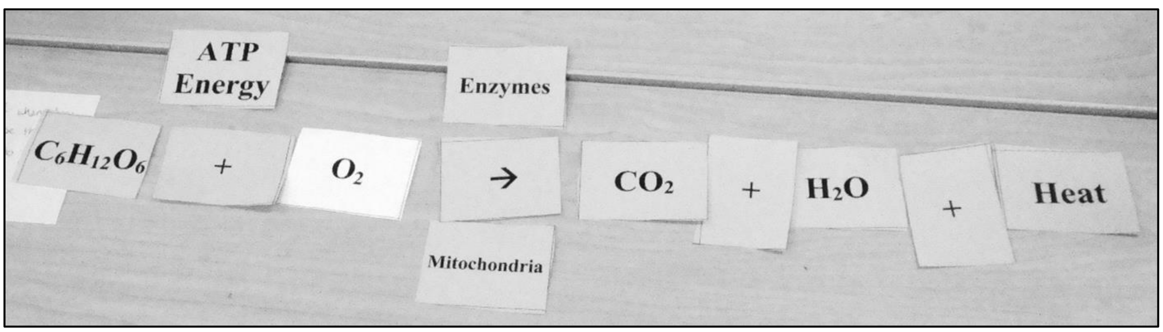

Figure 4.35. Group M's first cellular respiration equation model.

Dr. Pepper approached their table and questioned them to help them recognize their omission and improve their understanding. Dr. Pepper spent a long time with Group M, trying to scaffold their knowledge to a point where they realized that they needed ATP energy as a product. The group remained fairly oblivious to where she was going. Eventually, however, they realized that they needed ATP as a product. They gathered from her promptings that the purpose of cellular respiration was to convert the stored energy of glucose into the chemical energy of ATP, which could drive plant life functions.

The next time the purpose of cellular respiration was discussed, the group wrote down their claim that answered the guiding question, "How and when does a plant use the food it makes to sustain life?" (Cellular Respiration Lesson, 4/15/15). Mari, Macy, and Morgan discussed what should be written, and eventually Macy read aloud their final and accurate statement, correcting herself when she misspoke. Morgan extended the statement to include the purpose.

Macy: How does this first sentence sound? Plants store the glucose, uh, sorry, use the stored glucose. Plants use the stored glucose made from photosynthesis and combine it with oxygen with the enzymes inside the mitochondria.

Morgan: To produce ATP energy for metabolism.

(Cellular Respiration Lesson, 4/15/15)

During the rotations when the groups presented and analyzed the others' claims (Appendix J, Task 5), Macy continued to present this accurate statement. She did not make changes to it. When the rest of Group M returned and had the opportunity to revise their statement, they added in some information about thermodynamics. However, they did not revise their core claim. Despite this, toward the end of the class, it was revealed that Meg's understanding of the purpose of cellular respiration was not yet accurately developed. The following exchange occurred when Dr. Pepper questioned Meg directly about the purpose of cellular respiration.

Dr. Pepper: So, Meg, why do plants respire?

Meg: To get oxygen and carbon dioxide in or out.

Dr. Pepper: And why is that important?

Meg: Because if they don't, they die.

Dr. Pepper: But they need something else rather than just oxygen and carbon dioxide in and out. What else does cellular respiration do for [plants]?

Meg: Providing nutrients (trails off).

Mari: Energy for life functions.

(Cellular Respiration Lesson, 4/15/15)

Meg's answers revealed that even by the end of the class, after hearing her group mates repeatedly discuss the concept correctly, she did not yet understand the purpose of cellular respiration herself. She conflated it with the purpose of photosynthesis (to provide nutrients). It can be argued that she also did not have a clear understanding of the gas exchange that occurred during cellular respiration since she did not specify which gas was absorbed and which released.

ATP energy is a type of stored energy. This alternative conception was closely tied to the previous one. Group M had a general lack of understanding related to ATP energy and its importance as a key product of cellular respiration. Initially, they did not include ATP in their cellular respiration equation at all. Dr. Pepper attempted to scaffold their understanding by prompting them to notice that no energy was being released from their equation as they had it written. The following dialogue occurred in which the participants then decided to include heat as a product but not ATP.

Dr. Pepper: I can see energy stored here, but I don't see energy being released in your equation.

Macy: So would we put like heat?

Mari: Maybe

Morgan: Probably, because nothing else.

(Cellular Respiration Lesson, 4/15/15)

Shortly thereafter Macy inquired whether ATP energy was important. Mari responded incorrectly that ATP was a form of stored energy. However, she was unsure of where in the equation the ATP should be placed. The resulting exchange follows.

Macy: Does [ATP] have anything to do with it?

Morgan: Okay, I read something about that last night, but I still don't know.

Mari: ATP is a form of stored energy that cells use. Like, that's all I know about it.

Morgan: So if it wasn't this, it would be here.

Mari: Maybe ATP would go up above [the product side of the equation] to describe it?

Morgan: But I have no idea.

Mari: I really don't know.

(Cellular Respiration Lesson, 4/15/15)

Next, Dr. Pepper approached Group M's table and questioned them about their model. Her questions were intended to help scaffold their knowledge and encourage them to include ATP energy as a product. The following dialogue occurred starting about halfway into the questioning session.

Dr. Pepper: So where would the food be here? And where would our energy for life be?

Macy: On the other side [of the arrow in the equation].

Dr. Pepper: Okay, where? Where is it? Where would it be?

Macy: You mean, like, where on this it would be? Or, like it'll be over here?

Dr. Pepper: Okay, how can you show that?

Macy: Like a plus sign, and then we could, would it be like nutrients, or minerals, or fats?

Dr. Pepper: Nope, nope.

Macy: Really? Really, none of these?

Dr. Pepper: No.

Macy: I'm so confused.

Dr. Pepper: This would be the same as this.

Macy: Okay, and then these two have nothing to do.

Dr. Pepper: Correct.

Macy: And not light energy. Not soil.

Dr. Pepper: No. And nutrients are not energy. Minerals are not energy.

Macy: Okay, so really?

Dr. Pepper: Oxygen is not energy.

Macy: Okay, it's not the stomata. Okay, so we have an arrow [card].

Mari: Are we missing a card?

Dr. Pepper: You're not missing a card.

Macy: Do I need to move?

Dr. Pepper: Morgan knows.

Morgan: Is it that? You just move that [ATP energy card] right?

Mari: Oh, okay. Scribble, scribble, scribble (Mari moves the card to the products side of the equation).

Macy: Nice.

Morgan: Okay, so it's ATP is what's given off during cellular respiration?

Macy: But you said [ATP] was chemical energy.

Dr. Pepper: It is. It's the chemical energy that your body uses.

Macy: To do things, to function well.

Mari: Okay, that makes sense because to break down the enzymes. That makes sense.

(Cellular Respiration Lesson, 4/15/15)

The above exchange revealed that although Group M had considered ATP important in some way and thus placed it above their reactants in the equation, they were slow to recognize its true position as a key product. They thought of it as another type of stored energy, similar to glucose. The members of Group M offered up suggestions for every other available option (i.e., nutrients, minerals, fats, soil) before finally suggesting ATP as a product of the cellular respiration process. Mari then stated, "I'm so dumb; I should have known that. I feel stupid now" (Cellular Respiration Lesson, 4/15/15). Their correct and final equation model is shown in Figure 4.36. Every other time that ATP was mentioned during the lesson, it was accurately represented in Group M's discussions.

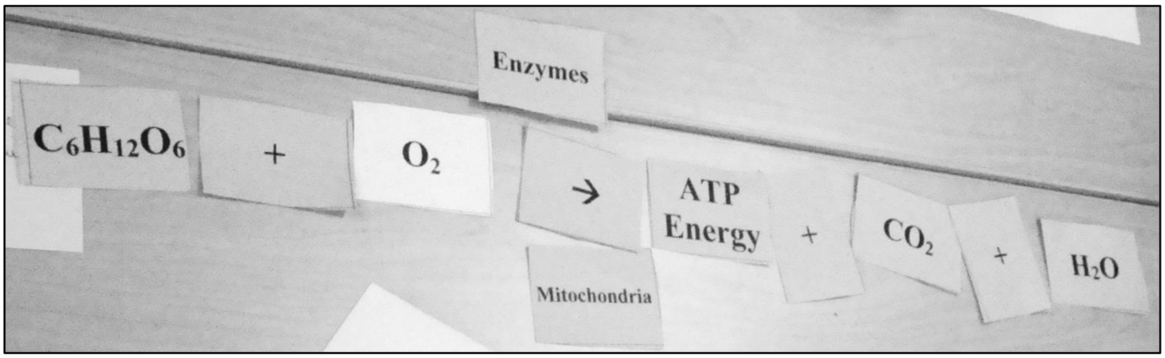

Figure 4.36. Group M's final cellular respiration equation model.

Cellular respiration is the exact reverse of photosynthesis. The last alternative conception that appeared during the cellular respiration lesson was the idea that cellular respiration is the exact reverse, or opposite, of photosynthesis. This naïve idea is plausible, as the gas exchange part of the two equations are the reverse of each other. However, thinking of the two processes as simply opposites obscures the critical purposes of each. This alternative conception appeared two times during the cellular respiration lesson while Group M was attempting to model the equation using the equation component cards (Appendix J, Task 3). The first appearance is recorded below.

Macy: We know CO_2 and water vapor [are released].

Mari: Is that, like, the reverse of (trails off)?

Macy: Photo[synthesis]? Yeah. Maybe.

Mari: Basically. Because, like, you have to have this to help fuel, like, the stored energy.

(Cellular Respiration Lesson, 4/15/15)

Mari's last comment hinted at an accurate conception of the carbon cycle, in which the carbon dioxide created during cellular respiration may be re-used by the plant to create glucose molecules during photosynthesis. She did not explain more, and it is unclear the extent of her correct conception of that idea at that time. However, she agreed that the process was essentially the reverse of photosynthesis. This underdeveloped conception reappeared later when the group was constructing their post-treatment group knowledge structure graphic. The dialogue follows.

Morgan: It's just photosynthesis flipped right?

Mari: Yeah, I think so. I think it's the base.

Macy: But without sunlight.

Mari: Yeah, because this is our energy source, because this has been made now.

(Cellular Respiration Lesson, 4/15/15)

The statements of Mari and Macy suggested they recognized there were differences between the two equations, beyond simply being the reverse. Of all the alternative conceptions discussed by Group M, this one probably had the least negative impact on their understanding of cellular respiration. However, this type of naïve, oversimplified idea should not be discounted. It is simplistic language like this, often used by elementary teachers to make the material more approachable or easier to remember, that can later stand in the way of learners' development of correct and complex conceptions (Zeidler & Lederman, 1989).

Summary. In general, Group M developed their understanding of cellular respiration more easily and smoothly than they did photosynthesis. Mari came into the lesson with the most accurate understanding of cellular respiration, although her understanding was not complete. She correctly extrapolated from evidence and quickly grasped accurate ideas when they were presented. Throughout the lesson, she corrected her fellow group members' alternative conceptions. Mari emerged as a leader of the group during this lesson, and the rest of Group M tended to defer to her judgment and knowledge. The main concept that Mari did not know already or comprehend immediately was ATP and its critical place in the cellular respiration equation. Macy and Morgan were usually quick to follow Mari's correct lead. Meg contributed little to most discussions, and her alternative conceptions persisted even in the face of group correction.

The next section presents the alternative conceptions that were still held individually and collectively by the members of Group M after the completion of the two treatment lessons. The post-treatment results include data collected at two separate times: immediately after the treatment lessons (designated as *post-treatment*) and approximately two weeks later (designated as *delayed post-treatment*). The next section will present the individual-level results at both the post- and delayed post-treatment times. Then the group-level results will be presented. Note that group-level results were collected only at the post-treatment time.

Post-treatment conceptions (individual- and group-level). Following the treatment lessons, Group M's individual and collective group alternative conceptions were identified. A comparison was made between the participants' understanding prior to the treatment lessons. There were two distinct data collection times following the treatment. The post-treatment data collection occurred within a few days of the completion of the cellular respiration lesson and consisted of individual knowledge lists, alternative conceptions survey, group knowledge structures, and group interviews. The delayed post-treatment results were collected approximately two weeks later. These results consisted of the alternative conceptions survey, which participants took for the third and final time.

The upcoming sections are organized as follows. First there will be a presentation of each member's individual alternative conception results at post-treatment, shortly after the treatment lessons ended. These results were taken from the participants' completed post-treatment individual knowledge lists and their responses on the post-treatment alternative conceptions survey. In addition to these post-treatment results, the delayed post-treatment results are shared. These individual-level results consisted of the survey score and alternative conceptions that were identified from the alternative conceptions survey given approximately two weeks after the treatment lessons concluded.

Once the individual-level results are shared for all the Group M members, the group-level results are provided. These collective group alternative conceptions were gleaned from the post-treatment group knowledge structure graphic, the group discussion that occurred during the construction of the knowledge structure graphic, and the post-treatment group interview. No group alternative conceptions were identified at the delayed post-treatment time.

Mari (individual-level). Mari's conceptual understanding of photosynthesis and cellular respiration was positively impacted through engagement in the tasks undertaken during this study. Mari's post-treatment individual knowledge lists contained more information than the ones she completed at the start of the study. Her responses on the post-treatment alternative conceptions survey, taken right after the treatment lessons, were markedly better than those on her pre-treatment survey. Mari scored 57% on the pre-treatment survey, 93% on the post-treatment survey, and 93% on the delayed post-treatment survey.

Mari's post-treatment score was the second highest achieved by any of the members of the group cases. Only Cady, from Group C, scored higher (100%). Mari correctly answered both tier one (main answer) and tier two (reasoning) items for all but one of the 14 survey questions. Mari maintained her correct responses on the delayed post-treatment survey, scoring 92% and again achieving the second highest score among the participants in the three group cases.

A comparison of the number of alternative conceptions that Mari held before, after, and two weeks after the treatment lessons is provided in Figure 4.37. The blue bar denotes how many alternative conceptions were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange on the middle bar indicates alternative conceptions that first appeared after the treatment lessons. Gray indicates any alternative conceptions that were expressed for the first time at the last data collection point two weeks after the lessons ended.

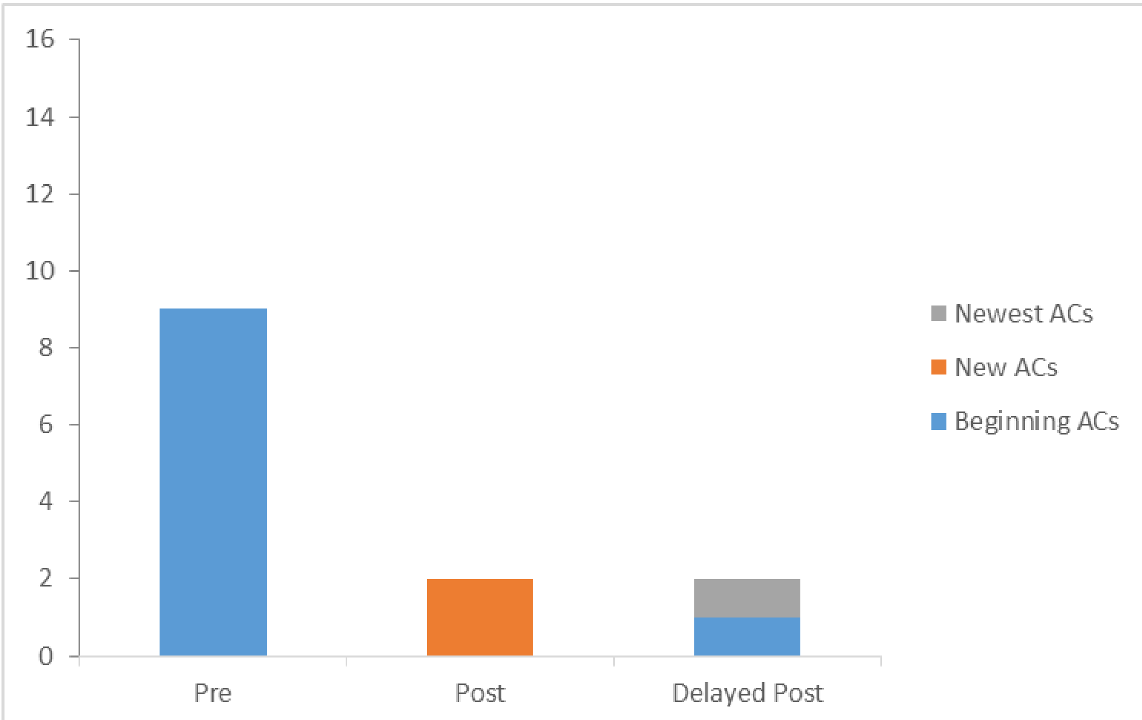

Figure 4.37. Mari's number of alternative conceptions at pre-, post-, and delayed post-treatment (ACs = alternative conceptions).

Mari held nine alternative conceptions prior to the study. Immediately following the treatment lessons, all those alternative conceptions were extinguished and only a few were newly expressed. Two weeks later, Mari's answers on the delayed post-treatment survey indicated that one of her original alternative conceptions had returned and one new one expressed. Mari's conceptual change results were extremely positive. The specific alternative conceptions that were identified in Mari at the three time points are listed in Figure 4.38. Additional narrative in the upcoming paragraphs provides details about Mari's alternative conceptions following the treatment lessons.

Pre-Treatment	Post-Treatment	Delayed Post-Treatment
P timing: occurs all the time in plants		
P oxygen is a waste product, ignoring its importance as a reactant for CR		
P produces energy directly		
CR equation: gas exchange is CO_2 in, O_2 out		
CR equation: water is a reactant		
CR equation: do not recognize energy is a product		CR equation: do not recognize energy is a product
CR timing: only occurs in light/day		
CR purpose: to produce sugar		
CR requires chlorophyll		
	P equation: unspecified energy is a reactant in addition to light	
	P purpose: main benefit to the plant is to remove CO_2 from air	
		CR equation: do not recognize sugar is a reactant
Total: 9	**Total: 2**	**Total: 2**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.38. Mari's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Mari provided greater and more detailed information on her post-treatment individual knowledge list about photosynthesis than on her previous one. There was only one small error in the facts she gave. When Mari reproduced the equation for photosynthesis, she included energy as a reactant along with, but clearly separate from, light. This was inaccurate as there is no input of energy in the process of photosynthesis other than light.

The one question she missed on the post-treatment alternative conceptions survey was about photosynthesis. She responded that the removal of carbon dioxide from the air was the most important benefit of photosynthesis to plants. This response showed a common human-centric alternative conception in which plant processes are viewed primarily in light of their benefits to humans. On the delayed post-treatment survey, Mari correctly answered the item she had missed on the post-treatment survey regarding the most important benefit of photosynthesis to the plant. Thus, all the photosynthesis-based items were answered correctly on the delayed post-treatment survey.

Cellular respiration. Mari's individual knowledge list about cellular respiration did not contain any noticeable alternative conceptions. She included a completely accurate representation of the equation. She also included many details explaining the process of cellular respiration and its relationship to photosynthesis.

Mari correctly answered all items on the post-treatment survey about cellular respiration. Her reasoning for all her answers was also correct. Thus, immediately after the treatment lessons, it seemed that Mari's understanding of cellular respiration was developed and free of alternative conceptions that the survey would diagnose.

Unfortunately, Mari did not reproduce her perfect answers about cellular respiration when she took the delayed post-treatment survey two weeks later. This time she missed the second tier answer on a cellular respiration item that she had answered correctly immediately after the treatment lessons. The item first asked for the cellular respiration equation, which Mari answered correctly. Her choice on the reasoning part, while partially accurate, was not the best reason. This was because it did not include any mention of the most critical part of the process, the derivation of energy from glucose using oxygen.

Morgan (individual-level). Like Mari, Morgan's conceptual understanding of photosynthesis and cellular respiration improved over the course of the treatment. Her post-treatment individual knowledge lists included more details and only one identifiable alternative conception regarding cellular respiration. Morgan's scores on the alternative conceptions survey reflected her increased understanding. She scored 36% on the pre-treatment survey, 79% on the post-treatment survey, and 71% on the delayed post-treatment survey.

A graphical representation of the number of alternative conceptions identified before, immediately after, and two weeks after the treatment lessons is shown in Figure 4.39. This figure shows how many alternative conceptions were revealed at each time point. The blue bar denotes the number of alternative conceptions that were identified before the treatment lessons. Additional blue on later bars indicates the number of those original alternative conceptions that were retained and reappeared immediately after and two weeks after the treatment lessons. Other colored bars would show the emergence of alternative conceptions newly revealed after the lessons; however, they were not needed for Morgan's chart since no new alternative conceptions were expressed at any time after the treatment lessons.

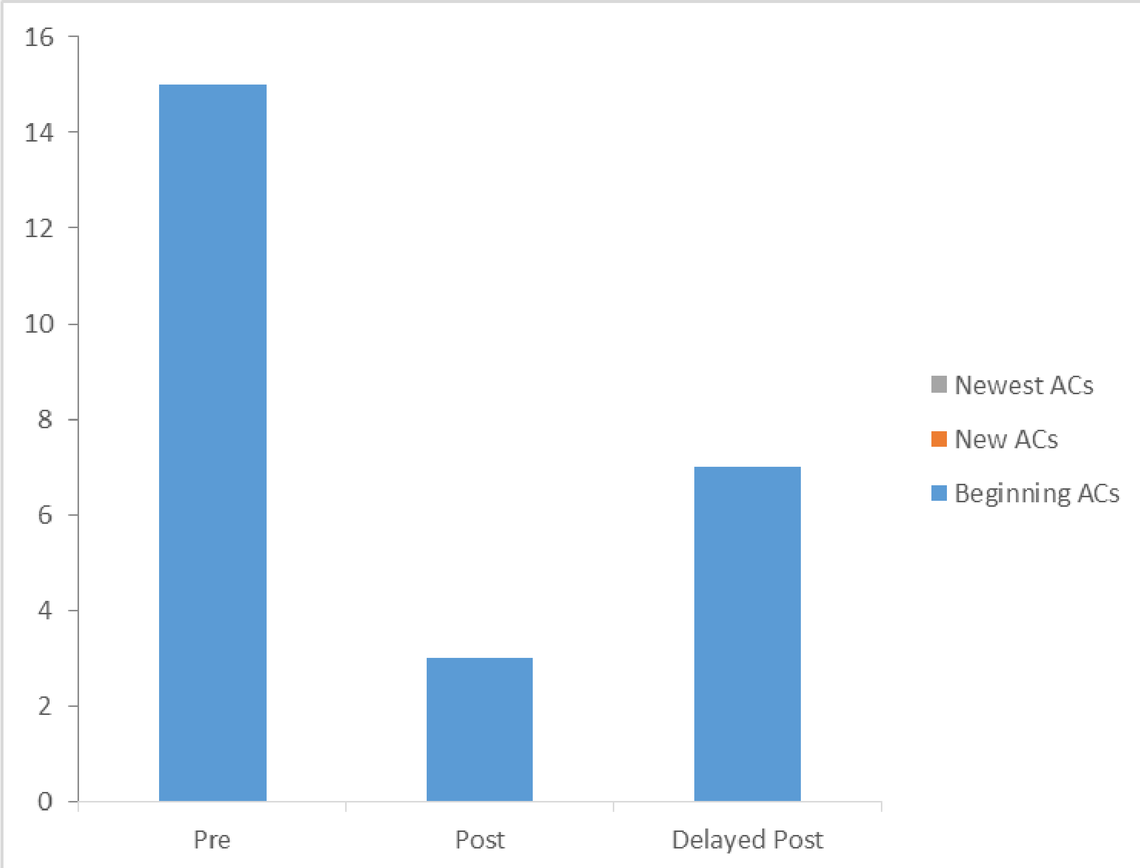

Figure 4.39. Morgan's number of alternative conceptions at pre-, post-, and delayed post-treatment (ACs = alternative conceptions).

Morgan began with a high number of alternative conceptions prior to the study. Those inaccurate ideas were reduced substantially following the treatment lessons. Unlike all the other participants, Morgan did not exhibit any newly expressed alternative conceptions emerging immediately nor two weeks after the treatment lessons. A few more of her original alternative conceptions had started to return, but there was still only half the number identified at the start of the study. The specific alternative conceptions she held are listed in Figure 4.40 and explained in more detail in the following paragraphs.

Pre-Treatment	Post-Treatment	Delayed Post-Treatment
P biomass: originates from soil		
P timing: only occurs in the dark		
P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly		
CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant		
CR equation: do not recognize energy is a product		
CR timing: only occurs in light/day		
CR timing: only occurs in dark/night		CR timing: only occurs in dark/night
CR timing: only occurs when P is not happening		CR timing: only occurs when P is not happening
CR purpose: simply to exchange CO_2 and O_2		
CR purpose: to provide energy when P is not occurring or has not made enough energy	CR purpose: to provide energy when P is not occurring or has not made enough energy	CR purpose: to provide energy when P is not occurring or has not made enough energy
CR purpose: to produce sugar		CR purpose: to produce sugar
CR requires chlorophyll		
CR animals do CR because they cannot do P		CR animals do CR because they cannot do P
Total: 15	**Total: 3**	**Total: 7**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.40. Morgan's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Morgan's post-treatment individual knowledge list about photosynthesis was much more detailed than her pre-treatment one. There were no alternative conceptions evident in what she wrote. Morgan included an accurate equation for photosynthesis as well as correct details describing the process.

On the post-treatment alternative conceptions survey, Morgan answered four of the photosynthesis-based items correctly that she had missed on the pre-treatment survey. For instance, Morgan correctly identified the main source of a plant's biomass and identified the correct gases that were exchanged during photosynthesis. There was only one item that was partially about photosynthesis, which Morgan answered incorrectly on the post-treatment survey. She answered the first part of the item correctly (tier one), identifying oxygen as the gas given out the most by plants in the presence of sunlight. However, her tier two (reasoning) answer was incorrect, as she chose the response that indicated oxygen was a total waste product and ignored the better response that acknowledged some oxygen was used in cellular respiration.

Morgan's response on the delayed post-treatment survey regarding photosynthesis remained quite accurate as she answered most items the same as she did on her post-treatment alternative survey. There were two items regarding photosynthesis that she answered partially incorrectly. Morgan maintained her incorrect reasoning answer to the item about how oxygen is released during photosynthesis. On the delayed post-treatment survey she also reverted to an incorrect reasoning response originally given on the pre-treatment survey for why photosynthesis takes place in the presence of light and cellular respiration occurs at all times. On both the pre- and delayed post-treatment (but not on the post-treatment), Morgan chose the answer that indicated plants respire when they cannot obtain enough energy from photosynthesis and animals respire continuously since they do not do photosynthesis. This answer represented a naïve conception and conflicted with her correct answer on the first part of the item.

Cellular respiration. Unlike her photosynthesis individual knowledge list, her cellular respiration list did contain an alternative conception. She wrote, “Plants use cellular respiration when no light is present to sustain life” (Post-Treatment Individual Knowledge list, 4/17/15). Thus, after the treatment lessons, Morgan correctly recognized that cellular respiration did not require light to occur, yet inherent in her statement was the alternative conception that it *only* occurred in the absence of light.

Morgan’s post-treatment alternative conception survey contained more accurate responses regarding cellular respiration than did her pre-treatment survey. One of her correct answers on the post-treatment survey completely contradicted the incorrect concept she had written on her individual knowledge list regarding when cellular respiration occurs. Although Morgan correctly answered more items about cellular respiration following the treatment, she continued in her incorrect understanding of the gas exchange that occurs during the process. She answered that carbon dioxide was taken in and oxygen released in large amounts when there was no light energy present (thus, during cellular respiration). Her reasoning responses were correct on those items.

On the delayed post-treatment survey, Morgan showed that her understanding of cellular respiration also remained a mix of accurate and alternative conceptions. Morgan again did not choose the correct gas that was taken in during cellular respiration, although she did choose the correct gas that was released. She also reverted to an incorrect answer she gave on the pre-treatment survey but not on the post-treatment survey regarding the most accurate statement provided about cellular respiration. Morgan answered that it is a chemical process, which manufactures food. This is an accurate statement about photosynthesis not cellular respiration.

Meg (individual-level). Meg's conceptual understanding of photosynthesis and cellular respiration following the treatment showed the least amount of improvement in Group M. Her post-treatment individual knowledge lists contained more information than her pre-treatment list. However, alternative conceptions were evident regarding both topics.

Meg scored 50% on the pre-treatment alternative conceptions survey. This was the second highest pre-treatment score in her group. Unfortunately, Meg's post- and delayed post-treatment scores did not improve meaningfully following the treatment. Meg earned 50% on the post-treatment survey and 57% on the delayed post-treatment survey. It should be noted that although Meg earned the same score on both the pre- and post-treatment surveys, her individual answers varied on each.

The number of alternative conceptions evident in Meg before, after, and two weeks after the treatment lessons are shown in graphical form in Figure 4.41. The first blue bar shows how many alternative conceptions were apparent before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange on the middle bar indicates alternative conceptions that first appeared after the treatment lessons. Orange on the last bar shows the number of those alternative conceptions retained two weeks after the treatment lessons. Gray indicates any alternative conceptions that were expressed for the first time at the last data collection point two weeks after the lessons ended.

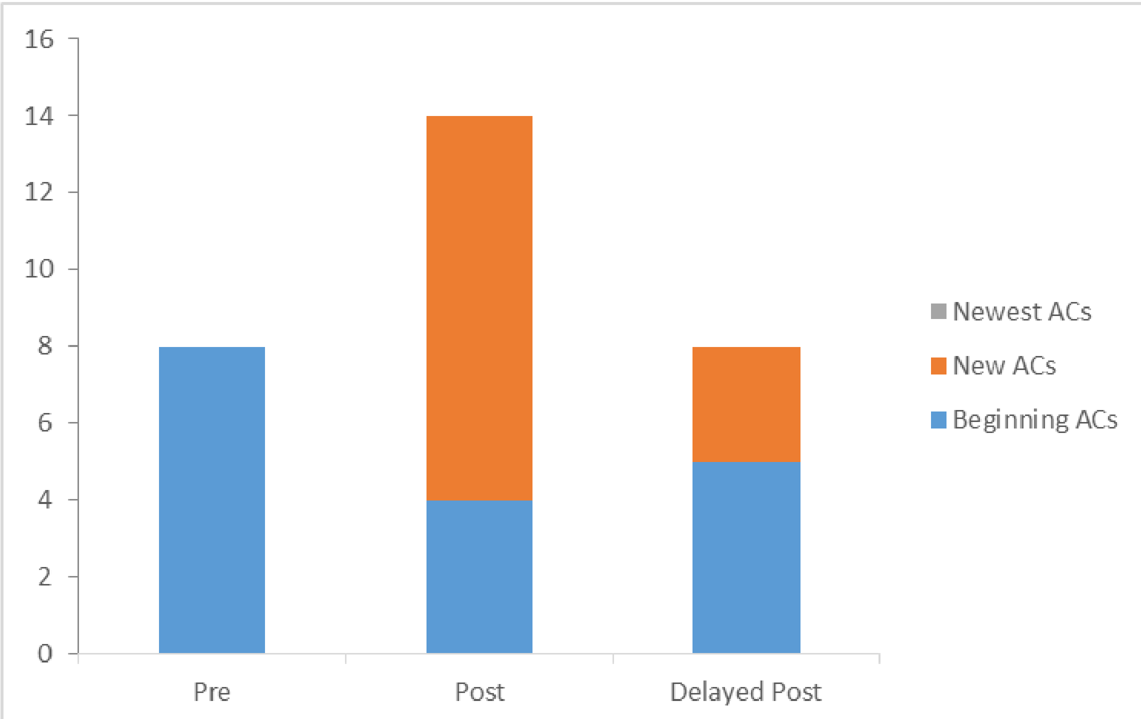

Figure 4.41. Meg's number of alternative conceptions at pre-, post-, and delayed post-treatment (ACs = alternative conceptions).

Meg began with few alternative conceptions identified prior to the study. In contrast to the results of her group members, Meg's alternative conceptions greatly increased following the treatment lessons. Many of her original alternative conceptions had disappeared, yet she expressed a large number that she had not revealed before. On the delayed post-treatment survey two weeks later, Meg's results showed that a few more of her original alternative conceptions had returned. Happily, though, a large number of the ones she had newly exhibited at the time of the post-treatment survey had disappeared. The following figure (Figure 4.42) lists the specific alternative conceptions held by Meg. The following paragraphs provide more details about Meg’s conceptual understanding immediately after and two weeks after the treatment lessons.

Pre-Treatment	**Post-Treatment**	**Delayed Post-Treatment**
Identified from pre-treatment alternative conceptions survey and pre-treatment individual knowledge list	**Identified from post-treatment alternative conceptions survey and post-treatment individual knowledge list**	**Identified from delayed post-treatment alternative conceptions survey**
P timing: light not required		
P equation: chlorophyll is a reactant		
P equation: unspecified energy is a reactant		P equation: unspecified energy is a reactant
P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly		
CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant	CR equation: water is a reactant	CR equation: water is a reactant
CR purpose: to produce sugar	CR purpose: to produce sugar	CR purpose: to produce sugar
	P biomass: originates in water	
	P equation: gas exchange is O_2 in, CO_2 out	
	P equation: sugar is a reactant	
	P chlorophyll is not required	P chlorophyll is not required
	P sugar may be "given off" after produced	
	CR equation: do not recognize energy is a product	CR equation: do not recognize energy is a product
	CR timing: only occurs in light/day	
	CR purpose: simply to exchange CO_2 and O_2	CR purpose: simply to exchange CO_2 and O_2
	CR requires chlorophyll	
	CR gas exchange varies: plants respire O_2, but animals respire CO_2	
Total: 8	**Total: 14**	**Total: 8**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.42. Meg's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Meg's post-treatment individual knowledge list on photosynthesis included three accurate bullet points. This was more than she wrote on her pre-treatment survey, which consisted of only one concept. In addition to the accurate conceptions, there were alternative conceptions still present.

Some of the alternative conceptions regarding photosynthesis that were evident in Meg's responses on the post-treatment survey included an incorrect understanding of the equation, the idea that oxygen was a complete waste product (discounting its importance for cellular respiration), and the idea that the amount of oxygen in the ambient air is an important factor in the process. Additionally, Meg changed from a correct answer on the pre-treatment survey to an incorrect answer on the post-treatment survey, stating that the main biomass of a plant originates from water.

Meg's responses on the delayed post-treatment survey remained similar to her post-treatment survey. She answered nearly all the items exactly as she did on the post-treatment survey, with only minor variations on three of them. Only one of those variations resulted in a correct response on both tiers of the item. In that case, Meg correctly chose the best reasoning answer regarding the release of oxygen during photosynthesis, acknowledging its usage in the process of cellular respiration. Otherwise, the alternative conceptions evident in Meg's responses on the post-treatment survey remained evident in her responses on the delayed post-treatment survey.

Cellular respiration. Meg's post-treatment individual knowledge list also showed a meaningful improvement in her knowledge growth regarding cellular respiration. Her pre-treatment list included just one word, "Mitochondria" (Meg, Pre-Treatment Individual Knowledge List, 4/10/15). In contrast, her post-treatment list included six bullet points of information, four of which were completely accurate. The last two bullet points were written in such a way as to make her true meaning unclear. Meg wrote, “Plants respire oxygen. Animals and humans respire CO_2” (Meg, Post-Treatment Individual Knowledge List, 4/17/15). Oxygen is a reactant in the process of cellular respiration in plants, animals, and humans. Meg may have been confusing cellular respiration with physical respiration. This statement may also reveal that she had maintained a common and deeply held alternative conception that the process that causes humans to give off carbon dioxide is the same process that causes plants to give off oxygen. The reality is more complex than that naïve idea. Plants release oxygen due to the process of photosynthesis, which is a process that does not occur in humans. Humans and plants both release carbon dioxide as they engage in the process of cellular respiration.

Although Meg’s individual knowledge list showed evidence of conceptual improvement regarding some aspects of cellular respiration, her responses on the post-treatment alternative conceptions survey revealed her retention of alternative conceptions throughout the treatment lessons. Meg did not identify the correct equation for cellular respiration. She consistently answered incorrectly that carbon dioxide was absorbed and oxygen released when there is no light energy present (thus, during cellular respiration). She had demonstrated on her individual knowledge list that she correctly understood cellular respiration occurred even without light energy and that it is photosynthesis that occurs in the light. Meg was unable to identify the most accurate statement about cellular respiration, choosing, “It is the exchange of carbon dioxide and oxygen gases” (Haslam & Treagust, 1987) over the better response of, “It is a chemical process in which energy stored in food is released using oxygen" (Haslam & Treagust, 1987). This revealed further evidence that her conception of the purpose of cellular respiration was flawed.

Meg's responses about cellular respiration on the delayed post-treatment survey were relatively consistent with how she had answered immediately after the treatment lessons. One response regarding oxygen release during photosynthesis was answered correctly, acknowledging the role of oxygen absorption in cellular respiration. However, all the other incorrect items on the post-treatment survey remained incorrect on the delayed post-treatment survey.

Macy (individual-level). Macy grew in her understanding of photosynthesis and cellular respiration as evidenced by her post-treatment individual knowledge lists and her alternative conceptions survey scores. Macy's post-treatment individual knowledge lists contained more details, all of which were accurate. Her alternative conception survey scores showed improvement as well. Macy scored 36% on the pre-treatment survey, 50% on the post-treatment survey, and 71% on the delayed post-treatment survey.

The number of alternative conceptions identified in Macy before, after, and two weeks after the treatment lessons is shown in Figure 4.43. The various colors indicate which alternative conceptions were revealed at each time point. The blue bar denotes how many alternative conceptions were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange on the middle bar indicates alternative conceptions that first appeared after the treatment lessons. No newly expressed alternative conceptions were exhibited by Macy two weeks after the treatment lessons.

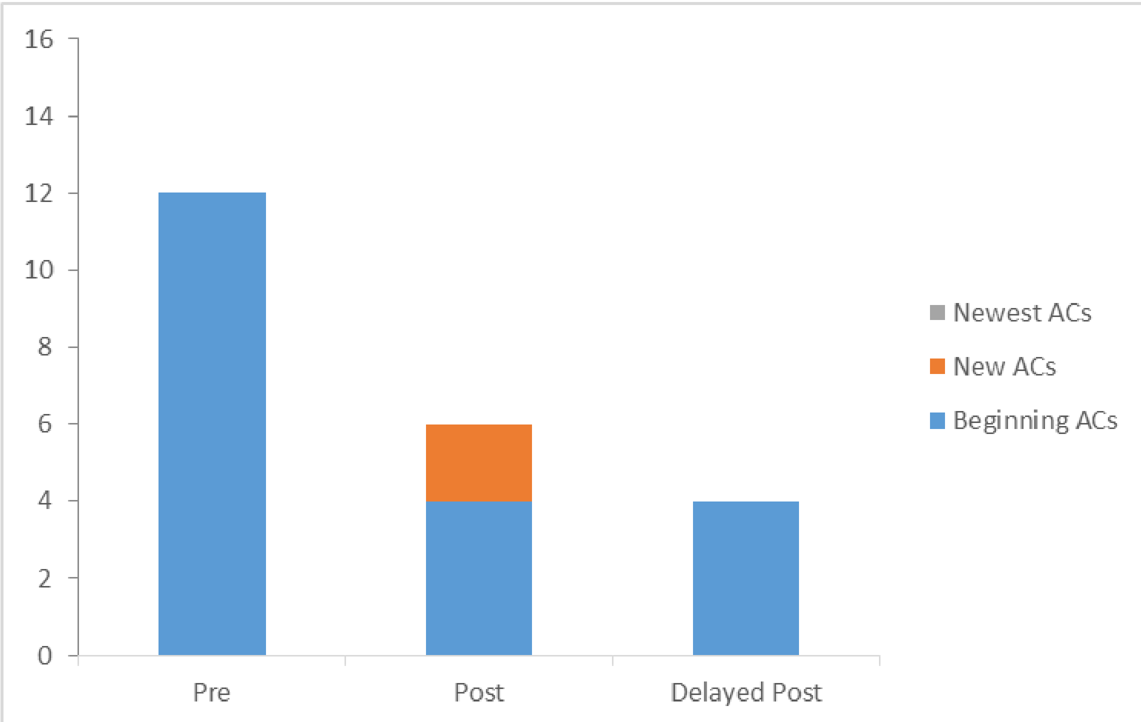

Figure 4.43. Macy's number of alternative conceptions at pre-, post-, and delayed post-treatment (ACs = alternative conceptions).

Twelve alternative conceptions were exhibited by Macy prior to the study. Similar to Mari, Macy's conceptions improved noticeably as the number of her alternative conceptions were reduced by half. At that time, she exhibited two newly identified alternative conceptions. On the delayed post-treatment survey, two weeks later, those had disappeared and about the same number of original alternative conceptions remained as had been identified on the post-treatment survey. Those alternative conceptions persisted in her thinking. Specific details regarding Macy's conceptual understanding as revealed on her post-treatment individual knowledge lists and alternative conceptions surveys follow. A list of all the alternative conceptions identified in Macy before, after, and two weeks after the treatment lessons can be found in Figure 4.44.

Pre-Treatment	**Post-Treatment**	**Delayed Post-Treatment**
Identified from pre-treatment alternative conceptions survey and pre-treatment individual knowledge list	**Identified from post-treatment alternative conceptions survey and post-treatment individual knowledge list**	**Identified from delayed post-treatment alternative conceptions survey**
P timing: occurs all the time in plants		
P equation: gas exchange is O_2 in, CO_2 out		
P equation: turns sunlight directly into sugar		
P equation: unspecified energy is a reactant		
P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly	P produces energy directly	P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant		
CR purpose: to produce sugar	CR purpose: to produce sugar	CR purpose: to produce sugar
CR location: occurs only in leaf cells		
CR only leaves have pores/stomata		
CR related to exercising (in humans)		
	P biomass: originates from O_2	
	P equation: chlorophyll is a reactant	
Total: 12	**Total: 6**	**Total: 4**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.44. Macy's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Macy's post-treatment individual knowledge list about photosynthesis was detailed and all the information she wrote was accurate. She included the correct equation as well as a description that provided more details about the process.

Macy's growth in understanding was clearly evident since her pre-treatment individual knowledge list contained much less information as well as incorrect details.

Macy answered a few items about photosynthesis more accurately on the post-treatment alternative conceptions survey as compared to her pre-treatment survey. For instance, she correctly identified the photosynthesis equation and selected a better reasoning (tier two) answer as to why a plant takes in carbon dioxide during photosynthesis. She did not correct her alternative conceptions regarding other photosynthesis concepts. For instance, Macy again incorrectly answered that the most important benefit to plants when they photosynthesize is the production of energy, rather than the correct answer that it is the conversion of light energy to chemical energy. She also persisted in her inaccurate conception that oxygen was simply a waste product of photosynthesis without acknowledging its connection to cellular respiration. Notably, Macy also changed her answer to an incorrect one regarding the biomass item. She had correctly answered *carbon dioxide* was the main source of a plant's biomass on her pre-treatment alternative conceptions survey. However, on the post-treatment survey she changed to an incorrect answer, *oxygen*. Macy still recognized that a plant's mass was being assembled from molecules in the air, not from soil or water, but her experiences during the treatment lesson resulted in creating an alternative conception rather than solidifying an accurate one.

Macy's score on the delayed post-treatment survey increased noticeably over her score immediately after the treatment lessons (50% and 71%, respectively). This change from post- to delayed post-treatment was a pattern not observed in her group mates whose scores changed little. Macy maintained previous correct answers about photosynthesis conceptions and had more incidences of identifying the accurate reasoning for those correct responses. She also selected the correct answer and reasoning as to the source of a plant's biomass, reverting to carbon dioxide. This was what she had originally answered on the pre-treatment survey. Alternative conceptions about photosynthesis that remained included persistence in the idea that oxygen is simply a waste product of the process and the most important benefit is the production of energy.

Cellular respiration. Like her post-treatment individual knowledge list on photosynthesis, Macy's cellular respiration information was much more detailed than her pre-treatment individual knowledge list. All of the details were accurate and no alternative conceptions were evident in what she wrote. Macy included a correct depiction of the cellular respiration equation and details that expanded on the process and its purpose.

Macy's responses on the post-treatment survey also revealed notable growth in her conceptual understanding of cellular respiration. On the post-treatment survey, she correctly identified the cellular respiration equation, the reasoning for it, and identified where cellular respiration occurs and why. Both of those items changed from completely incorrect on the pre-treatment survey to completely correct on the post-treatment survey. Oddly, Macy failed to correctly answer items that asked which gas was given off in large amounts when there was no light energy and which gas was taken in under the same conditions. Although she recognized the equation for cellular respiration in another item, which clearly showed that carbon dioxide is released and oxygen absorbed, she could not translate that understanding to these items. Macy also did not recognize that cellular respiration was a process that released energy from stored sugar. This was consistent with her naïve alternative conceptions that photosynthesis simply creates energy and lack of clarity as to the purpose of cellular respiration. She did not hold the more sophisticated and nuanced understanding that photosynthesis converts light energy to stored chemical energy, and then cellular respiration converts that stored chemical energy to usable ATP energy.

Regarding cellular respiration, Macy again did better on the delayed post-treatment survey. She correctly identified the cellular respiration equation and this time she correctly answered the item that specifically asked about which gas was given off during that process. Strangely, however, she did not correctly answer the item that specifically asked about which gas was taken in during cellular respiration. Another alternative conception that persisted was Macy's inability to distinguish that the main purpose of cellular respiration was converting stored energy to usable energy.

Group M (individual-level). As detailed in the preceding sections, most members of Group M increased in their individual conceptual understanding of photosynthesis and cellular respiration. A summary of their individual scores on the pre-, post-, and delayed post-treatment alternative conceptions survey provides a useful overview of their individual conceptual changes during the course of the study. Figure 4.45 provides a comparison of all of Group M members' scores.

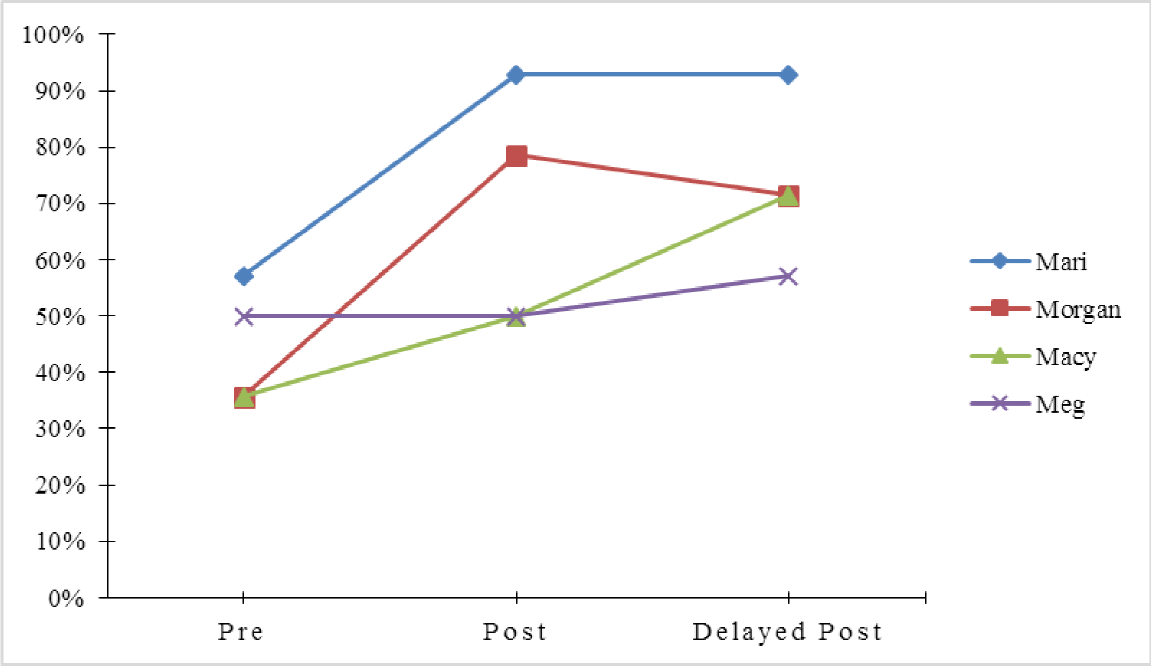

Figure 4.45. Comparison of Group M members' scores on alternative conceptions survey at pre-, post-, and delayed post-treatment. Higher scores indicated more accurate conceptual understanding.

All members of Group M began with low scores on the pre-treatment survey, indicating their baseline knowledge of photosynthesis and cellular respiration was limited and included alternative conceptions. Mari and Morgan showed the most increase in growth in their scores from the pre- to the post-treatment. Morgan's score dropped a little on the delayed post-treatment survey, but Mari maintained her gains. Macy's scores increased from the pre- to the post-treatment and then again on the delayed post-treatment. Mari, Morgan, and Macy all ended the study with scores above 70%, a percentage typically associated with a passing score. Only Meg showed essentially no growth over the course of the study. Meg's highest score, attained on the delayed post-treatment survey, was 57%, which is below a typical passing level.

Group M (group-level). The collective group-level alternative conceptions of Group M following the treatment lessons will be discussed in the upcoming paragraphs. Although individual members of the group held certain alternative conceptions as outlined in the previous paragraphs, they did not always appear within the group as a whole. Therefore it was important to identify what alternative conceptions were persistent and prominent enough to be mentioned and accepted by the entire group. Group M's collective changes in conceptual understanding were identified from the following three data sources: the post-treatment group knowledge structure graphic, the group discussion that occurred while creating the knowledge structure graphic, and the post-treatment group interview.

It is evident that Group M's conceptual understanding of photosynthesis and cellular respiration was more extensive and more detailed following the treatment lessons (Figure 4.46). Most of the original, correct conceptions on the pre-treatment knowledge structure graphic were also included on the post-treatment knowledge structure graphic, but they were much more detailed and elaborate than before. In addition, multiple newly expressed accurate concepts were included. No clear, foundational alternative conceptions could be identified on the knowledge structure graphic.

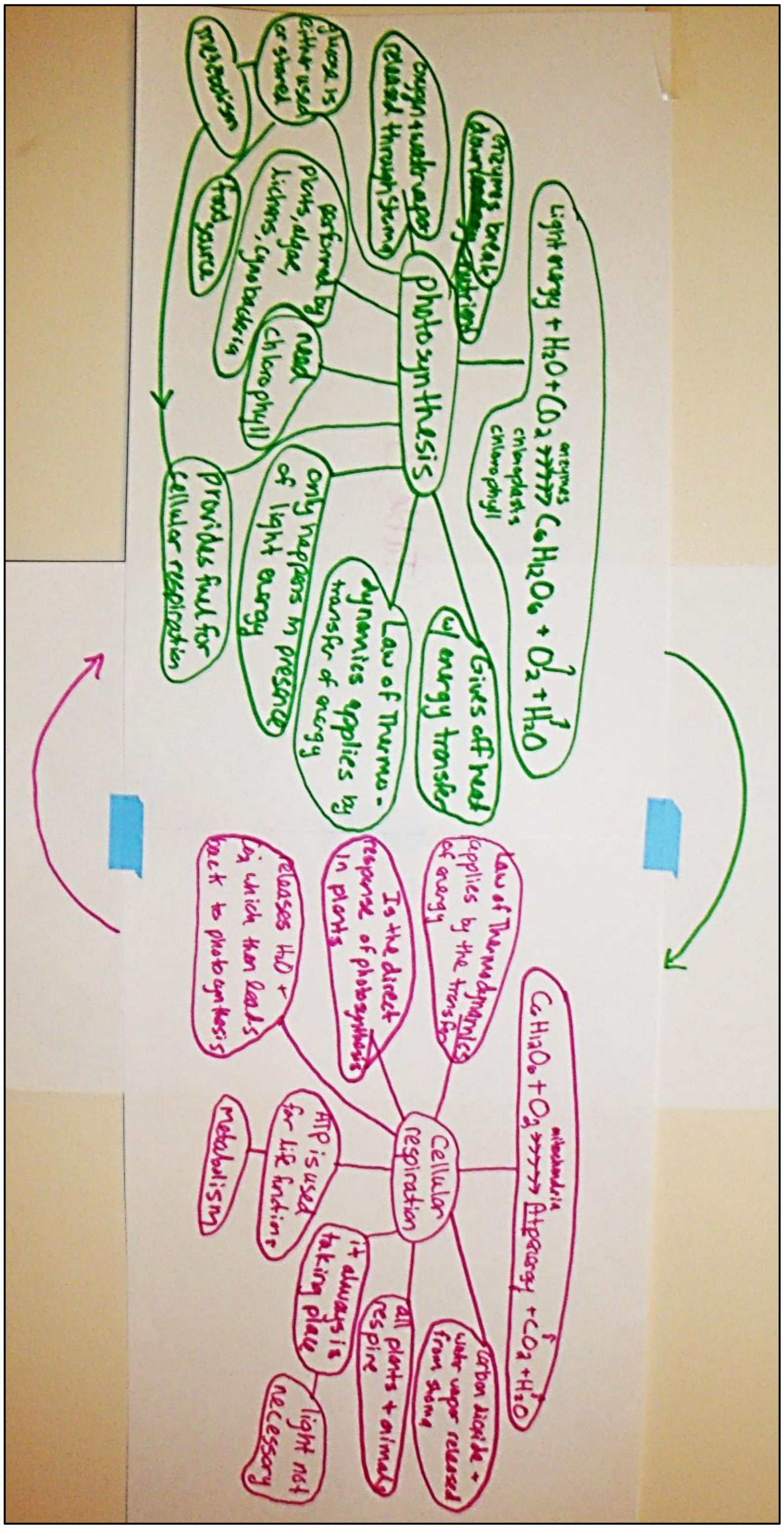

Figure 4.46. Group M’s post-treatment knowledge structure graphic.

Figure 4.47 provides a list of all the alternative conceptions that were identified collectively in Group M before, during, and after the argumentative discourse-based lessons. Only one alternative conception was revealed prior to the treatment lessons. During the lessons, seven more newly expressed alternative conceptions were revealed. Group M's collective understanding was clearly more extensive than prior to the treatment. For example, during the post-interview they spoke enthusiastically and confidently about the large amount of information on their post-treatment knowledge structure graphic. As stated before, there were no clear alternative conceptions included on the graphic or identified during the group's discussion as they created the graphic.

Pre-Treatment	During	Post-Treatment
Identified from pre-treatment group knowledge structure, pre-treatment discussion, and pre-treatment interview	**Identified from photosynthesis and cellular respiration lesson discussions**	**Identified from post-treatment group knowledge structure, post-treatment discussion, and post-treatment interview**
P produces energy directly		
	P biomass: originates from multiple sources (e.g., soil, water, air, sun)	
	P biomass: originates from soil	
	CR and P equations: exact reverse/opposite of each other	
	CR purpose: simply to exchange CO_2 and O_2	
	CR purpose: to provide energy when P is not occurring or has not made enough energy	
	CR purpose: to store sugar	
	CR ATP energy is a type of stored energy	
		P biomass: originates from O_2
		CR similar to physical respiration in animals; plants do CR, but animals breathe
Total: 1	**Total: 7**	**Total: 2**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.47. Group M's alternative conceptions at pre-, during, and post-treatment.

During the post-interview, however, two alternative conceptions were revealed: cellular respiration and physical respiration are analogous processes and a plant's biomass originates mainly from a source such as oxygen or something other than carbon dioxide in the air. These alternative conceptions were not held strongly, and there was evidence that some group members had more accurate conceptions than others. However, in general, the group expressed a lack of confidence in their understanding related to these two concepts. They also made various incorrect statements that supported the supposition that their conceptions were not completely aligned with accepted scientific thought.

Cellular respiration and physical respiration are analogous processes. The fact that Group M was not collectively certain regarding how the process of cellular respiration differed from that of physical respiration was not immediately apparent during the interview. The following exchange illustrates how early in the discussion, Macy explained the purpose of cellular respiration in a vague, but ostensibly correct way. Then, with probing, she revealed her lack of confidence and lack of clarity of understanding in exactly how it related to and differed from physical breathing. Mari had the most accurate conception, although her explanation fell short of clearly delineating the purpose and differences of each process in detail.

Macy: And now I know why we respire and it's for like metabolism, which is every life function. So of course we can't apply [photosynthesis] to people or any animals or anything that's not a plant.

Researcher: Right, but do animals do [cellular respiration]?

Group M: Yes.

Researcher: Okay, and what is the purpose of cellular respiration in plants and in animals? What is its purpose?

Mari: To support life and fuel our cells.

Macy: And our metabolism for all life functions. If we didn't respire we wouldn't be living.

Researcher: Okay. So, also, if I quit breathing I wouldn't be living. Are you saying physical respiration and cellular respiration are the same or are they different?

Macy: They're, well, I don't know how to answer that.

Mari: Well, with physical respiration, you are taking in the air, so you're taking in the oxygen which in turn goes through your bloodstream, is redistributed throughout the bloodstream, the cells, the organs, and then cellular respiration takes place from that if my understanding of the process is right.

Researcher: Okay. So they're different but they're connected?

Mari: Yeah. Physical respiration is the big picture, and cellular respiration is like the little things that make the physical respiration, you know, meaningful I guess, kind of. Because if your cells didn't do that, then physical respiration you'd just be breathing and no living cells and you'd still be dead.

(Post-Treatment Interview, 4/17/15)

Unfortunately, I did not probe further, nor require Morgan and Meg to explain their understanding of cellular respiration and how it differed from physical respiration. I assumed that their understanding was similar to Macy's. Judging from her behavior during the lessons, Morgan was likely to speak up if her understanding differed from what was being said by the group. Meg tended not to speak at all unless expressly requested to do so. She appeared to agree with the ideas proposed by her group members and rarely, if ever, expressed any opinion or observation different from the prevailing one.

A plant's biomass originates mainly from oxygen. The second alternative conception expressed by Group M members during the interview concerned their continued challenge in confidently and accurately identifying the main source of a plant's biomass. When probed, Mari gave the correct answer, but she expressed no confidence in it. Morgan also was unsure.

Mari: I kind of think I might remember but that lesson was just so (pause). Not really, I don't know, I feel like the information wasn't related enough because we didn't have the prior knowledge to apply the information properly. So because I want to say it's from the carbon dioxide in it, but I can't remember exactly (trails off).

Morgan: Um, go ahead, sorry.

Mari: Go ahead.

Morgan: Okay, today I thought I got it, because I thought it came from [$C_6H_{12}O_6$], but it came from [$C_6H_{12}O_6$] in that it produces carbon dioxide. And then I kind of got confused. So I don't think I really, like, understand it enough to, like, I can be like, it's definitely this. And I agree, I think when we had that lesson we were all like how does this all connect? What, what are we looking for? So, you know.

Mari: Okay, because when we talked about it with like animals or trees and stuff like that, like in the wide sense when we were just focusing on, yeah, you just dehydrate it, that was simple. Now that we're getting more in-depth, I feel like we seriously had a lack of proper knowledge and education given before we went into the thing.

(Post-Treatment Group Interview, 4/17/15)

When I asked Macy what her answer would be to the biomass question, she also gave a waffling response. Macy was sure she had heard Dr. Pepper say it came from oxygen and she trusted that false memory. Mari also added that the biomass might be from gases, but she was not confident in that answer. Their responses are recorded below.

Macy: Okay, so I answered oxygen on the prompt you passed out during lecture, but, that's because, like, I swear the other day Dr. Pepper was like, "It's crazy, plants come from oxygen!" I just kept hearing her voice saying that, but like, why doesn't it also come from CO_2? Like why are CO_2 and oxygen both nutrients?

Researcher: Right.

Macy: I don't know, yeah. That's where I'm a little I know it's not from water and I know it's not from soil.

Mari: Part of me keeps hearing gases, like it comes from gases, in my head, like the CO_2 and O_2 gas like I don't know.

Macy: But I'm remembering Dr. Pepper's voice for some reason, that's how I remember her lecture stuff best, I just remember her voice, so I'm just remembering oxygen, but part of me also thinks, uh, CO_2.

(Post-Treatment Group Interview, 4/17/15).

Following this, I asked Meg to explain what her answer would be to the biomass question. She said, "Nah, um, I know it's not like more water and stuff because you can take the water out, but other than that, I'm not sure" (Post-Treatment Group Interview, 4/17/15). Meg's answer revealed she understood that water does not contribute substantively to biomass since biomass is calculated after drying out the plant. However, she did not rule out any of the other two incorrect options, nor mention the correct answer of carbon dioxide.

Then Morgan asked, "Can you tell us where it comes from?" (Post-Treatment Group Interview, 4/17/15). I proceeded to give a brief explanation and question the group as I sought to scaffold their understanding. We discussed how Dr. Pepper said that the biomass came from air (one of the original options), but that she never said it came from oxygen. I explained how the carbon molecule is a large molecule and that it contributes mainly to the sugar molecule, from which the plant stores and builds its biomass. The explanation finally made sense to Macy and Morgan, and Mari began making new connections to her prior knowledge. The dialogue follows.

Mari: See, now it makes sense.

Morgan: It's kind of amazing.

Macy: Yeah, that's really awesome.

Researcher: Yeah, it's really an amazing process.

Macy: That was my, what I wrote most on Monday was how, like, I kind of get the concept, but for me it's still just unfathomable. And now it's fathomable for me.

Researcher: Cool.

Macy: Like a tree coming from that.

Researcher: Yeah, so yeah, sometimes you kind of need that tie up definitely.

Mari: And now you, like, now I know this is kind of unrelated, but now I understand why carbon dating is so accurate, because when you look at it and you think in the terms of we're, you know, made of carbon so much more than anything else, that makes more sense to see the deterioration of the carbon over any of the other molecules. Because I always wondered why that specific one.

(Post-Treatment Group Interview, 4/17/15)

Meg did not contribute to the conversation, so it was unclear if the explanation had impacted her conceptual understanding in any way. In considering their answers on the pre-treatment alternative conceptions survey, before the treatment lessons, Mari, Macy, and Meg correctly answered that carbon dioxide was the main source of a plant's biomass. Immediately after the lessons and before the post-treatment interview discussion outlined above, only Mari and Morgan correctly answered carbon dioxide. Then, two weeks after the post-treatment interview discussion, all members of Group M answered the question about biomass correctly.

The previous sections have presented the detailed results of the alternative conceptions that were identified both individually and collectively in Group M members before, during, and after the treatment lessons. By providing these results, a picture of the participants' changes in conceptual understanding emerged. The next section will present the results of the group's argumentation quality during the photosynthesis lesson.

Argumentation Quality of Group M

It is important to understand the quality of Group M's argumentation during the lessons. Understanding their level of sophistication in scientific argumentation was critical to evaluating the research question, even if it did not answer it directly. The conceptual changes that occurred, or did not occur, may have been influenced by the quality of the group's discourse around developing and defending arguments from evidence.

The presentation of these results is divided into two parts. The conceptual and cognitive aspects of the group's scientific argumentation will be discussed first, followed by their epistemic aspects. Each part will begin with the group's scores on that part of the protocol for the photosynthesis lesson. Narrative with quotations will provide support for the observation protocol scores.

Conceptual and cognitive aspects. This section of the observation protocol evaluated how effective the group was in negotiating meaning among themselves and developing their collective understanding. One of the main goals of quality scientific argumentation is to positively impact the participants' conceptual knowledge of the scientific content. The presence or absence of certain aspects of their collaborative and argumentative discourse are posited to support the development of their knowledge and lead to more and better conceptual change. The scores of Group M on the conceptual and cognitive aspects of scientific argumentation are shown in Figure 4.48. Each item was scored from zero to three, with higher scores indicating better quality of argumentation and group performance that is more sophisticated. A total of 21 points was possible on the conceptual and cognitive aspects section.

Conceptual and Cognitive Items	**Score**
1. The talk of the group was focused on solving a problem or advancing understanding.	2
2. The participants sought out and discussed alternative claims or explanations.	1
3. The participants modified their explanation or claim when they noticed an inconsistency or discovered anomalous data.	1
4. The participants were skeptical of ideas and information.	1
5. The participants provided reasons when supporting or challenging an idea.	1
6. The participants based their decisions or ideas on inappropriate reasoning strategies (reverse scored).	3
7. The participants attempted to evaluate the merits of each alternative claim or explanation in a systematic manner.	1
Total	**10**
Percent	**48%**

Figure 4.48. Group M's scores on conceptual and cognitive aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

Group M had low to medium scores on the conceptual and cognitive aspect items of their argumentation as evaluated using the observation protocol. For most items they scored a one, which indicated that aspect was apparent in their discourse at least once or twice but was not common. However, they had high scores on two of the items.

Group M's highest score was on item six, meaning that there was no evidence of Group M using inappropriate reasoning (since it was reverse-scored). This was a good result. There was little to no evidence of them using hasty generalizations, correlation equated to causality, confirmation bias, or other inappropriate reasoning tactics. Their reasoning strategies, when used and verbalized, were appropriate. The other area in which Group M did well was staying focused on solving a problem and advancing their understanding. The following exchange exemplified this positive cognitive aspect of argumentation in which Group M engaged.

Mari: Because [another group] did the, um, the energy from the sun, and they did the, um, absorption through the leaves because they remembered reading that. And their reasoning was, like, stems can absorb and leaves can by the food and stuff. But you know that they talked about how they didn't choose what we did because the whole word *soil*. That it wasn't necessary. But I told them we chose what we did mainly because nutrients are necessary. And they come from soil.

Macy: I changed our claim a little. I just added parentheses, like nutrients, quote, in the soil, like.

Morgan: Right.

Mari: Yeah, and so.

Macy: We can take that out.

Mari: Because what she said, she said that their thing, it would only work if nutrients were provided. Otherwise, such as in the hydroponic gardening, where they sprayed it on there and stuff, so that you know like they were realizing that the nutrients had to be there.

Morgan: Right. And they come from, that was the one that said, they said it comes through the leaves, and I was, like, but nutrients don't come through the air, only through the roots. The air only has like whatever the air has in it.

Mari: Well, the nutrients of carbon dioxide would, but the other like. The other nitrogen could as well.

Morgan: Right.

Mari: But nitrogen is also very rich in soil and de-comp, like decomposed matter.

Morgan: But as far as like sucrose and all that?

Mari: Sucrose is produced in the plant.

Morgan: Oh okay.

Mari: Sucrose is sugar. Glucose is sugar, like it's different kinds. Um, but there are certain things that they would get more out of soil, or soil-like substances, like, but you, it has, the majority of it is absorbed through the roots. Unless it's an air molecule, then it's absorbed through the leaves.

Macy: How's it sound so far? Since plants can survive without soil, only needing CO_2 and nutrients from water to grow, uh the, that sentence needs more in it. Uh therefore, biomass must come from nutrients, not soil, and definitely not water.

(Photosynthesis Lesson, 4/13/15)

The previous dialogue was one of the best examples of Group M staying focused on solving a problem. They were diligently trying to make sense of the evidence and ideas they had noted other groups mention. In addition, there is evidence of them seeking alternative claims and explanations and being willing to modify their explanations when they noticed an inconsistency that warranted the change.

Epistemic aspects. This part of the observation protocol helped identify how consistent the group's collaborative and argumentative discourse were with the culture and language of science. Items in this section were concerned with aspects such as whether the group evaluated the relevance and quality of the evidence, how much they used the evidence to support their arguments, how they incorporated science terms in their discussions, and how well they applied broad scientific theories or models within their explanations. The observation protocol scores for Group M's epistemic aspects of scientific argumentation follow (Figure 4.49).

Epistemic Items	Score
8. The participants relied on the "tools of rhetoric" to support or challenge ideas (reverse scored).	3
9. The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	2
10. The participants examined the relevance, coherence, and sufficiency of the evidence.	0
11. The participants evaluated how the available data was interpreted or the method used to gather the data.	0
12. The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	1
13. The participants made distinctions and connections between inferences and observations explicit to others.	0
14. The participants used the language of science to communicate ideas.	2
Total	**8**
Percent	**38%**

Figure 4.49. Group M's scores on epistemic aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

Overall, Group M did not exhibit highly sophisticated epistemic aspects of science in their discourse, although they scored well on a few items. For example, they astutely avoided using "tools of rhetoric" in their argumentation, earning a high score on that item. Group M also referred to their available evidence often while seeking to solve the tasks in the lesson. The dialogue recorded below contains two examples of that. First, Mari refers to facts from the hydroponics station about how a plant can grow even without any soil and later Morgan referenced evidence that added carbon dioxide increased plant growth.

Mari: [The hydroponics evidence station] kind of goes in with that. Like, it was saying soil is optional, but it proved that carbon dioxide, like air, water, and nitrogen, nutrients were essential for plant growth. Because it had to have, that, they grew better with it, and faster, and, you know, lots of energy.

Morgan: Mm-hmm. Yeah, they all affect the growth, so.

Macy: Yeah.

Mari: But it just steals the nutrients from the soil; it doesn't actually need the soil itself.

Morgan: Right.

Mari: Because the fish food was kind of, you know, another form of soil replacement with the nutrients.

Macy: So really this is all a plant needs: light energy, water, and CO_2 to produce sucrose and oxygen.

Morgan: Yeah, if you want to say something about, because I had the one that had carbon dioxide and then it was, like, you needed carbon dioxide to increase, like, the growth, so that would affect the biomass of the plant.

Mari: Yeah.

Morgan: Eventually.

Macy: Yeah.

Morgan: Would you just say added CO_2 affects growth overall?

Macy: Yeah, okay.

(Photosynthesis Lesson, 4/13/15)

Although Group M was adept at avoiding rhetoric in making arguments, they still struggled to effectively and consistently use epistemic tools of scientific argumentation. For instance, there was no evidence of them seeking to examine the relevance of data or evaluating how it was gathered. They also did not make distinctions between observations and inferences clear to others.

Case Summary

The case of the group with moderate epistemic beliefs was presented in the preceding pages. The members of Group M began the study with a number of alternative conceptions related to the processes of photosynthesis and cellular respiration (Figure 4.50). There were some noticeable differences in how many of those alternative conceptions were retained immediately following the treatment lessons and two weeks later.

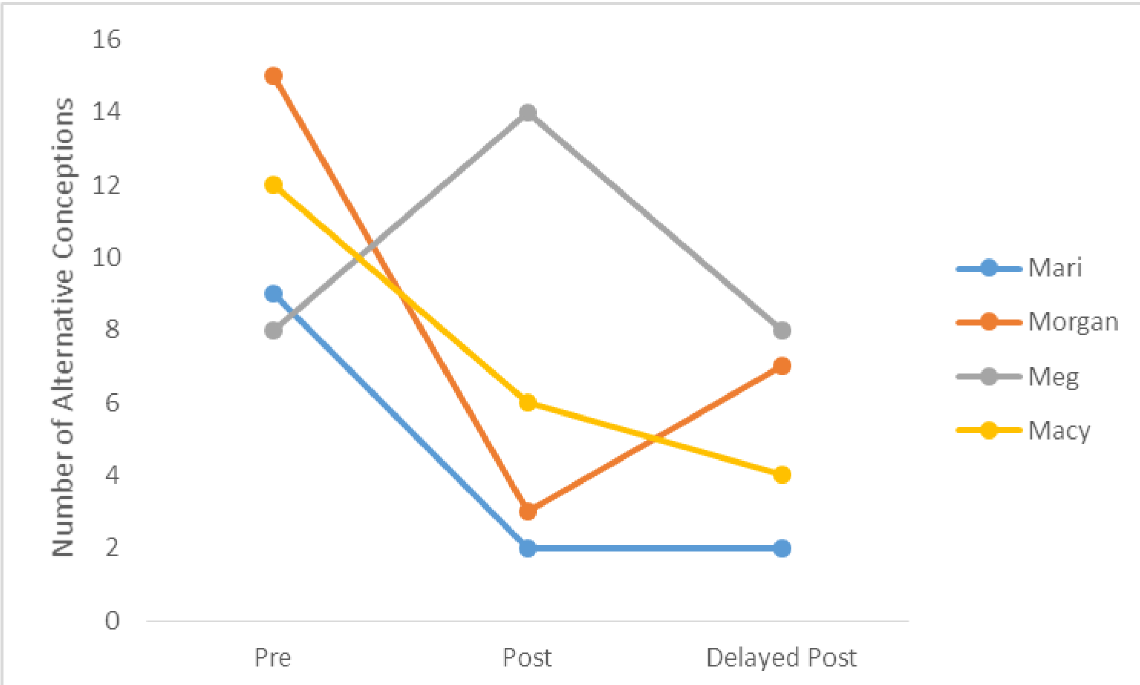

Figure 4.50. Comparison of Group M members' total number of alternative conceptions at pre-, post-, and delayed post-treatment.

Immediately following the lessons, all but Meg had reduced their individual alternative conceptions noticeably. She, in contrast, increased her alternative conceptions following the treatment lessons. During the treatment lessons, Meg almost never spoke or engaged with her group members as they tried to make sense of the processes and reach consensus.

Approximately two weeks later, the members of Group M took the alternative conceptions survey again. This was to see how well they retained, increased, or reduced their conceptual understanding after the passing of time. Mari's alternative conceptions stayed essentially the same, although there were differences in which ones were exhibited. Morgan's alternative conceptions rose some on the delayed post-treatment survey. Meg's alternative conceptions were reduced on the delayed post-treatment from the 14 identified from her post-treatment data. She again exhibited eight alternative conceptions, which matched the amount she held prior to the study. Macy's alternative conceptions had been reduced even more by the time of the delayed post-treatment survey. Meg's results were the poorest, with the treatment lessons increasing her alternative conceptions noticeably. Then she returned to a similar baseline number of alternative conceptions two weeks after the treatment lessons.

As far as group collective alternative conceptions identified, Group M ended with one more alternative conception than they began (Figure 4.51). One alternative conception was identified in the group prior to the lessons, seven were discussed during the lessons, and two were exhibited following the lessons. It is notable that there were no specific alternative conceptions that were held over by the group; they were always newly expressed alternative conceptions discussed at each time period.

A graphical representation (Figure 4.51) shows the number of alternative conceptions that were identified before, during, and immediately following the treatment lessons. Also, the figure shows when and how many newly expressed group alternative conceptions were revealed during and after the lessons. The initial purple bar denotes how many alternative conceptions were identified before the treatment lessons. Additional purple on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Yellow indicates alternative conceptions that first appeared during the treatment lessons. Yellow on the last bar shows the number of those alternative conceptions retained immediately after the treatment lessons. Green indicates any collective alternative conceptions that were newly expressed following the treatment lessons.

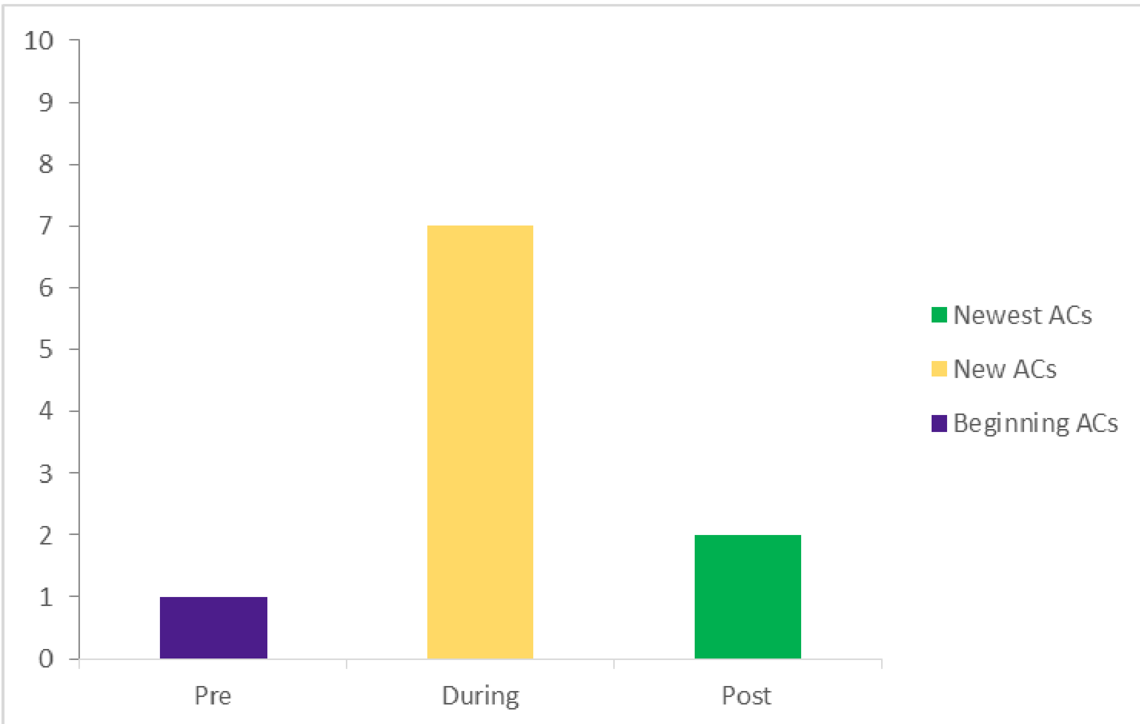

Figure 4.51. Group M's number of alternative conceptions at pre-, during, and post-treatment (ACs = alternative conceptions).

The Case of Group C

Group C included three female members: Camille, Cady, and Claire. These three participants had been identified as having some of the most constructivist epistemic beliefs among the class members at the beginning of the study. This was determined based on their scores on the epistemic beliefs survey (Hofer, 2000). In general, the members of the entire class skewed toward the constructivist perspective. Camille, Cady, and Claire were the participants with the most extremely constructivist scores who were also available for the additional data collection opportunities.

The results of Group C will be presented in the upcoming sections. The first main section will detail the conceptual changes that occurred over the course of the study, determined based on the identified alternative conceptions in each of the individuals as well as collectively as a group over time. These are arranged in three chronological sections: alternative conceptions present *before* the treatment lessons (individual-level and group-level), alternative conceptions present *during* the treatment lessons (group-level only), and alternative conceptions present *after* the treatment lessons (individual-level and group-level). Note that results from after the treatment lessons are subdivided into results from two different time periods: immediately after the treatment lessons (post-treatment) and two weeks after the treatment lessons (delayed post-treatment).

After the conceptual change results are presented, an additional section reports the results of Group C's argumentation quality. This is divided into two parts: conceptual and cognitive aspects of argumentation and epistemic aspects of argumentation. A brief summary concludes the section on Group C's results.

Conceptual Changes in Group C

The upcoming section will present a case study report of the conceptual changes that appeared over the course of the study. Both individual and collectively accepted group alternative conceptions will be discussed. These will be presented in three chronological parts. The first part will present first the individual and then the collective group alternative conceptions that were identified prior to the treatment lessons. The second part will provide a detailed account of any alternative conceptions that were initially accepted by the group and discussed more than once during the treatment lessons. Finally, the last part will present the individual and collective group alternative conceptions that remained following the treatment lessons at the post-treatment and delayed post-treatment times.

Pre-treatment conceptions (individual- and group-level). It was important to identify the individual participants' alternative conceptions that were present before the group members began working together at all. These baseline alternative conceptions for Camille, Cady, and Claire individually were identified from two data sources: their pre-treatment individual knowledge lists and their pre-treatment alternative conceptions survey. These data sources were individually generated and not influenced by peers.

The collective group-level alternative conceptions were also important to elicit before the treatment lessons. For Group C, these were gleaned from two data sources: the pre-treatment group knowledge structure graphic and the discussion the group engaged in while creating the pre-treatment group knowledge structure graphic. Since all three members of Group C were not together during the pre-treatment interview, no alternative conceptions that arose then were considered group-level alternative conceptions.

The upcoming section presents these beginning alternative conceptions. Each individual's alternative conceptions are first presented in the order of Camille, Cady, and then Claire. Their baseline understanding of photosynthesis and cellular respiration are explained and their clearly identified alternative conceptions are listed. That is followed by a section that presents the collectively agreed upon Group C alternative conceptions that were present before the treatment lessons.

Camille (individual-level). Camille's baseline knowledge of photosynthesis and cellular respiration was limited and included some alternative conceptions. Her score on the pre-treatment alternative conceptions survey was 36%. She included correct, but vague, facts on her individual knowledge lists. When required to answer specific questions about the processes, her alternative conceptions became evident. A summation of the alternative conceptions identified in Camille prior to the treatment lessons is found in Figure 4.52.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P biomass: originates from soil
P timing: occurs all the time in plants
P timing: light not required
P equation: gas exchange is O_2 in, CO_2 out
P equation: sugar is a reactant
P equation: chlorophyll is a reactant
P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: do not recognize energy is a product
CR timing: only occurs in light/day
CR timing: only occurs in dark/night
CR timing: only occurs when P is not happening
CR related to exercising (in humans)
CR similar to physical respiration in animals; plants do CR, but animals breathe
Total: 14

P = Photosynthesis, CR = Cellular Respiration

Figure 4.52. Camille's pre-treatment alternative conceptions.

Photosynthesis. Camille's individual knowledge list about photosynthesis was organized as a typical concept map. She included six separate words and statements coming off her center word of photosynthesis, such as "oxygen," "sunlight," "makes food," and "uses chlorophyll" (Pre-Treatment Individual Knowledge List, 4/10/15). Due to the lack of specificity and detail in what Camille wrote, no specific alternative conceptions were identified.

Camille answered few questions about photosynthesis completely correct on the alternative conceptions survey. For example, although she identified oxygen as a gas released during photosynthesis, the answer she chose to support that reasoning indicated incorrectly that plants do not respire in the presence of light. She was unable to identify the correct equation for photosynthesis, did not recognize that the amount of ambient oxygen is unimportant to the process, and could not identify the main benefit of photosynthesis to the plant. Additionally, Camille stated that the main source of a plant's biomass was soil.

Cellular respiration. Camille's individual knowledge list about cellular respiration was designed as a concept map in the same way that she organized the sheet about photosynthesis. She included four separate words and phrases such as "uses oxygen" and "occurs in the mitochondria" (Pre-Treatment Individual Knowledge List, 4/10/15). Camille also included the word "breathing," which indicated that she held the alternative conception that cellular respiration is synonymous with physical respiration.

Camille answered approximately half of the items about cellular respiration correctly on the alternative conceptions survey. For example, she recognized that cellular respiration occurs in all plant cells, it occurs in both plants and animals, and that its main purpose is to release energy from stored food. Although Camille correctly identified the cellular respiration equation, her choice of reasoning for that answer was inexplicably a description of photosynthesis instead. She also answered other items incorrectly related to the gas exchange that occurs in the absence of light. This indicated that her understanding of cellular respiration was not well established.

Cady (individual-level). Comparatively, Cady began the study with more accurate conceptual knowledge than her group mates as evidenced by her higher score on the alternative conceptions survey (64% compared to Camille and Claire's pre-treatment survey scores of 36% each). In fact, she tied with Tess, from Group T, for the highest score in the entire class on the pre-treatment alternative conceptions survey. However, her specific responses on the individual knowledge list and the pre-treatment alternative conceptions survey revealed she also held some alternative conceptions related to both photosynthesis and cellular respiration. These specific alternative conceptions are summarized in Figure 4.53.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P timing: occurs all the time in plants
P equation: unspecified energy is a reactant in addition to light
P equation: chlorophyll is a product
P oxygen is a waste product, ignoring its importance as a reactant for CR
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR equation: do not recognize energy is a product
CR timing: only occurs in light/day
CR purpose: to produce sugar
CR requires chlorophyll
Total: 10

P = Photosynthesis, CR = Cellular Respiration

Figure 4.53. Cady's pre-treatment alternative conceptions.

Photosynthesis. Cady's individual knowledge list about photosynthesis contained three correct facts about photosynthesis, including the accurate conception that photosynthesis is the process by which plants convert carbon dioxide into glucose. She included one alternative conception. Cady stated that photosynthesis "produces chlorophyll" (Pre-Treatment Individual Knowledge List, 4/10/15). The process of photosynthesis enables a plant to produce all its plant structures, including chlorophyll, so her statement is technically correct. However, it can be argued that Cady believed chlorophyll was a direct product of the process rather than understanding its true function in the process.

Cady's responses to the photosynthesis items on the alternative conception survey revealed a developed understanding of that process. She correctly answered all the photosynthesis questions, except she chose an incorrect reasoning answer as to why plants give off oxygen in the presence of sunlight. Cady's incorrect choice indicated that she held the alternative conception that oxygen was merely a waste product, ignoring its integral importance to the plant in the process of cellular respiration.

Cellular respiration. Cady wrote only one statement on her pre-treatment individual knowledge list about cellular respiration. She wrote, "[Cellular respiration] is when the cells change CO_2 into oxygen allowing photosynthesis to happen" (Pre-Treatment Individual Knowledge List, 4/10/15). The statement represented at least two alternative conceptions: an incorrect understanding of the gas exchange that occurs during cellular respiration and an incorrect understanding of the relationship between cellular respiration and photosynthesis.

The pre-treatment alternative conceptions survey revealed that Cady's conceptual understanding of cellular respiration was less advanced than that of photosynthesis. Cady's responses revealed her fundamental alternative conception regarding the purpose of cellular respiration. She selected answers that indicated she believed the purpose of cellular respiration was to produce sugar. Cady also did not correctly identify that oxygen was absorbed and carbon dioxide gas released when plants are not in the presence of light, thus engaged in cellular respiration.

Claire (individual-level). Claire's foundational knowledge of photosynthesis and cellular respiration at the start of the study was a combination of accurate and alternative conceptions. She generated accurate, though vague, information about photosynthesis and cellular respiration on her individual knowledge lists. However, the alternative conceptions survey revealed her conceptual understanding was limited and flawed. She scored 36% on the pre-treatment alternative conceptions survey. Figure 4.54 lists Claire's alternative conceptions that were identified before the treatment lessons.

Pre-Treatment Alternative Conceptions
Identified from the pre-treatment individual knowledge lists and pre-treatment alternative conceptions survey
P biomass: originates in water
P timing: occurs all the time in plants
P equation: unspecified energy is a reactant
P oxygen is a waste product, ignoring its importance as a reactant for CR
P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out
CR equation: water is a reactant
CR equation: do not recognize energy is a product
CR timing: only occurs in light/day
CR purpose: to produce sugar
CR requires chlorophyll
CR process only in animals
Total: 12

P = Photosynthesis, CR = Cellular Respiration

Figure 4.54. Claire's pre-treatment alternative conceptions.

Photosynthesis. Claire's individual knowledge list included more facts about photosynthesis than either of her group mates' lists. Like Camille, Claire also created a concept map with photosynthesis in the middle and numerous phrases surrounding it. All of the phrases were accurate and were connected to photosynthesis or each other in comprehensible ways. Of the eight discrete facts included, no alternative conceptions were identified on Claire's pre-treatment individual knowledge list.

Claire's responses on the pre-treatment survey revealed she held a number of alternative conceptions regarding photosynthesis. Although she recognized that carbon dioxide was a reactant and oxygen was a product, she considered oxygen to be entirely a waste product. This conception ignored the reality of the use of the oxygen in cellular respiration. She also did not choose the correct photosynthesis equation. She chose the one that was almost correct, but it did not include water as a product. Claire also held an alternative conception regarding the benefit of photosynthesis to the plant. She chose an answer that the benefit was the "production of energy," not the more accurate answer of "conversion of light energy to chemical energy" (Haslam & Treagust, 1987). Additionally, Claire incorrectly chose water as the main source of a plant's biomass.

Cellular respiration. In contrast to her baseline knowledge about photosynthesis, Claire's cellular respiration knowledge was minimal. She included three phrases: "aerobic and anaerobic," "uses oxygen," and "needs a catalyst" (Pre-Treatment Individual Knowledge List, 4/10/15). These statements were technically correct and thus no alternative conceptions could be inferred from what she included. It should be noted, though, that none of these facts touched on foundational ideas related to cellular respiration in plants, such as its purpose, or any mention of the gas exchange or other concepts related to what occurs during the process.

Claire's responses about cellular respiration on the pre-treatment alternative conceptions survey showed that her understanding of that process was limited. Claire did not correctly identify the gas that is absorbed and the gas that is released when there is no light energy present. Predictably, she did not recognize the correct equation for cellular respiration. Claire also held the alternative conception that the purpose of cellular respiration was to create food from water and carbon dioxide, which was actually a description of the purpose of photosynthesis. Finally, it was revealed in her survey responses that Claire believed cellular respiration only occurred in animals.

Group C (group-level). Group C's collectively agreed upon alternative conceptions were important to identify prior to their engagement in the treatment lessons. These initial group alternative conceptions were gleaned from two data sources: their pre-treatment group knowledge structure graphic and their discussion while creating the pre-treatment group knowledge structure graphic. Unlike the other groups, Camille, Cady, and Claire could not be interviewed together following the construction of their group knowledge structure graphic. Therefore, alternative conceptions that were discussed during the two separate interviews were not included as group alternative conceptions.

After the members of Group C completed their individual knowledge lists and alternative conceptions surveys, they were tasked with creating a group knowledge structure graphic (Figure 4.55) of photosynthesis and cellular respiration. This group knowledge structure graphic was intended to reveal the starting alternative conceptions that were agreed upon by the group as a whole. It was also an opportunity for the group to begin discussing the concepts and influencing each other's conceptual understanding through their discussion.

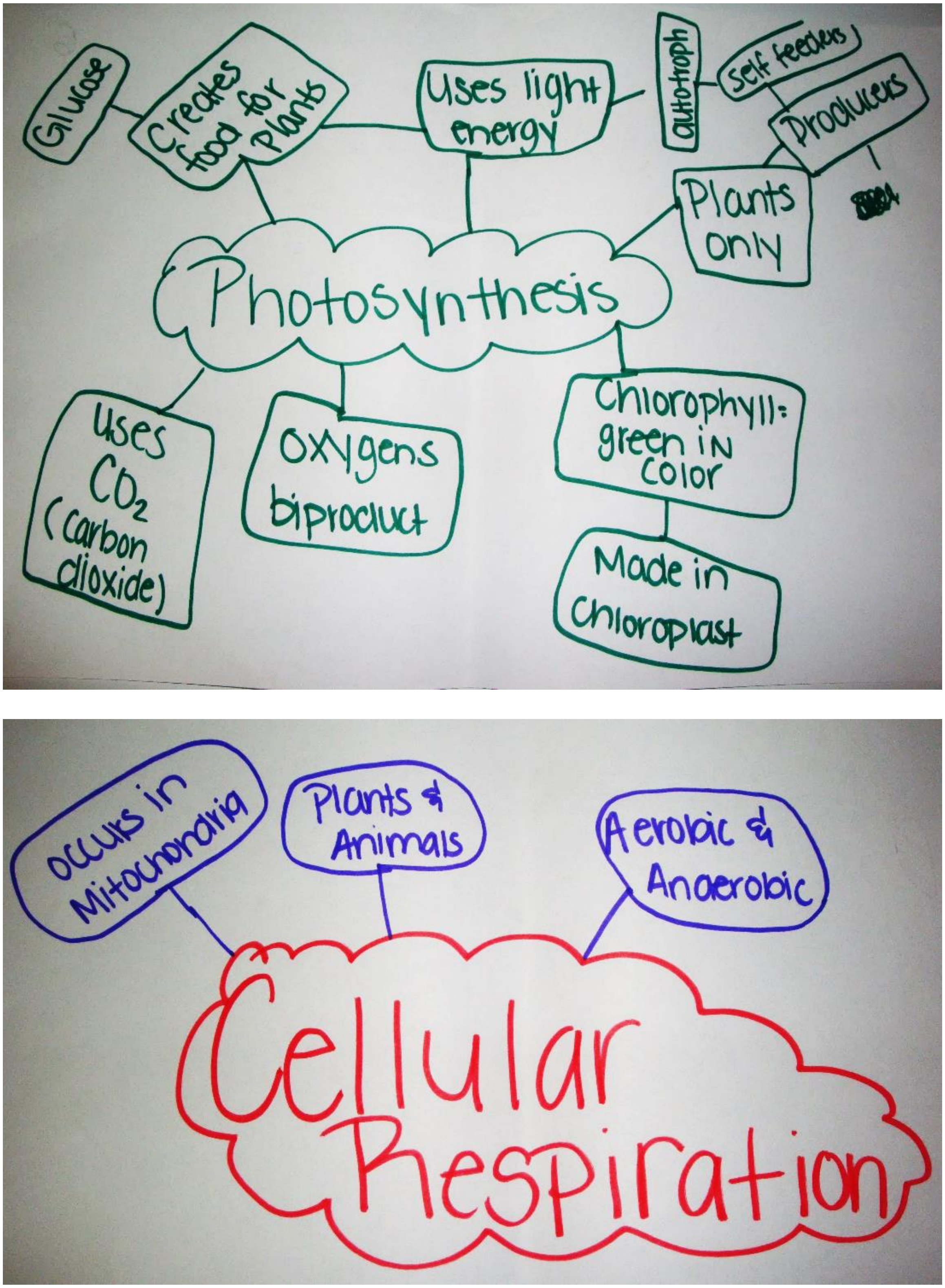

Figure 4.55. Group C's pre-treatment knowledge structure graphic.

There were two alternative conceptions about photosynthesis and cellular respiration that were identified from Group C's pre-treatment knowledge structure graphic and the discourse that occurred while they were creating it. These alternative conceptions were suggested and agreed upon by the group. Since they were not interviewed together, no group-level alternative conceptions were identified from their pre-treatment interviews. If an alternative conception was suggested by a group member, but then immediately refuted, it was not included. In addition, omissions of correct information were not deemed alternative conceptions. The two alternative conceptions identified were that plants convert light directly into sugar and that cellular respiration and photosynthesis are exact opposite processes. These were both mentioned and accepted by Group C while they discussed the creation of their pre-treatment group knowledge structure graphic. Although these alternative conceptions did not appear on the graphic itself, they were relevant and representative of Group C's agreed upon alternative conceptions prior to the treatment lessons. A summary of the two alternative conceptions identified collectively in Group C is provided in Figure 4.56 and an explanation of each follows.

Pre-Treatment Alternative Conceptions
Identified from pre-treatment group knowledge structure and discussion
P equation: turns light directly into sugar
CR and P equations: exact reverse/opposite of each other
Total: 2

P = Photosynthesis, CR = Cellular Respiration

Figure 4.56. Group C's pre-treatment alternative conceptions.

Plants convert light directly into sugar. This common naïve conception discounted the significance of the carbon dioxide in providing the basic building blocks to create the food. The light merely serves as an energy input to drive the chemical bonding process. Cady said, “Let’s see, um, it’s converting light into food. The light energy into food energy, into glucose energy and water I think it is, and oxygen” (Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15). Camille and Claire did not respond to the statement to affirm or deny it. Later in the discussion, Cady mentioned that photosynthesis “uses CO_2” (Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15), so she was aware of its inclusion in the equation. However, her statements earlier supported the assumption that her conception of the role of light in generating food energy was vague and inaccurate.

Cellular respiration and photosynthesis are exact opposite processes. The idea that cellular respiration and photosynthesis are opposites was suggested by Claire twice during Group C’s discussion as they created their pre-treatment group knowledge structure graphic. The first appearance came while they were brainstorming ideas to include about cellular respiration. The following exchange occurred.

Claire: I don’t remember a thing [about cellular respiration]. My junior year of high school teacher would be so disappointed.

Camille: I know. Um, let’s see.

Claire: It’s like the opposite of the formula for photosynthesis.

Cady: Basically.

(Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15)

Cady agreed with Claire's statement. Camille did not respond. Claire brought up the idea again later in the discussion. In that instance, she mentioned it as a response to Cady's correct, but undeveloped, statement that photosynthesis and cellular respiration were linked in some way.

Cady: Yeah. You know, photosynthesis occurs in plants only. I think cell respiration, cellular respiration allows photosynthesis to occur. It's something like that. I don't remember. They're somehow linked, but I don't remember. It's been a while.

Camille: What's linked?

Cady: Photosynthesis and cellular respiration, they're linked.

Claire: Yeah, it's like the opposite. Like, there's one formula for photosynthesis and then [cellular respiration's formula is] the opposite.

(Pre-Treatment Group Knowledge Structure Graphic Discussion, 4/10/15)

Neither Cady nor Camille responded to Claire's statement, and the conversation moved in another direction. Cady recognized that the two processes were linked, although she did not know how. Her other group mates did not provide additional information to extend and develop that conception. Instead, Claire suggested incorrectly that the processes were opposites as an explanation for how they were linked. Camille did not voice agreement or disagreement, and she did not include anything about these ideas on the completed pre-treatment knowledge structure graphic. However, since she did not voice any dissent or provide any clarification, it was assumed to be collectively held by all.

The next section will examine what occurred with the group's collective alternative conceptions and any newly expressed ones that were exhibited while they worked through the argumentative discourse lessons on photosynthesis and cellular respiration. During the lessons, they were provided evidence to use in developing and supporting their assertions regarding the scientific processes of photosynthesis and cellular respiration. They were asked to make claims and defend them using the evidence provided.

During treatment conceptions (group-level). The members of Group C engaged in extensive dialogue during the course of the two treatment lessons. Through their collaborative and argumentative discourse, alternative conceptions were revealed and accepted by the group. Any alternative conception that was accepted by the group and mentioned more than incidentally was counted as a group-level alternative conception. It should be noted that many of these alternative conceptions changed at some point during the treatment lessons (i.e., the group might not have continued to exhibit the alternative conception by the end of the lesson). No individual-level alternative conception results were collected during the treatment lessons since the participants were collaborating and negotiating understanding dynamically.

The group-level alternative conceptions that were identified in Group C during the photosynthesis and cellular respiration treatment lessons are listed in Figure 4.57. The upcoming section will provide more details about the occurrence and acceptance of these alternative conceptions through narrative and quoted dialogue. The alternative conceptions that occurred during the photosynthesis lesson will be discussed first, followed by those from the cellular respiration lesson.

During Photosynthesis Lesson	During Cellular Respiration Lesson
P biomass: originates from soil	
CR ATP energy is a type of stored energy	
	CR similar to physical respiration in animals; plants do CR, but animals breathe
	CR and P equations: exact reverse/opposite of each other
	CR purpose: to store sugar
	CR timing: only occurs in dark/night
Total: 2	**Total: 4**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.57. Group C's alternative conceptions during the treatment.

Photosynthesis lesson. Group C discussed two alternative conceptions during the photosynthesis lesson (Appendix G). They were as follows: 1) a plant's biomass comes mainly from nutrients in the soil and 2) ATP energy is a type of stored energy. The group discussed the first alternative conception extensively throughout the lesson, since attaining the correct conception was the focus of the lesson. The second alternative conception was more incidental. The following paragraphs detail the dialogue of Group C as they engaged in the lesson and discussed the above alternative conceptions regarding photosynthesis.

A plant's biomass comes mainly from nutrients in the soil. The main task of the lesson was to identify and argue in favor of the correct claim regarding the primary source of a plant's biomass. This fundamental concept was intended to encourage the development of a unified understanding of the purpose and products of photosynthesis.

Group C wrestled with this answer throughout the entire lesson. Initially they were hesitant to choose one source from the list of four options they were provided (i.e., air, water, soil, sunlight). The exact wording of the four options was nutrients in the soil taken up by the plant's roots; water taken up by the plant's roots; molecules in the air that come in through the holes in the plant's leaves; and the sun's energy (Photosynthesis Lesson, 4/13/15). Throughout the lesson, their choice fluctuated.

The members of Group C eventually claimed that a "plant's biomass comes from nutrients taken up by the roots. It doesn't necessarily have to come from the soil" (Photosynthesis Lesson, 4/13/15). This inaccurate claim was a combination of the provided options and represented an alternative conception, although they correctly rejected the idea that the nutrients had to originate from the soil. The evolution of the group's shared conception regarding this claim is described in the following paragraphs.

At the start of the lesson before being given the four source options (i.e, air, water, soil, sunlight) from which to choose, each member of Group C individually expressed a lack of confidence in an answer. Claire simply said, "I don't know" (Photosynthesis Lesson, 4/13/15). Camille said, "I think of earth, then I think of soil, then I think of atmosphere. I don't know why" (Photosynthesis Lesson, 4/13/15). In contrast, Cady expressed the accurate conception that carbon dioxide provides the main mass to a plant. She said, "It's from carbon, I think" (Photosynthesis Lesson, 4/13/15), and then a few minutes later she added, "Carbon and carbon dioxide, I think" (Photosynthesis Lesson, 4/13/15). She qualified both statements with the words, "I think" (Photosynthesis Lesson, 4/13/15). She explained her reason for the idea.

> Something tells me whenever [my sister] was studying this, it was carbon. I don't remember exactly, because I remember her studying this in her biology classes and I remember her, helping her study about this, but, I honestly don't remember. (Photosynthesis Lesson, 4/13/15)

Cady remembered the correct fact regarding where a plant gets the main large molecules to build its mass, but it appeared from her hesitance that she did not fully understand the conception. This lack of clarity and depth in her conceptual understanding became more evident as the lesson progressed. For instance, Cady almost immediately contradicted her statement that the biomass mainly came from carbon dioxide when discussing the four source options provided by Dr. Pepper. The following dialogue occurred.

> Cady: I think probably nutrients because I know water does not count. And air does not give you much of a mass.
>
> Camille: And the sun is just by, it does not make any sense.
>
> Cady: So, yeah, it would definitely makes sense it would be the nutrients.
>
> Claire: I got to agree with you on that.
>
> Cady: Let's put soil on here [as our claim].
>
> (Photosynthesis Lesson, 4/13/15)

Cady dismissed the air as an option immediately, even though she had just stated a few minutes earlier that carbon dioxide was the source. She felt that the air would contribute only a small amount of mass. Thus, it seemed obvious to her that the source could not be air, which contradicted the fact she had remembered about carbon dioxide contributing the most to a plant's biomass. Camille and Claire agreed with the claim that the source was from nutrients in the soil.

The inclusion of *nutrients* in the wording for the soil option as a main source of biomass became a major point of confusion for Group C as it had been for Group M, and to a lesser extent, Group T. They decided that the undefined nutrients were the key source of a plant's biomass. They realized, however, from the evidence station about hydroponics, that soil is optional to a plant's growth. Therefore, instead of dismissing the entire option and looking to another option for a correct biomass source, Group C modified the answer by keeping the nutrients part but rejecting the soil part. They also maintained that the nutrients that contributed to the biomass were absorbed through the roots. This final decision for a modified claim developed from multiple instances of dialogue as the group tried to make sense of the evidence and choose the correct source option. The notable instances of this are explained in the upcoming paragraphs, illustrating how the alternative conception developed and persisted.

At the beginning of the photosynthesis lesson, Group C chose *nutrients in the soil* as the main source of a plant's biomass. Then, they were asked to model the photosynthesis equation (Appendix G, Task 3). Group C's initial model is shown in Figure 4.58. It should be noted that this model was incorrect on a number of points. There was no water included as a reactant and no glucose as a product. Instead, ATP energy was included as a product. As the group discussed and created this model, Claire astutely made a connection between the equation model and their previous claim that soil was the source of a plant's biomass. She said, "I know it's not part, soil's not part of the equation.

So maybe our [claim] was wrong" (Photosynthesis Lesson, 4/13/15). Cady and Camille did not directly respond to that point and continued staring at their equation model. Then Claire proceeded to convince herself that their claim was still correct.

Claire: Well, those are nutrients (pointing to oxygen and carbon dioxide).

Cady: Yeah.

Claire: So, that kind of counts as the soil thing.

Cady: Yeah.

Claire: Except not soil itself. What's *in* the soil.

(Photosynthesis Lesson, 4/13/15)

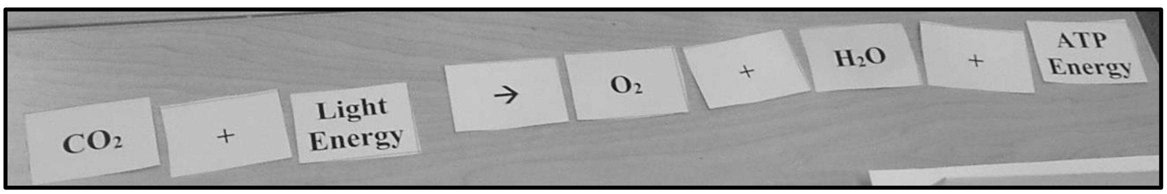

Figure 4.58. Group C's first photosynthesis equation model.

Later, the groups were asked to write their claim regarding the biomass source and include the evidence that supported their claim (Appendix G, Task 5), which they had gathered during the previous task. Group C revisited their discussion regarding their chosen claim. Claire again raised her objection to soil. The following dialogue occurred in which they agreed that the nutrients were the source, but the soil was not.

Cady: So where do plants get their biomass from? I still say it's from nutrients.

Claire: I don't think it has anything to do with the soil, to be honest.

Cady: See, I think it does because the air, it has mass, but I know it has nothing to do with water because it's dry weight, obviously. Um, light does not really have, you know, a mass to it. And gases have a mass but it's small. I think it's more nutrients.

Claire: I think nutrients too, but not soil.

Camille: Yeah, I don't think it has soil.

Cady: No, not soil just nutrients. I think we could just say nutrients.

Claire: Yeah.

Camille: I think it'd be more than just nutrients though. But, I mean if it's just limited to one thing, then I guess. I don't care, I guess I'll just go along with what y'all say.

Cady: Okay.

Camille: We can just, we'll get the right answer eventually anyway.

Cady: Yeah, I will.

Camille: It mainly comes from nutrients.

Cady: Uh huh.

(Photosynthesis Lesson, 4/13/15)

In the above discussion, both Claire and Camille expressed their dissatisfaction with choosing the *nutrients in the soil* option. Cady, in contrast, argued for it. She explained that they should be able to claim that the nutrients were the main source and ignore the soil part. Notably, in the above comments, Cady acknowledged that air has mass. Camille did not press her objection to soil, instead saying “I don’t care, I guess I’ll just go along with what y’all say” (Photosynthesis Lesson, 4/13/15).

As mentioned previously, the inclusion of the word *nutrients* in one of the claims and not all of the claims contributed to Group M and Group C’s confusion. They were accurate in claiming that some type of nutrients made up the biomass of a plant and that those nutrients did not have to come from soil. However, they maintained an alternative conception that the nutrients had to be absorbed by the roots. They also were slow to consider the idea that a nutrient, such as carbon dioxide, could be absorbed from the air.

As the members of Group C discussed their evidence, the importance of carbon dioxide began to emerge. In addition, Cady eventually acknowledged that soil was not needed. The importance of nitrogen to plant growth was also mentioned. Nitrogen became another point of confusion in Group C as they tried to determine the role of nitrogen and its importance in either answering their guiding question about biomass or in determining the accurate photosynthesis equation. The exchange is recorded below.

Cady: Yes. That nitrogen is absolutely needed for plants to grow. And that soil is not needed.

Camille: Nitrogen?

Cady: Uh huh.

Camille: All [my evidence stations] have to do with carbon dioxide, so I don’t know.

Cady: But carbon dioxide is a nutrient.

Camille: Right.

Cady: So is there anything on there that could go along with that as to why carbon dioxide is needed so much?

Camille: I mean, it depends on how big you want your plant is going to depend on the CO_2 levels.

Cady: Then you should put that down [as evidence for our claim].

(Photosynthesis Lesson, 4/13/15)

Cady correctly stated that carbon dioxide was a nutrient. This correct conception actually led her to focus on the incorrect claim that had nutrient in the wording, instead of focusing on the true source (i.e., air is the source of the carbon dioxide, not soil). Camille emphasized the importance of carbon dioxide for increasing the size of a plant. Cady thought that was evidence for their *nutrients from the soil* claim. No one logically connected it to the idea that carbon dioxide molecules in the air contribute most of the mass to a plant.

Next, Dr. Pepper approached Group C and questioned them about the nutrients and soil and their evidence for their claim choice. This prompting led to the group changing their claim from *nutrients in the soil*, one of the provided options, to *nutrients in the atmosphere.* While accurate, this was not precisely one of the claim choices, as the wording of the correct option was "molecules in the air that come in through the holes in the plant's leaves" (Photosynthesis Lesson 4/13/15). The questioning by Dr. Pepper that prompted this change follows.

Dr. Pepper: A plant's biomass comes from nutrients found where? Where are those nutrients coming from?

Cady: That's the debate that we're having.

Dr. Pepper: Uh, well, you need to find some evidence that will help you with that. Where are those nutrients coming from?

Camille: Because, I don't think it comes from the soil. Looking at, like, listening to like, going to their [evidence] stations and stuff.

Dr. Pepper: Mm-hmm.

Camille: Like the way the plants are growing, like, with my [evidence] station it grew because of the carbon dioxide. Like the more carbon dioxide levels, the bigger the plant grew.

Claire: Which, that's a nutrient.

Cady: Yeah. Yeah, it is a nutrient.

Researcher: And where does it come from?

Camille: The atmosphere. Trees.

Dr. Pepper: Um, and you've got, "It doesn't come from the soil."

Camille: Mm-hmm.

Claire: But, there's nutrients in the soil, but they're not soil.

Dr. Pepper: Where's your, where's your evidence about this, that it's not the soil?

Cady: Um, under, we did it with the hydroponic gardening.

Camille: So that one and that one, so those.

Dr. Pepper: So you need to tell me a little bit more than just from nutrients. I need to know from where you get them from.

Cady: Okay, so do you want to put that it comes from atmosphere?

(Photosynthesis Lesson, 4/13/15)

Note that I was sitting near this group while observing the whole group engaged in the photosynthesis lesson. While my plan was simply to observe, I unintentionally interjected a question into the dialogue above. Neither Claire nor Camille answered Cady's question aloud, but Camille proceeded to add *in the atmosphere* to their claim. The group then shifted from discussing their claim to complaining about how confused they were and how pointless the lesson had been. Cady felt that a better approach would have been to provide the correct claim and require them to identify evidence that supported it, rather than asking them to choose the correct claim based on the evidence.

Next, the groups visited other tables in order to evaluate others' claims (Appendix G, Task 6). Cady stayed at Group C's table and presented their claim to the visiting members of other groups. During the discussion that followed, Cady expressed her personal disagreement with the part of their claim that indicated the nutrients came from the atmosphere.

Cady: Yeah, the atmosphere, one of the girls added at the very end, I'm not sure if I agree with that. I think it's mostly nutrients.

Morgan: Mm-hmm.

Cady: The nutrients can come from anywhere.

Morgan: Right.

Cady: But it's mostly from nutrients.

Tia: That's what I said. First, we said the one, the nutrients, the leaves, the roots, the first one [nutrients in the soil]. But, then it was, like, we went to the third one [molecules in the air], but we couldn't back it up.

Cady: Gotcha.

(Photosynthesis Lesson, 4/13/15)

During the second rotation, Cady again explained her group's claim to a new group of peers. This time she immediately expressed her personal dissatisfaction with part of her group's claim, stating, "Now I'm going to tell you, one of the girls at our table added the atmosphere part at the very end. I'm not too sure how much I agree with that" (Photosynthesis Lesson, 4/13/15). The comments of a visiting participant convinced Cady that her group should get rid of the part in which they said the nutrients came from the atmosphere. The pertinent dialogue is recorded below. It begins as the participants discuss Cady's evidence that soil was not necessary for plant growth, so the nutrients must be coming from the atmosphere.

Nina: I'm going to, I really don't see how that [evidence] supports the atmosphere.

Cady: She just added it in.

Nina: Oh, okay. Oh, okay. I mean it's good evidence, but I don't see how, it's, since it's not supported, the atmosphere.

Cady: I think it's from more like anywhere. It can come from you know the soil, it can come from the atmosphere.

Nina:	Yeah.
Cady:	It's nutrients from anywhere.
Nina:	Because she, like we were saying the same thing, because, we were talking about how one of them, it said, like, the plants survive without the nutrients, so it's the nutrient enriched water.
Cady:	Yeah, exactly. Mm-hmm.
Nina:	But either way though, [Dr. Pepper] made us, she said we have to pick one of the four to just focus on.
Cady:	I know, I know. That's why [Dr. Pepper], and the, one of the girls in our group was so adamantly opposed to soil, I'm like okay, bye. We're going to placate you.

(Photosynthesis Lesson, 4/13/15)

In this exchange, Cady agreed with Nina that there was not enough evidence to support the inclusion of atmosphere in the claim. She returned to a previously mentioned viewpoint that the plant's main source of biomass was from nutrients that came "from anywhere" (Photosynthesis Lesson, 4/13/15). It was also noteworthy that Cady described including atmosphere as the source to placate one of her group members. Later in the conversation, this topic was revisited.

Cady:	All right. So, I got a critique. So you, any ways to improve?
Natalie:	Um, you gave really good evidence but the, it's just the atmosphere.
Nina:	It's the atmosphere, the atmosphere's not supported.

Cady: So, what do you think instead it supports?

Nasima: You have to focus in on like one [option]. I feel like atmosphere is too vague.

Cady: Okay.

Natalie: So I think just get rid of it, the atmosphere part, probably get rid of it.

Cady: [Dr. Pepper] said, though, that we have to have something else there.

Nina: Yeah. Okay. Yeah, she said it has to get nutrients from something.

Natalie: Yeah, nutrients from the soil or sun or (trails off).

Nina: Yeah, nutrients from something.

Cady: And one of the girls was so adamantly opposed to soil. "No, it's not the soil!"

Nina: Yeah, it just, it just has to be. Atmosphere is too broad because the atmosphere has some of everything in it, like, we couldn't just use that.

Cady: Okay. Okay. Okay. Okay, well wonderful, thank you for backing me up.

(Photosynthesis Lesson, 4/13/15)

During this dialogue, Cady became convinced that the atmosphere should be removed from their claim. Surprisingly, no one in the above conversation made a connection between *atmosphere* and *air*, one of the provided claim options. Nasima stated that the atmosphere was too vague of a source. This inability to link the idea of air with atmosphere perhaps represented a peripheral alternative conception in which the scientific definition of the meaning of atmosphere, the mass of air surrounding earth (Atmosphere, n.d.), was not accurately understood.

Camille and Claire returned to Cady at their home table, and time was provided for them to revise their claim and evidence (Appendix G, Task 7) based on what they had learned during the rotations to other tables. Camille reported that one table she had visited stated that the biomass came from nutrients in the soil. This led into a discussion regarding whether Group C should keep their claim the way it was or remove the atmosphere part.

Camille: So, I told her that with our claim, we didn't include soil in the claim, we just included it in the evidence to show that soil can be optional. Another girl said they chose the one about the atmosphere.

Cady: Uh huh.

Camille: And they said because many things, well, the question that I told her that there are many things in the air that could be, it could affect the biomass and like I don't know. I forgot.

Cady: All right.

Camille: And then she said that, um, leaves can absorb water through pores. Leaves absorb through holes in the plants, and that's why they chose that.

Cady: Okay, well, for our biggest critique was, is, they said our evidence was phenomenal. But, the main critique was plants' biomass mainly comes from nutrients from the atmosphere. They felt that our evidence didn't necessarily back that up.

Camille: Yeah, from the evidence it didn't make any sense to me.

Cady: No, so they said that we need to change that. They said they agreed it came from nutrients, but not necessarily from the atmosphere.

Claire: And then, I don't even remember putting the atmosphere on there.

Camille: Yeah, I just wrote down that because you told me to.

Cady: Yeah.

Camille: Well, I wrote it down.

(Photosynthesis Lesson, 4/13/15)

In this exchange, Camille disagreed with the other group's claim that the nutrients came from the soil, and she supported her reason with evidence about how a plant does not actually require soil to grow. Throughout the discussions, referring to evidence was a relatively rare occurrence, and it was notable that Camille did that here. Further, Group C was acknowledged by other participants to have done a good job with including evidence, but there was not enough evidence to support the idea that the source was the atmosphere. Toward the end of the previous exchange, no one in the group defended the atmosphere idea and instead they began to disavow their involvement in including it in the claim previously. They eventually decided to revise their claim. The discussion follows.

Cady: So, yeah. So, what do you guys want to revise on our claim? How do you guys want to revise that because it needs to be revised?

Claire: I'd just mark out *from the atmosphere*.

Cady: But [Dr. Pepper] said we have to have something else.

Claire: Who cares? Just keep it like that.

Cady: Okay.

Camille: We can say, we can say, plants' biomass mainly comes from nutrients taken up by the roots. It doesn't necessarily have to come from the soil.

Cady: Okay, from the roots, that's a good one. That's good.

Claire: Yeah.

Cady: It's definitely better. Because it doesn't necessarily, it just has to be nutrients absorbed in from the roots because the pond centric one, or "pondic" one, sorry, "ponic" I think is how you say it. Okay. You might want to put on there that soil is optional. Because in the claim to make it.

Camille: I did.

Cady: Oh, you did?

Camille: Soil is optional.

(Photosynthesis Lesson, 4/13/15)

Thus, Group C decided on an incorrect final claim that the main source of biomass is unspecified nutrients that are taken up by the roots. Their claim was not one of the four options provided. The group modified one of the given options to something that better fit their alternative conception. Of the three groups in the study, they were the only ones who were willing to work this creatively with the options and did not feel constrained to use only what they were given. Unfortunately, however, this did not support them in developing a more accurate conception. Notably, though, their final claim did align with much of their evidence and correctly acknowledged that the provided evidence clearly did not support soil as a source.

Cady presented Group C's final claim with no objections from other participants during the third and fourth rotations for analyzing others' claims (Appendix G, Task 8). The visiting members of other groups agreed that the claim made more sense now and then explained how their own groups had or had not revised their claims. Although some of them had different claims, no one attempted to argue for or against a certain claim. When Group C came back together, they made no changes to their claim. However, there seemed to be a general acknowledgement that their claim was not correct. Camille said, "So, where does it get its biomass? I want to know the answer so I can write it down. I feel like that's the only thing we learned today" (Photosynthesis Lesson, 4/13/15). Cady replied, "Yeah, that's really just disappointing because it's usually, like, we learned" (Photosynthesis Lesson, 4/13/15).

Dr. Pepper then did a whole class lecture and questioning session (Appendix G, Task 10) that revealed and reinforced the correct claim for the biomass question. It was revealed later during the post-treatment interviews that Cady had accepted and retained that accurate conception. However, Camille and Claire were still unsure.

ATP energy is a type of stored energy. The members of Group C did not have an accurate conception of ATP energy or its role in plant growth during the photosynthesis lesson. ATP energy was included as one of the possible components that participants could have used to create the photosynthesis equation. It was a necessary component in the cellular respiration equation for the next lesson but not in the photosynthesis equation.

When tasked with first creating the model of the photosynthesis equation (Appendix G, Task 3), Claire took the cards and moved them into position. Claire included ATP energy as a product of photosynthesis but did not include the glucose molecule. Camille and Cady looked on with no comment regarding the inclusion of ATP energy.

The first time ATP energy was discussed aloud, it was prompted by Dr. Pepper. She stopped by Group C's table during the second group rotation (Appendix G, Task 6) and asked, "Some people have ATP energy, some don't. Did that come up?" (Photosynthesis Lesson, 4/13/15). Cady answered in the negative, and then this exchange followed.

Cady: Yeah with our [equation], like with ours, honestly, I had no clue what was going on. I'm sitting here, I'm like I have no memory of any of this. So, um, I let one of our girls, we think that nutrients goes in here somewhere, but we honestly are so confused we're, like (trails off). And the ATP thing, one of the girls just added.

Natalie: Okay, the equation for photosynthesis is CO_2 plus H_2O yields, and then under the yields sign is light energy, and then it yields, like, sugar, which is, like, $C_6H_{12}O_6$ plus carbon plus O_2, I think.

Cady: I thought so, I thought that was part of it.

Natalie: And then we put, plus ATP at the end of ours, but like their word ones are different from like how it normally is arranged.

Cady: Mm-hmm.

(Photosynthesis Lesson, 4/13/15)

In this exchange, Cady revealed that she had no memory or knowledge of ATP, and that it was only included because Claire had done so. Natalie provided a mostly accurate description of the photosynthesis equation, except she also erroneously included ATP as a product. Cady agreed with her.

When Group C reconvened at their table after the second group rotation, they discussed revising their equation. Cady presented Natalie's suggested equation to Camille and Claire and they briefly added glucose as a product in their equation. ATP energy was discussed again at this time and Claire mentioned that ATP is "kind of the same thing as [glucose]" (Photosynthesis Lesson, 4/13/15). Cady replied that she did not know and Camille said, "I forgot" (Photosynthesis Lesson, 4/13/15). Note that I was unable to photograph their model at this time, so there is no figure for Group C's second photosynthesis model.

Later, Dr. Pepper questioned Group C about their equation, which still included ATP energy. The following exchange occurred in which Claire again stated that ATP was the same as sugar and should be removed. This alternative conception was a naïve and underdeveloped idea that ATP energy was a direct food source equivalent to the sugar, rather than a type of usable energy that was created from the sugar.

Claire: So I feel like we're going to take ATP out.

Dr. Pepper: Why?

Claire: Because, it's, like, the same thing as sugar.

Dr. Pepper: Then why did you put it there? Why did you put it up here then?

Cady: Oh, it was already there but we added [glucose] instead.

Dr. Pepper: Oh, you replaced [ATP]?

Cady: Yeah.

Dr. Pepper: I gotcha, so put [ATP] back in your envelope.

Claire: Okay, okay.

(Photosynthesis Lesson, 4/13/15)

Group C's final model of the photosynthesis equation is shown in Figure 4.59. This equation was more accurate than their previous since it did not include ATP energy and did include the glucose molecule ($C_6H_{12}O_6$). The only inaccuracy in the revised equation was the absence of water as a product.

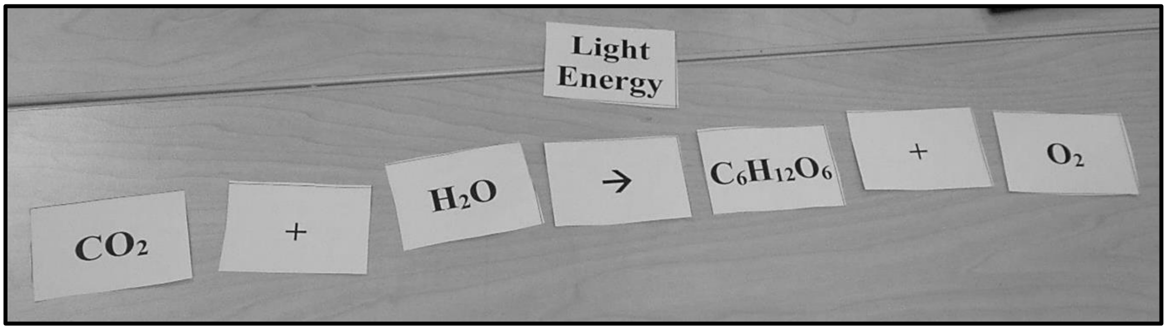

Figure 4.59. Group C's final photosynthesis equation model.

Cady later revealed she had more knowledge about ATP energy than she had previously shared. She did not express much confidence in her knowledge, though. During questioning by Dr. Pepper, Cady said ATP is "the energy produced by the mitochondria, I think. I honestly don't remember" (Photosynthesis Lesson, 4/13/15). She did not take an opportunity to share that knowledge with her group mates after she returned to her table. At the end of the lesson, Dr. Pepper asked the class what information they would have found helpful to have as they engaged in the activities. Camille immediately called out "ATP," and then, "the correct answer" (Photosynthesis Lesson, 4/13/15). The members of Group C did not completely understand ATP at the completion of the photosynthesis lesson.

Summary. Although there were only two alternative conceptions that were discussed frequently during the photosynthesis lesson, they proved to be challenging for the group to overcome. The alternative conception regarding the main source of a plant's biomass proved the most challenging. It was discussed throughout the entire lesson. Group C was unhappy with the claim choices and took initiative in choosing to modify the language of their chosen claim to keep “nutrients” but remove “in the soil.” They recognized that the soil was not necessary but could not reject the soil claim since it included the word *nutrients* which they felt was vital.

Cellular respiration lesson. The format of the cellular respiration lesson (Appendix J) was similar to the photosynthesis lesson (Appendix G), which had occurred during the previous class period. The cellular respiration lesson was designed to encourage the participants to gather evidence and engage in discussions and scientific argumentation to answer the guiding question and explore the process as a whole. The participants were given a guiding question and asked to create the cellular respiration equation using evidence provided from the stations. Four group alternative conceptions arose during the cellular respiration lesson (Figure 4.57). They were that cellular respiration is the same as physical respiration, cellular respiration is the exact reverse of photosynthesis, sugar is stored during cellular respiration, and cellular respiration occurs only in the dark. Each of the four alternative conceptions will be discussed below.

Group C had less difficulty in creating the cellular respiration equation model than they had making the photosynthesis equation model during the previous class period. They attributed this to more familiarity with the expectations and more guidance. Cady explained, “Because we had that base with the photosynthesis, and so once we figured out that base with the photosynthesis, and also with that, the cellular respiration day, we kind of had a bit more guidance in a sense” (Cady’s Post-Treatment Interview, 4/23/15). Their first cellular respiration equation model they created after some discussion was completely accurate (Figure 4.60). They did not change it throughout the lesson.

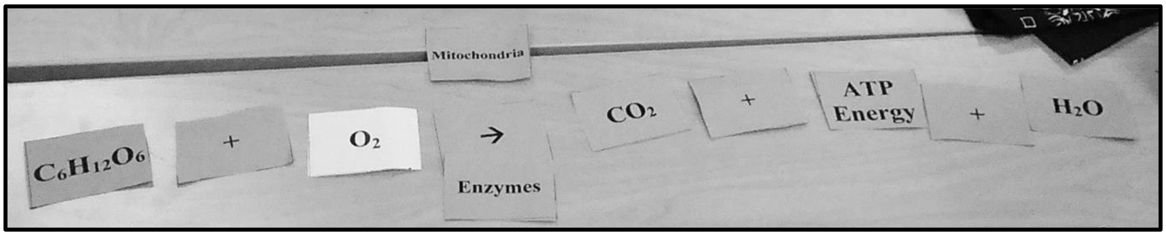

Figure 4.60. Group C's cellular respiration equation model.

Although Group C created the correct cellular respiration equation, their discussions throughout the lesson revealed various alternative conceptions. The cellular respiration alternative conceptions that arose during Group C's discussion were typically only mentioned once. Unlike during the photosynthesis lesson, the alternative conceptions that appeared were corrected by the group through their discussions. The alternative conceptions may have persisted within individual participant's minds, but as a group the correct conception was established fairly soon after its initial emergence and acceptance by the group.

Cellular respiration is the same as physical respiration. The members of Group C held an alternative conception that cellular respiration and physical respiration were essentially the same process. The first appearance of this conflation was in Camille's comments as she explained her evidence station. The dialogue follows.

Camille: And, um, during cellular respiration, the carbs don't go away. They're just stored because cellular respiration is just an ongoing process, it never stops. We're good with that.

Claire: Good.

Camille: That's why we can breathe at, like, nighttime.

Cady: Okay.

(Cellular Respiration Lesson, 4/15/15)

Camille accurately stated that cellular respiration occurs at all times and recognized that it took place in both plants and animals. However, her statement about humans breathing at nighttime showed that her understanding of the purpose and process of cellular respiration was limited and confused with the idea of physical respiration in animals. Later, Camille also said, "Light is not needed for cellular respiration because if that was so, then we would all die" (Cellular Respiration Lesson, 4/15/15). It was unclear from the statement and its context exactly what Camille meant. It was possible that she was again likening cellular respiration to breathing and considering how breathing continues whether there is light or not. Claire also shared this alternative conception, as seen in the following dialogue.

Claire: And, um, what organs are involved in physical respirations in animals? All cells are involved but lungs are, like, the organ involved.

Cady: Yeah, an important organ.

Claire: Yeah, and plants also use respiration.

Cady: Yes.

Claire: And it's in the mitochondria.

(Cellular Respiration Lesson, 4/15/15)

Claire correctly stated that cellular respiration occurs in all cells, specifically in the mitochondria of plant cells. However, she incorrectly emphasized the importance of the lungs in the process, which is a clue to her alternative conception conflating breathing with cellular respiration. No one attempted to correct her or prompt her to explain more fully. During the post-treatment interview, it was revealed that Claire and Camille's conceptual understanding of how cellular respiration differed from physical respiration was not appropriately developed. Cady's post-treatment interview showed evidence that by the end she did understand the basic differences between the two processes and was not conflating them.

The process of cellular respiration is the exact reverse of photosynthesis. Claire had originally suggested this alternative conception when Group C was generating their pre-treatment group knowledge structure graphic. Later she mentioned it again briefly during the photosynthesis lesson, saying, "Cellular respiration's like this, but backwards" (Photosynthesis Lesson, 4/13/15). Camille and Cady did not comment. Claire invoked this idea again during the cellular respiration lesson in response to Camille's lack of knowledge about the process of cellular respiration. The dialogue follows.

Camille: So the chemical equation for cellular respiration is kind of the same except for without light energy?

Cady: I don't know. Remember it gives, it uses.

Claire: No, it's the opposite.

Cady: It's like the opposite, it's like that.

Claire: Um, because you, for cellular respiration, you need O_2.

Camille: Mm-hmm.

Claire: And you need, and CO_2 is a byproduct.

Cady: Yeah, CO_2 is what's given off in cellular respiration. I just wait until we get it.

Claire: And ATP is a byproduct, which is energy.

(Cellular Respiration Lesson, 4/15/15)

In the dialogue above, Claire, supported by Cady, corrected Camille's statement that the process of cellular respiration was similar to the process of photosynthesis. This time Claire provided more details for the equation and recognized that the processes were not fully the opposite, only the gas exchange was the opposite. That distinction may not have been as clear to Camille. Later during the lesson, Camille struggled to write the cellular respiration equation correctly. The following discussion illustrated this.

Camille: Hold on, sorry.

Claire: I missed something, what happened?

Cady: She messed up and wrote the wrong thing.

Camille: I put they use ATP instead of they use sugar.

Claire: Ah.

Cady Got it backwards. It happens to the best of us.

Camille: Okay whatever. They'll get the idea.

Cady: Okay. Okay, good enough. Good enough. Okay. Um.

(Cellular Respiration Lesson, 4/15/15)

Thinking of cellular respiration as the opposite of photosynthesis can be a memory device for recalling that the gas exchange is the reverse. However, it can cause students to oversimplify the process and obscure an accurate conception of the details and the purpose of each. The preceding dialogue indicated that the group in general was moving away from an oversimplified idea of the processes being exact opposites and toward a more nuanced and accurate conception.

Sugar is stored during cellular respiration. This alternative conception originated with Camille, but then was corrected through the process of group discussion. The group, as a whole, began with an incomplete understanding of the purpose of cellular respiration. As they worked through the evidence and talked about the cellular respiration equation, however, clarity and accuracy emerged. At the start of the lesson, Camille said, “And, um, during cellular respiration, the carbs don’t go away. They’re just stored because cellular respiration is just an ongoing process, it never stops” (Cellular Respiration Lesson, 4/15/15). Neither Claire nor Cady objected at that time. Their silence was assumed to be approval. Later, Cady suggested that sugar is used during cellular respiration and referred to evidence from one of the evidence stations to support her assertion. She then said it was stored. Claire agreed that sugar was used, but Camille seemed undecided. The issue did not appear to be resolved at that time. The exchange is recorded below.

Cady: Do you think it, doesn’t it use, though the, use the sugars?

Camille: Are we doing cellular respiration?

Cady: Uh huh.

Camille: Okay, good, because that was not my question.

Claire: Doesn't it use sugar though?

Camille: I'm just guessing.

Claire: Yeah.

Cady: It does?

Claire: Yeah.

Camille: I think maybe.

Cady: Well it's, it's stored. You see that thing over there?

Camille: Mm-hmm.

Cady: Number 5. Cellular respiration is the one that's in green.

Claire: Yeah.

Camille: So it doesn't necessarily decline, it just kind of gets stored.

Claire: Well we're making the formula for it, not what's.

Camille: Some of it's given off.

Claire: Yeah.

Camille: So I know it does do something with that. Okay let's try that first.

(Cellular Respiration Lesson, 4/15/15)

A little later in the discussion as they were seeking to support their claim with evidence, the members of Group C revisited the topic and began to clarify their understanding. The dialogue follows.

Dr. Pepper: That's our guiding question, so what evidence have you gathered?

Claire: Oh, so maybe you're right about the, the sugars.

Cady: It uses sugar to do cellular respiration.

Claire: Yeah, okay.

Cady: It has to.

Claire: That makes more sense.

Cady: Oh so maybe one of our pieces of evidence could be our, uh, equation.

Claire: Yeah.

(Cellular Respiration Lesson, 4/15/15)

Camille did not contribute to the above discussion. There was evidence that she still retained the alternative conception since she later stated aloud and wrote that sugar was stored during cellular respiration. Claire and Cady, however, were quick to correct her. The exchange below occurred while Camille was writing Group C's claim and evidence to answer the guiding question, "How and when does a plant use the food it makes to sustain life?" (Appendix J, Task 4).

Camille: During cellular respiration, sugar is stored. What about ATP?

Claire: Wait, no. They're using the stored sugar.

Camille: Is stored. What? Sugar is used. Or sugar is?

Cady: Sugar is used.

Camille: Okay.

Claire: It's a work in progress.

Camille: Sugar is used.

Cady: To create ATP in the mitochondria.

Camille: Without the presence of sunlight.

(Cellular Respiration Lesson, 4/15/15)

Camille appeared to have accepted the correct conception at that time. She did not mention sugar being stored during cellular respiration at any other point in the cellular respiration lesson. Cady discussed the idea correctly at various points later in the lesson when she presented to other groups. Group C started with varying degrees of accuracy in their conception of this idea, but by the conclusion of the lesson, they had all moved toward a more accurate understanding.

Cellular respiration occurs only in the dark. Claire first introduced this alternative conception, to which Cady and Camille agreed. The exchange follows.

Cady: So, we could say, the plant uses the sugar it makes to partially, er, uses some of the sugar it makes to do cellular respiration.

Claire: Right, when the sun's not out.

Camille: Yeah. During cellular respiration.

Claire: The plant uses stored sugar.

Camille: Without the presence of sunlight.

Claire: There you go!

(Cellular Respiration Lesson, 4/1/5/15)

Later, Cady restated that it occurred without the presence of sunlight, but immediately after stated that "no matter the light energy, cellular respiration will always occur" (Cellular Respiration Lesson, 4/15/15). She recognized that cellular respiration occurs all the time and meant to emphasize that it did not require sunlight. During the first rotation when peers visited their table (Appendix J, Task 5), Cady was forced to clarify her position when it was suggested that including "without the presence of sunlight" (Cellular Respiration Lesson, 4/15/15) was misleading. The dialogue is recorded below.

Morgan: The only, the only thing is, like, um, which isn't, you kind of have it on there. You put, like, without the presence of sunlight,

Cady: But it can also be with.

Morgan: Yeah, so I would just put, um, for as, like, the when, just make sure you say it's, like, a continuous process. Because that's kind of misleading.

Cady: [Camille] added the without sunlight at the end.

Morgan: Yeah.

Cady: My little darling. I should add that real quick, let me fix that.

(Cellular Respiration Lesson, 4/15/15)

Following the rotations, Claire and Camille returned to their table to join Cady. They all proceeded to discuss what they had learned from other groups. Cady explained how they needed to clarify in their claim that cellular respiration occurred all the time, with and without the presence of sunlight. Claire and Camille agreed. Claire seemed unconvinced, though, as she asked at one point, "[Cellular Respiration] does not require sunlight?" (Cellular Respiration Lesson, 4/15/15). Camille confirmed that was true.

Finally, at nearly the end of the lesson, Camille revealed she still maintained an alternative conception regarding when people engage in cellular respiration. Claire and Cady corrected her.

Dr. Pepper: When does photosynthesis occur and respiration take place in plants, when does photosynthesis and respiration take place in animals?

Claire: [Photosynthesis] never takes place in animals, [respiration] at all times.

Cady: They asked when does photosynthesis take place in animals and it never takes place in animals. Right?

Claire: Right.

Cady: Okay, yeah. And, then, for plants, [photosynthesis] only occurs in the presence of sunlight and [respiration occurs] all the time.

Claire: Cool. Yeah.

Camille: Cellular respiration occurs at nighttime for people.

Claire: All the time for people.

Cady: All the time for people, not night. There we go.

(Cellular Respiration Lesson, 4/15/15)

Earlier, Camille had stated that plants only engaged in cellular respiration without the presence of light. The dialogue above indicated that she had transferred the same alternative conception to the occurrence of cellular respiration in people. This discussion occurred at the end of the lesson, so there were no opportunities for the topic to be mentioned again.

Summary. In general, Group C struggled less with the cellular respiration lesson than they did during the previous photosynthesis lesson. Their knowledge complemented each other in that when one person stated an alternative conception, another person would usually correct it either immediately or soon after. Although more alternative conceptions arose during the cellular respiration lesson, they were all simpler and easily corrected, in contrast to those that arose during the photosynthesis lesson.

The next section presents the alternative conceptions that were still held individually and collectively by the members of Group C after the completion of the two treatment lessons. The post-treatment results include data collected at two separate times: immediately after the treatment lessons (designated as *post-treatment*) and approximately two weeks later (designated as *delayed post-treatment*). The next section will present the individual-level results at both the post- and delayed post-treatment times. Then the group-level results will be presented. Note that group-level results were collected only at the post-treatment time.

Post-treatment conceptions (individual- and group-level). After the photosynthesis and cellular respiration lessons, some individual and group alternative conceptions remained in the members of Group C. These remaining alternative conceptions were identified and comparisons made between the participants' understanding prior to the treatment lessons. There were two distinct data collection time periods following the treatment. The post-treatment data collection occurred within a few days of the completion of the cellular respiration lesson and consisted of individual knowledge lists, alternative conceptions survey, group knowledge structures, and group interviews. The delayed post-treatment results were collected approximately two weeks later. These results consisted of the alternative conceptions survey, which participants took for the third and final time.

The upcoming sections are organized as follows. First, there will be a presentation of each member's individual alternative conception results at post-treatment, shortly after the treatment lessons ended. These results were taken from the participants' completed post-treatment individual knowledge lists and their responses on the post-treatment alternative conceptions survey. In addition to these post-treatment results, the delayed post-treatment results are shared. These individual-level results consisted of the survey score and alternative conceptions that were identified from the alternative conceptions survey given approximately two weeks after the treatment lessons concluded.

Once the individual-level results are shared for all the Group C members, the group-level results are provided. These collective group alternative conceptions were gleaned from the post-treatment group knowledge structure graphic, the group discussion that occurred during the construction of the knowledge structure graphic, and the post-treatment group interview. No collective alternative conceptions were identified at the delayed post-treatment time.

Camille (individual-level). The pre- and post-treatment data sources revealed that Camille's conceptual understanding of photosynthesis and cellular respiration increased over the course of the study. Her post-treatment individual knowledge lists contained more numerous and more detailed information about the two processes. Camille's responses on her alternative conceptions surveys showed growth. She scored 36% on the pre-treatment survey, 57% on the post-treatment survey, and 64% on the delayed post-treatment survey taken two weeks after the post-treatment survey.

Another representation of Camille's alternative conceptions over the course of the study presents the data graphically (Figure 4.61). This graph displays when and how many alternative conceptions were identified throughout the study. The blue bar denotes how many alternative conceptions were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange on the middle bar indicates alternative conceptions that first appeared immediately after the treatment lessons. Orange on the last bar shows the number of those alternative conceptions retained two weeks after the treatment lessons. Gray indicates any alternative conceptions that were expressed for the first time at the last data collection point two weeks after the lessons ended.

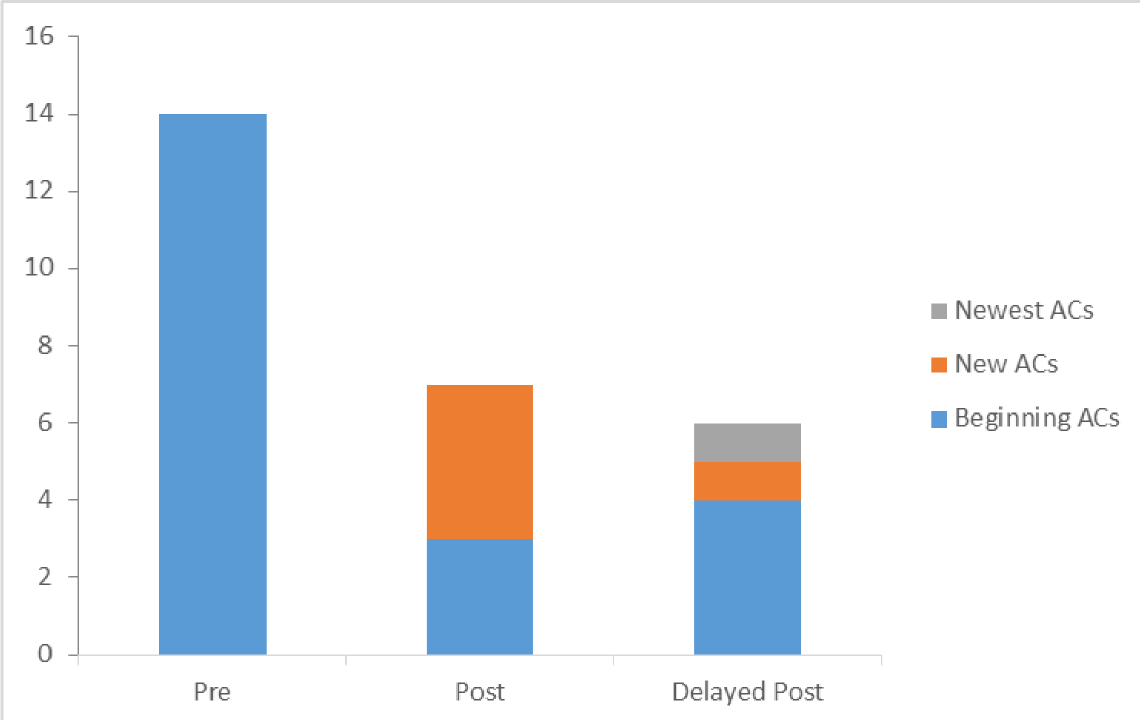

Figure 4.61. Camille's number of alternative conceptions at pre-, post- and delayed post-treatment (ACs = alternative conceptions).

Camille began the study with many alternative conceptions. She showed great improvement on the post-treatment survey, retaining only three of those original 14 alternative conceptions. Four newly expressed alternative conceptions were identified at this point. Two weeks later, her total number of alternative conceptions diminished slightly. Of those, four were ones that had been originally identified prior to the treatment lessons. One alternative conception was retained from when it first emerged on the post-treatment survey and one newly identified on the delayed post. The following paragraphs provide more details regarding Camille's conceptual understanding and alternative conceptions following the argumentative discourse-based lessons. The following figure

(Figure 4.62) details the specific alternative conceptions revealed on the post- and delayed post-treatment data sources in comparison to the alternative conceptions prior to the argumentative discourse-based lessons.

Pre-Treatment	**Post-Treatment**	**Delayed Post-Treatment**
Identified from pre-treatment alternative conceptions survey, pre-treatment individual knowledge list, pre-treatment interview	**Identified from post-treatment alternative conceptions survey, post-treatment individual knowledge list, post-treatment interview**	**Identified from delayed post-treatment alternative conceptions survey**
P biomass: originates from soil		
P timing: occurs all the time in plants		
P timing: light not required		
P equation: gas exchange is O_2 in, CO_2 out		P equation: gas exchange is O_2 in, CO_2 out
P equation: sugar is a reactant		P equation: sugar is a reactant
P equation: chlorophyll is a reactant		
P produces energy directly	P produces energy directly	P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out	CR equation: gas exchange is CO_2 in, O_2 out
CR equation: do not recognize energy is a product		
CR timing: only occurs in light/day		
CR timing: only occurs in dark/night		
CR timing: only occurs when P is not happening		
CR related to exercising (in humans)		
CR similar to physical respiration in animals; plants do CR, but animals breathe	CR similar to physical respiration in animals; plants do CR, but animals breathe	
	P biomass: originates from O_2	P biomass: originates from O_2
	P oxygen is a waste product, ignoring its importance as a reactant for CR	
	CR purpose: to produce sugar	
	CR happens in lung organs only	
		P equation: unspecified energy is a reactant
Total: 14	**Total: 7**	**Total: 6**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.62. Camille's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Camille's post-treatment individual knowledge list included numerous correct facts about photosynthesis. She included an accurate and detailed depiction of the equation as well as six descriptive phrases about photosynthesis. There were no alternative conceptions present on Camille's individual knowledge list following the treatment lessons.

Camille's answers on the post-treatment alternative conceptions survey revealed that her understanding of photosynthesis had increased. This time, Camille answered most of the photosynthesis items correctly. There were two items that she answered incorrectly. In the first she answered that the most important benefit of photosynthesis was the "production of energy" (Haslam & Treagust, 1987). The second error made was that she attributed oxygen as the main source of a plant's biomass. Thus, following the treatment lessons, Camille still held alternative conceptions about photosynthesis.

On the delayed post-treatment alternative conceptions survey, Camille answered similarly as she did on the post-treatment survey. This time, however, she did not choose the correct equation for photosynthesis. The one she chose did not include water as a product and included unspecified *energy* as a reactant. On the positive side, for the first time she answered correctly that carbon dioxide was the main source of a plant's biomass.

Cellular respiration. Similar to photosynthesis, Camille's post-treatment individual knowledge list on cellular respiration revealed notably more factual knowledge about the process. She included a correct representation of the cellular respiration equation. In addition, she wrote seven descriptive phrases that added more information. No evident alternative conception was present in those statements.

Camille's accurate conceptions of cellular respiration increased, as evidenced by her improved answers on the post-treatment alternative conceptions survey. However, there were still a number of incorrect answers, which indicated that she continued to hold alternative conceptions about the process. Additionally, there was little consistency in her answers. For example, Camille again did not choose the correct gas reactant and gas product that occurred during times when a plant was not exposed to light energy, i.e., during cellular respiration. Yet she chose the correct cellular respiration equation on another item. Her reasoning answer, however, indicated again that carbon dioxide was a reactant and oxygen was a product. Clearly, Camille still held an alternative conception regarding the inputs and outputs for the process of cellular respiration.

On the delayed post-treatment survey, Camille was slightly more consistent in her accurate answers regarding the gas exchange that occurred during cellular respiration. However, she persisted in choosing carbon dioxide as a reactant and oxygen as a product on the items that asked for what happens in the dark.

Cady (individual-level). Cady showed notable gains in her conceptual understanding of both processes and especially of cellular respiration over the course of the study. Cady's responses on the post-treatment individual knowledge lists were more detailed, more numerous, and generally more accurate than her pre-treatment responses. Her scores on the alternative conceptions survey increased from her pre-treatment survey score of 64% to a perfect score on both the post- and the delayed post-treatment survey.

Cady was the only participant of the three group cases to achieve 100% on the alternative conceptions survey at any time throughout the study. Cady's understanding at the conclusion of the treatment was extremely well–developed. Only two alternative conceptions were identified on her individual data sources.

A graphical representation of Cady's alternative conceptions before, after, and two weeks after the treatment lessons is shown in Figure 4.63. This graph clearly displays when and how many alternative conceptions were revealed over the course of the study. The blue bar denotes how many alternative conceptions were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange on the middle bar indicates alternative conceptions that were first expressed immediately after the treatment lessons.

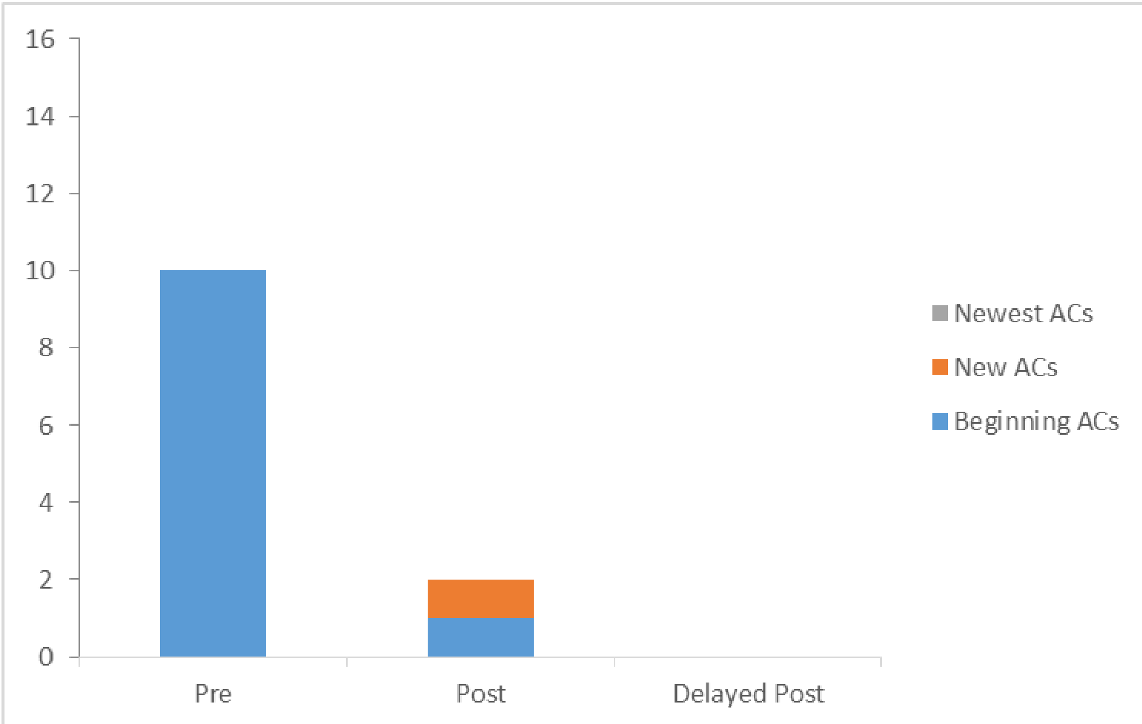

Figure 4.63. Cady's number of alternative conceptions at pre-, post- and delayed post-treatment (ACs = alternative conceptions).

Like most of her group members and classmates, Cady began with a high number of alternative conceptions prior to the study. Those inaccurate ideas were reduced substantially following the treatment lessons. Only one original alternative conception was retained and one newly identified. Cady's results on the delayed post-treatment survey were good. She answered every question correctly. Figure 4.64 lists the specific alternative conceptions that Cady held before, after, and two weeks after the treatment lessons. The paragraphs that follow provide more specific information regarding Cady's conceptual understanding.

Pre-Treatment	Post-Treatment	Delayed Post-Treatment
Identified from pre-treatment alternative conceptions survey, pre-treatment individual knowledge list, pre-treatment interview	**Identified from post-treatment alternative conceptions survey, post-treatment individual knowledge list, post-treatment interview**	**Identified from delayed post-treatment alternative conceptions survey**
P timing: occurs all the time in plants		
P equation: unspecified energy is a reactant in addition to light		
P equation: chlorophyll is a product		
P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR	
CR equation: gas exchange is CO_2 in, O_2 out		
CR equation: water is a reactant		
CR equation: do not recognize energy is a product		
CR timing: only occurs in light/day		
CR purpose: to produce sugar		
CR requires chlorophyll		
	P equation: turns light directly into sugar	
Total: 10	**Total: 2**	**Total: 0**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.64. Cady's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Cady's post-treatment individual knowledge list was more complete and more detailed than her pre-treatment knowledge list. Many of the facts she included were accurate; however, there were two identified alternative conceptions included. For example, first Cady said, "Photosynthesis is the process plants turn the light into food" (Post-Treatment Individual Knowledge List, 4/17/15). This represented a common naïve understanding of the process of photosynthesis that misattributes the role of light and discounts the necessity of carbon dioxide as the starting material for creating glucose. Second, Cady stated, "O_2 is a waste gas" (Post-Treatment Individual Knowledge

List, 4/17/15). Although oxygen is a product of the process, describing it exclusively as a waste ignores the fact that the plant needs and uses oxygen in cellular respiration.

On the post-treatment survey, Cady correctly answered all questions related to photosynthesis. She also chose the correct reasoning for the answers. Cady maintained her perfect score when she took the delayed post-treatment survey again, two weeks later. No alternative conceptions were evident in her answers on the post- or the delayed post-treatment survey.

Cellular respiration. Cady's conceptions of cellular respiration immediately following the treatment lessons were noticeably more detailed and developed than prior to the lessons. On Cady's pre-treatment individual knowledge list she had included only one statement which was incorrect and represented an alternative conception. Her post-treatment individual knowledge list contained numerous facts and details about cellular respiration, all of which were correct. She included a representation of the correct equation as well as six other descriptive phrases. No alternative conceptions were present in her statements.

As previously mentioned, Cady achieved a perfect score on both her post- and delayed post-treatment alternative conceptions survey. No alternative conceptions regarding cellular respiration were revealed in Cady's individual understanding following the treatment lessons. At the beginning of the study, Cady held more alternative conceptions regarding cellular respiration than she did regarding photosynthesis. However, by the end her cellular respiration conceptual understanding was free of identifiable alternative conceptions.

Claire (individual-level). Claire showed growth in her understanding of photosynthesis and cellular respiration over the course of the study. Her post-treatment individual knowledge list contained more information than her pre-treatment knowledge list about both topics. However, Claire included alternative conceptions in what she wrote, which is detailed in the paragraphs that follow. Her scores on the alternative conceptions survey increased notably from pre-treatment (36%) to post-treatment (86%). Claire's score on the delayed post-treatment decreased to 79%, implying that she did not fully retain the accurate conceptual understanding.

A representation of Claire's alternative conceptions before, after, immediately after, and two weeks after the treatment lessons is shown in Figure 4.65. This figure clearly presents when and how many alternative conceptions were identified over the course of the study. The blue bar denotes how many alternative conceptions were identified before the treatment lessons. Additional blue on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Orange on the middle bar indicates alternative conceptions that first appeared immediately after the treatment lessons. Gray indicates any alternative conceptions that were expressed for the first time at the last data collection point two weeks after the lessons ended.

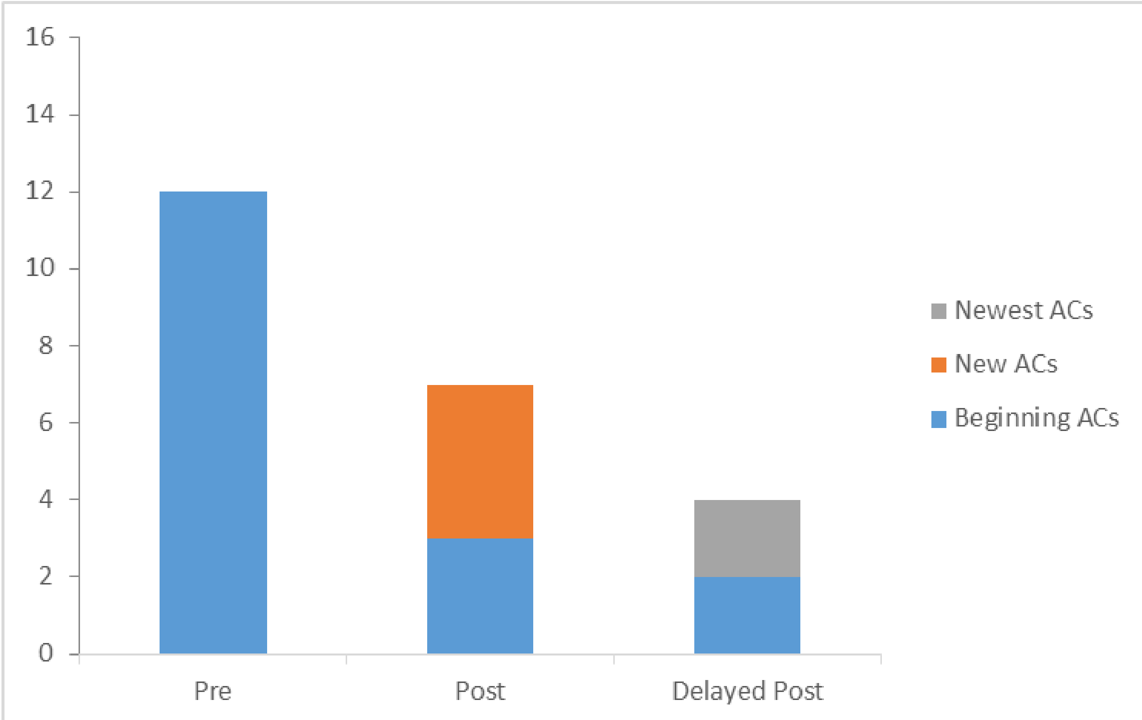

Figure 4.65. Claire's number of alternative conceptions at pre-, post- and delayed post-treatment (ACs = alternative conceptions).

Claire began with a similarly high number of alternative conceptions to those of her group mates prior to the study. Over the next two time points, Claire showed steady improvement. Her number of alternative conceptions was noticeably reduced on the post-treatment survey, although she retained some of her original ones and a few newly expressed ones were identified. On the delayed post-treatment survey two weeks later, all those newly identified alternative conceptions had disappeared. More of the original alternative conceptions were also reduced at that time. There were two new alternative conceptions identified on the delayed post-treatment survey. Figure 4.66 lists the specific alternative conceptions held by Claire before, immediately after, and two weeks after the treatment lessons.

Pre-Treatment	Post-Treatment	Delayed Post-Treatment
Identified from pre-treatment alternative conceptions survey, pre-treatment individual knowledge list, pre-treatment interview	**Identified from post-treatment alternative conceptions survey, post-treatment individual knowledge list, post-treatment interview**	**Identified from delayed post-treatment alternative conceptions survey**
P biomass: originates in water		
P timing: occurs all the time in plants		
P equation: unspecified energy is a reactant		
P oxygen is a waste product, ignoring its importance as a reactant for CR	P oxygen is a waste product, ignoring its importance as a reactant for CR	
P produces energy directly	P produces energy directly	P produces energy directly
CR equation: gas exchange is CO_2 in, O_2 out		
CR equation: water is a reactant	CR equation: water is a reactant	
CR equation: do not recognize energy is a product		CR equation: do not recognize energy is a product
CR timing: only occurs in light/day		
CR purpose: to produce sugar		
CR requires chlorophyll		
CR process only in animals		
	CR purpose: to provide energy when P is not occurring or has not made enough energy	
	CR related to exercising (in humans)	
	CR happens in lung organs only	
	CR similar to physical respiration in animals; plants do CR, but animals breathe	
		P equation: chlorophyll is a reactant
		CR equation: do not recognize sugar is a reactant
Total: 12	**Total: 7**	**Total: 4**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.66. Claire's alternative conceptions at pre-, post-, and delayed post-treatment.

Photosynthesis. Claire's post-treatment individual knowledge list about photosynthesis included many more accurate facts than her pre-treatment one. However, some of her included details represented alternative conceptions. Like Cady, Claire described oxygen as a waste product (Post-Treatment Individual Knowledge List, 4/17/15). She also included the following words in a list: "respiration," "metabolisms [*sic*]," and "decomposition" (Post-Treatment Individual Knowledge List, 4/17/15). These words are more connected to cellular respiration than photosynthesis. Without more explanation included, it can only be assumed that Claire still held an alternative conception regarding the purpose and process of photosynthesis, and how it differed from cellular respiration. Claire also said, "Nutrient cycle energy flows away and relies on cellular respiration" (Post-Treatment Individual Knowledge List, 4/17/15). Although this statement is essentially true, its inclusion as a purported fact about photosynthesis potentially supported the idea that she held an alternative conception regarding the purpose of photosynthesis.

Claire's correct answers increased dramatically on the post-treatment alternative conceptions survey as compared to the one she took prior to the treatment lessons. However, her responses revealed two alternative conceptions about photosynthesis were still maintained. First, she chose the item in which oxygen was characterized as simply a waste product. This was something she had chosen on the pre-treatment survey and mentioned on her post-treatment individual knowledge list as already stated. Second, she repeated another error from her pre-treatment survey and indicated that the most important benefit to plants was the production of energy.

On the delayed post-treatment survey taken two weeks after the post-treatment survey, Claire answered some items differently than she had done before. For the first time, Claire correctly ignored the response about oxygen being a waste product and chose the better answer that explained it is given off but is then used in cellular respiration. Claire answered that chlorophyll was a reactant in the process of photosynthesis and actually combined with the carbon dioxide to create glucose. Last, she maintained her alternative conception regarding the production of energy as being the most important benefit to plants. This was a persistent idea, since it was the same answer she provided every time she took the survey.

Cellular respiration. Claire's post-treatment individual knowledge list was markedly more detailed than her pre-treatment individual knowledge list about cellular respiration. Although many of these were accurate details, four statements indicated alternative conceptions. First, Claire included water as a reactant in the cellular respiration equation. Water is required in photosynthesis but not in cellular respiration. Second, Claire stated that cellular respiration "occurs in lung organs" (Post-Treatment Individual Knowledge List, 4/17/15). This statement indicated that she was still confusing cellular with physical respiration, and she did not have a clear understanding of how plants do cellular respiration since they clearly do not have lungs. This statement contradicted her other accurate statement, which specified that cellular respiration occurs in the mitochondria of all cells. The third notable alternative conception of Claire's was embedded in the statement that cellular respiration "relies on plants photosynthesizing to make more oxygen" (Post-Treatment Individual Knowledge List, 4/17/15). This was accurate but only part of the full picture. It ignored the foundational importance of the glucose made by photosynthesis for cellular respiration, not simply the necessity of the oxygen. Finally, Claire stated, "Cellular respiration is vital to plants, especially when sunlight is not present. They have less energy – uses stored energy" (Post-Treatment Individual Knowledge List, 4/17/15). Cellular respiration is vital to plants at all times to convert glucose into usable ATP energy, and the necessity of that process does not increase in the absence of light. This indicated Claire held an alternative conception regarding the purpose of cellular respiration and possibly viewed that its purpose was to provide energy when photosynthesis was not occurring. Her additional statement about plants having less energy when sunlight is not present and thus using stored energy is additional evidence that her conception of the purpose of cellular respiration was not completely accurate.

Claire answered all of the items about cellular respiration correctly on the post-treatment alternative conceptions survey. On the delayed post-treatment survey, Claire answered only one reasoning level (tier two) item incorrectly. She did not choose the best answer that was most descriptive of the cellular respiration equation. Instead, she mistakenly chose the answer that explained the correct gas exchange, but ignored the purpose of the process in creating energy from glucose.

Group C (individual-level). The previous paragraphs detailed the individual alternative conceptions that were held by each member of Group C following the treatment lessons. A summary of their individual scores on the pre-, post-, and delayed post-treatment alternative conceptions survey provides an informative snapshot of their individual conceptual changes over the course of the study. Figure 4.67 shows a comparison of all of Group C members' scores.

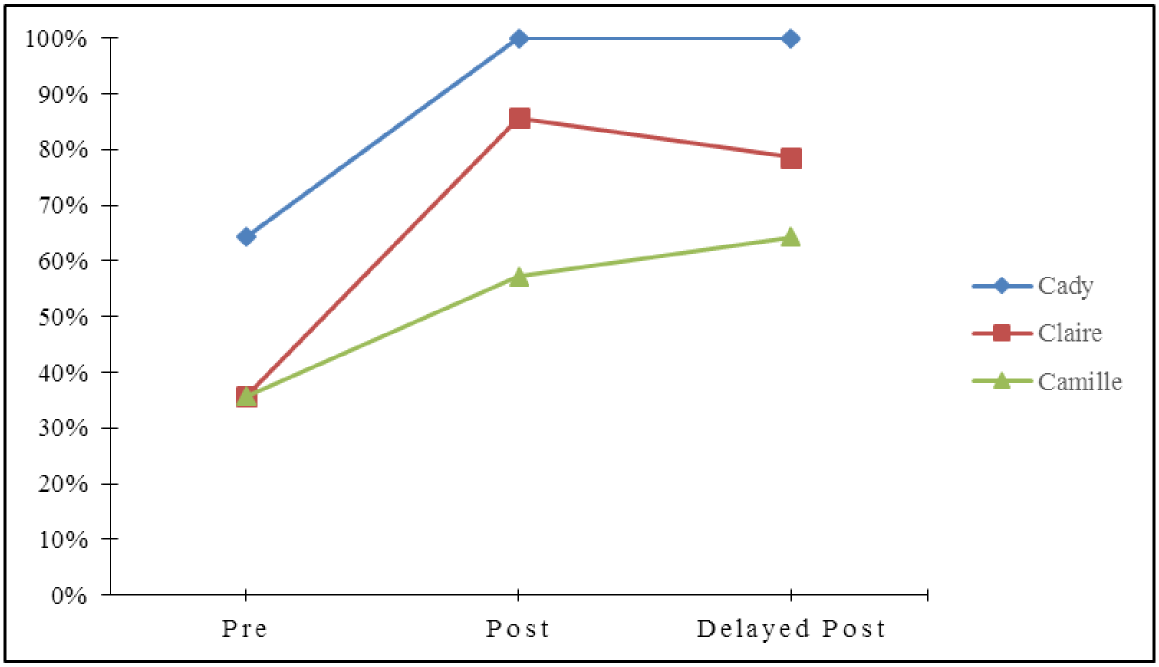

Figure 4.67. Comparison of Group C members' scores on alternative conceptions survey at pre-, post-, and delayed post-treatment. Higher scores indicated more accurate conceptual understanding.

All members of Group C improved their responses on the alternative conceptions survey. All increased their scores notably, with Claire showing the most change pre- to post-treatment. In general, the members of Group C maintained similar scores on the delayed post-treatment survey that they had achieved on the post-treatment survey, pointing to retention of their improved conceptual understanding. Although the correct answers increased overall, there was little to no evidence of convergence of group understanding over time. For example, Cady achieved scores of 100% on both the post- and delayed post-treatment survey, but Camille's highest score, attained on the delayed post-treatment survey, was 64%, which is typically considered below passing. Claire's final scores remained at an approximate midpoint between Cady's and Camille's scores.

Group C (group-level). The upcoming section presents the alternative conceptions that appeared within the group collectively after the treatment lessons. Although individual members of the group held certain alternative conceptions as outlined in the previous paragraphs, they did not always appear within the group as a whole. Therefore, it was important to identify what alternative conceptions were persistent and prominent enough to be mentioned and accepted by the entire group. A depiction of the group's collective conceptual growth will be gleaned from the following three data sources: the post-treatment group knowledge structure graphic, the group discussion that occurred while creating the knowledge structure graphic, and the post-treatment group interview.

The post-treatment group knowledge structure graphic created by Group C contained many more correct conceptions regarding both photosynthesis and cellular respiration than their pre-treatment group knowledge structure graphic. The information included was much more detailed, especially about cellular respiration. See Figure 4.68 for the completed post-treatment group knowledge structure graphic.

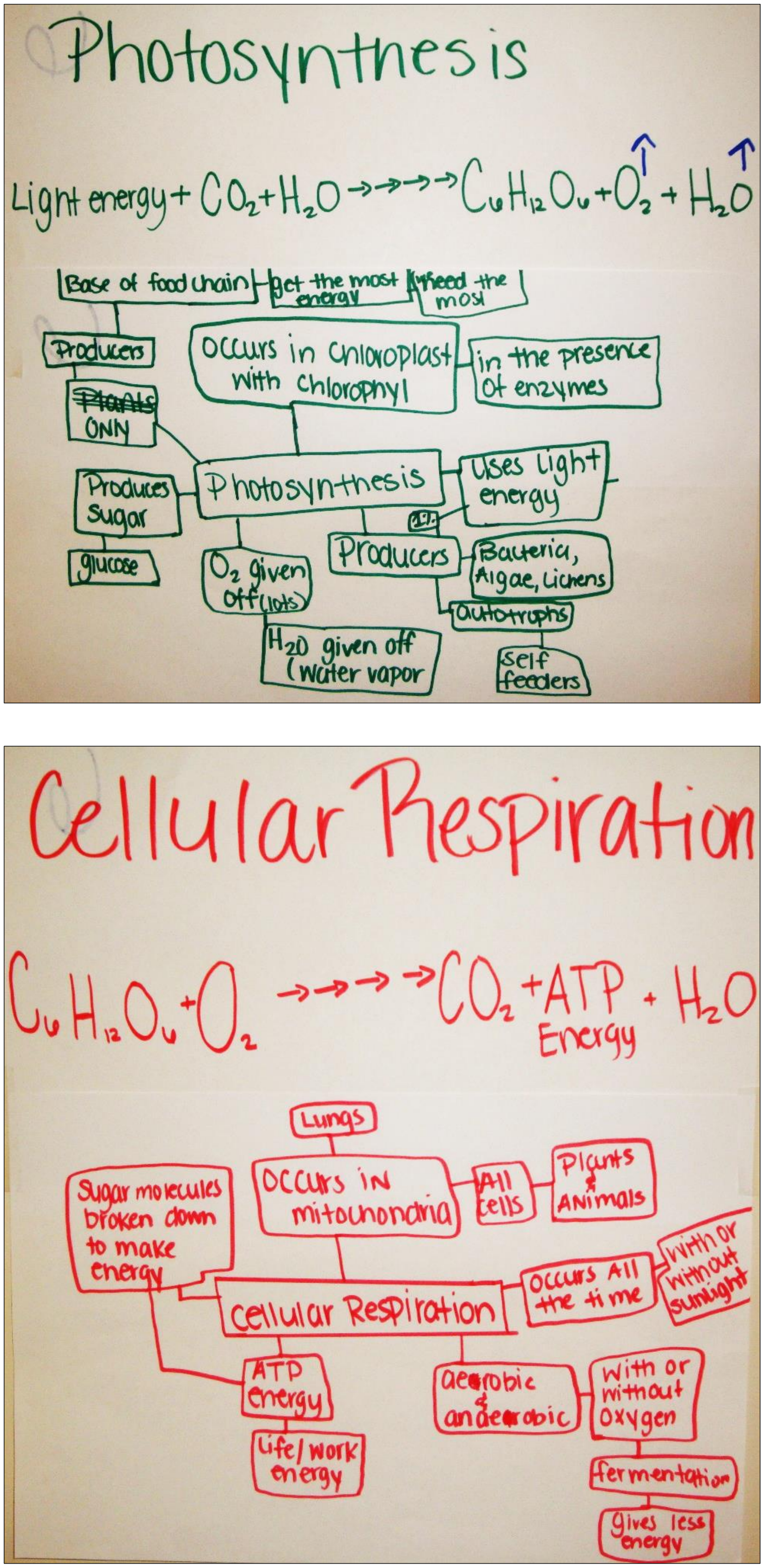

Figure 4.68. Group C’s post-treatment knowledge structure graphic.

A comparison of the accurate concepts identified on the pre- and post-treatment group knowledge surveys shows an increase in group collaborative knowledge over the course of the treatment lessons. The overall accuracy and depth of conceptual understanding was greater following the treatment lessons. The greatest knowledge growth was evident in the topic of cellular respiration. Although there was a large amount of accurate conceptual understanding, there were still group alternative conceptions present following the treatment lessons. Figure 4.69 summarizes the collective alternative conceptions that were agreed upon by Group C before, during, and after the argumentative discourse lessons.

Pre-Treatment	**During**	**Post-Treatment**
Identified from pre-treatment group knowledge structure and discussion	**Identified from photosynthesis and cellular respiration lesson discussions**	**Identified from post-treatment group knowledge structure and discussion**
P equation: turns sunlight directly into sugar		
CR and P equations: exact reverse/opposite of each other	CR and P equations: exact reverse/opposite of each other	
	P biomass: originates from soil	
	CR ATP energy is a type of stored energy	
	CR similar to physical respiration in animals; plants do CR, but animals breathe	CR similar to physical respiration in animals; plants do CR, but animals breathe
	CR purpose: to store sugar	
	CR timing: only occurs in dark/night	
		CR happens in lung organs only
Total: 2	**Total: 6**	**Total: 2**

P = Photosynthesis, CR = Cellular Respiration

Figure 4.69. Group C's alternative conceptions at pre-, during, and post-treatment.

Only two alternative conceptions arose while the group was creating their post-treatment group knowledge structure graphic. They were: 1) the idea that cellular respiration happens primarily in the lungs and 2) the general conflation of cellular respiration with physical respiration. These two alternative conceptions are extremely interconnected and thus will be discussed together in the paragraphs that follow.

Cellular respiration mainly occurs in the lungs, and cellular respiration is the same as physical respiration. Only one alternative conception was actually written on Group C's post-treatment knowledge structure graphic. That was the inclusion of the word *lungs* as the location for cellular respiration. This indicated that the group did not understand the correct location of cellular respiration in both plants and animals. By extension, it was clear they did not understand that cellular respiration was distinctly different than physical respiration. Including lungs as the location for cellular respiration was suggested by Claire during the creation of the post-treatment group knowledge structure graphic. She said, "That, and then attach to that, lungs, because that's the organ" (Post-Treatment Group Knowledge Structure Graphic Discussion, 4/17/15). Cady appeared to agree by making an affirmative sound, and Camille wrote it down with no hesitation. Thus, it seemed to be a collectively agreed upon alternative conception.

Later, during the post-treatment interview with Camille and Claire, it was confimed that they both held the alternative conception that cellular respiration was essentially breathing and considered the lungs to be integral to the process. However, it was revealed during Cady's post-treatment interview that she actually did not hold that alternative conception. Cady said she disagreed with the inclusion of lungs at that time.

She expained the following in her individual post-treatment interview after I asked if there was anything on the knowledge structure graphic with which she disagreeed.

Cady: Oh, and the lungs thing, but I just don't agree with that.

Researcher: Yeah. So talk to me about that.

Cady: Well, you have to think about, we're talking about cellular respiration, not like actual respiration, you know breathing in and breathing out through our lungs.

Researcher: Mm-hmm.

Cady: Cellular respiration is on the cellular level, which means every single cell in our body does it. The lungs are just the lungs. It does not correlate necessarily with, you know, the larger organ systems, because every single cell in our body is doing cellular respiration. So, I don't agree that it should go there.

(Cady's Post-Treatment Interview, 4/23/15)

Since Cady's understanding was accurate, I wondered why she had not influenced her group toward a better conceptual understanding while they were creating the post-treatment knowledge structure graphic. She had not protested when Camille suggested including lungs. In fact, the audio recording revealed that Cady's only response was an affirmative "Mm-hmm" (Post-Treatment Group Knowledge Structure Graphic Discussion, 4/17/15). So in her post-treatment interview, I probed her about what happened during the discussion when this alternative concept was introduced.

Researcher: So when [Camille] put [lungs] there, was there any discussion about it? Or were you just kind of, like, we'll just let it go, or?

Cady: I was more like, let's pick and choose our battles, you know, if it's not right, you know. I said, I know, I said to myself, I'll probably mention this at the [post-treatment interview], and just say, look, I didn't agree with this. I said, "Are you sure, you know, are you positive about this?"

Researcher: Mm-hmm.

Cady: "Oh yeah, yeah, yeah, we're good." And I'm, like, "I don't know." But, I was, like, we can mention it later, not a big deal.

Researcher: Yeah. Okay. Pick and choose the battles.

Cady: Right.

(Cady's Post-Treatment Interview, 4/23/15)

In her explanation above, Cady first implied that she did not say anything at all, but mentally planned to mention her disagreement later. Then, she recounted that she had asked the others if they were sure about that, and someone told her it was fine, so she dropped it. That is not what actually happened.

I asked Cady to elaborate more on what occurred during the cellular respiration lesson related to this alternative conception. I wanted to know what she remembered taking place during the lesson that might have encouraged or discouraged Camille and Claire's alternative conception. She acknowledged that Claire and Camille were confused by the evidence station that was intended to help the participants recognize that cellular respiration was not physical respiration.

Researcher: Okay. Do you think that [having put lungs on the post-treatment knowledge structure graphic] might have been a misconception on [Camille's] part?

Cady: I think it might have been, because, I mean, you think respiration, you think like lungs and stuff, but cellular respiration happens everywhere.

Researcher: Right.

Cady: You know, every single cell has some cellular respiration of some form. So, the fact that she was immediately thinking lungs is a bit of a misconception.

Researcher: Yeah. There was a station about that in the cellular respiration lesson.

Cady: There was. I think that might have gone with that, that caused that misconception.

Researcher: Oh really? Rather than clearing it up you think it caused it?

Cady: Yeah, I think it might have, kind of, made it a little hazy.

Researcher: Okay.

Cady: These people, they were, even Claire was, like, yeah, yeah, lungs, lungs. And I'm, like, no.

(Cady's Post-Treatment Interview, 4/23/15)

I probed and encouraged Cady to explain more about what happened during the cellular respiration lesson when Claire had originally visited the evidence station showing physical respiration.

Cady: Yeah, and so [Claire] saw lungs, she saw cellular respiration, oh, they go together.

Researcher: Okay, interesting. So when she, like, came back to the group and talked about it, you don't, do you remember that happening?

Cady: Mm-hmm.

Researcher: Was she, do you think she was confused then, or she seemed like she understood then?

Cady: I don't think she understood that.

Researcher: The point, really?

Cady: I don't think she read it closely enough that they were not connected.

Researcher: Okay. Gotcha.

Cady: I really don't think she read it closely enough. I think she saw lungs, I don't think she saw cellular respiration. Oh, they go together.

(Cady's Post-Treatment Interview, 4/23/15)

Cady did not explain why she did not attempt to correct Claire's misunderstanding regarding the difference between cellular respiration and physical respiration at that time. In reviewing the dialogue that occurred during the cellular respiration lesson, it appeared that Claire's description of that evidence station was brief. It is possible that the vague explanation obscured her actual underlying alternative conception. Perhaps Cady did not recognize Claire's mistaken understanding at the time.

The previous sections have presented the detailed results of the alternative conceptions that were identified both individually and collectively in Group C members before, during, and after the treatment lessons. By providing these results, a picture of the participants' changes in conceptual understanding emerged. The next section will present the results of the group's argumentation quality during the photosynthesis lesson.

Argumentation Quality of Group C

It is important to understand the quality of Group C's argumentation and the general functioning of their group during the lessons. Understanding their level of argumentation was critical to evaluating the research question, even if it did not answer it directly. The conceptual changes that occurred, or did not occur, may have been influenced by the quality of the group's discourse around developing and defending arguments from evidence. The changes may have also been influenced by other factors such as how well the members functioned as a productive learning group.

The presentation of the results is divided into three parts, which correspond to the two parts of the observation protocol. The conceptual and cognitive aspects of the group's scientific argumentation will be discussed first, followed by their epistemic aspects. Each part will begin with the group's scores on that part of the protocol for the photosynthesis lesson. A narrative with quotations will support the observation protocol results.

Conceptual and cognitive aspects. This section of the observation protocol evaluated how effective the group was in negotiating meaning among themselves and developing their collective understanding. One of the main goals of quality scientific argumentation is to positively influence the participants' conceptual knowledge of the scientific content. The presence or absence of certain aspects of their discussions and argumentative discourse are posited to support the development of their knowledge and lead to more and better conceptual change. The scores of Group C on the conceptual and cognitive aspects of scientific argumentation are shown in Figure 4.70. Each item was scored from zero to three, with higher scores indicating better quality of argumentation and group performance that is more sophisticated. A total of 21 points was possible on the conceptual and cognitive aspects section.

Conceptual and Cognitive Items	Score
1. The talk of the group was focused on solving a problem or advancing understanding.	1
2. The participants sought out and discussed alternative claims or explanations.	1
3. The participants modified their explanation or claim when they noticed an inconsistency or discovered anomalous data.	2
4. The participants were skeptical of ideas and information.	2
5. The participants provided reasons when supporting or challenging an idea.	2
6. The participants based their decisions or ideas on inappropriate reasoning strategies (reverse scored).	2
7. The participants attempted to evaluate the merits of each alternative claim or explanation in a systematic manner.	1
Total	**11**
Percent	**52%**

Figure 4.70. Group C's scores on conceptual and cognitive aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

Group C had relatively consistent medium scores on their conceptual and cognitive aspects of argumentation. They scored a one on three items, which meant there was evidence of those aspects occurring at least once or twice during the lesson dialogue. They scored a two on the other four items, indicating those aspects were present a few times.

For example, Group C exhibited a healthy skepticism related to ideas and information that arose during discussions. The dialogue excerpt recorded below is one instance in which Camille, Cady, and Claire exhibited an initial unwillingness to accept each other's statements about what needed to be included or excluded in the photosynthesis equation.

Claire: We don't really need to change anything I don't think. Did we add water over here? But I don't think there was another H_2O card, so.

Cady: Oh, we need nitrogen, we need to add nitrogen to this one.

Camille: So soil has nothing to do with anything? But I think it's, I think it has to do with the atmosphere.

Claire: I had one with nitrogen here.

Cady: Are you sure?

Claire: I thought so.

Camille: No.

Cady: Maybe minerals?

Claire: I don't feel like that's right.

Cady: Okay.

Claire: Because that has to do with the soil.

Cady: Okay then, never mind.

Claire: I think we're still good.

Camille: Anything that has to do with the soil doesn't go in there. The majority of the stuff that happened had to do with light energy. The atmosphere, the sun.

(Photosynthesis Lesson, 4/13/15)

Group C also scored well on the aspect of providing reasons when supporting or challenging ideas. Providing support for statements and ideas is a defining characteristic of scientific argumentation. Novices may provide erroneous, illogical, or undeveloped reasons, but simply the effort to support their statement with a reason is promising. The following exchange provides a good example of Cady providing a detailed and logical reason for her idea:

Cady: So where do plants get their biomass from? I still say it's from nutrients.

Claire: I don't think it has anything to do with the soil, to be honest.

Cady: See, I think it does because the air, it has mass, but I know it has nothing to do with water because it's dry weight, obviously. Um, light does not really have, you know, a mass to it. And gases have a mass but it's small. I think it's more nutrients.

(Photosynthesis Lesson, 4/13/15)

Here is another example of Cady providing a reason. This time her reasoning is less than ideal, but it still contributed to the group's score on the reasoning item. Cady said,

> Something tells me whenever [my sister] was studying this, it was carbon. I don't remember exactly, because I remember her studying this in her biology classes and I remember her, helping her study about this, but, I honestly don't remember. (Photosynthesis Lesson, 4/13/15)

The participants of Group C were also willing to modify their explanation or claim when they noticed an inconsistency or discovered anomalous data. They did this most notably when they modified the provided claims to adjust the biomass source of "nutrients in the soil" to "nutrients in the atmosphere," and then to "nutrients from anywhere" (Photosynthesis Lesson, 4/13/15).

Epistemic aspects. This part of the observation protocol helped identify how consistent the group's discussions and arguments were with the culture and language of science during their discussions and argumentative discourse. Items in this section were concerned with aspects such as whether the group evaluated the relevance and quality of the evidence, how much they used the evidence to support their arguments, how they incorporated science terms in their discussions, and how well they applied broad scientific theories or models within their explanations. The observation protocol scores for Group C's epistemic aspects of scientific argumentation follow (Figure 4.71).

Epistemic Items	Score
8. The participants relied on the “tools of rhetoric” to support or challenge ideas (reverse scored).	2
9. The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	1
10. The participants examined the relevance, coherence, and sufficiency of the evidence.	0
11. The participants evaluated how the available data was interpreted or the method used to gather the data.	1
12. The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	2
13. The participants made distinctions and connections between inferences and observations explicit to others.	1
14. The participants used the language of science to communicate ideas.	2
Total	**9**
Percent	**43%**

Figure 4.71. Group C’s scores on epistemic aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

Group C earned the highest scores of the three case study groups on the epistemic aspects of argumentation. This aligned with the fact that these group members had the most sophisticated epistemic beliefs about science according to their scores on the epistemic beliefs survey. It should be noted that their scores, although the highest of the group, were not particularly high when compared with the possible scores. There is still much room for improvement in their epistemic aspects of scientific argumentation.

Group C scored fairly well on a couple of items. There was evidence of them referring to underlying scientific principles, models, and theories to support their explanations. For example, in seeking to explain why a candle burned in a closed environment with a photosynthesizing plant, Cady said,

> Um, the, it was producing enough, it had enough carbon dioxide in there that it was producing oxygen, and it had enough oxygen in there that it could burn it. Because you know you have to have oxygen in order to have fire. (Photosynthesis Lesson, 4/13/15)

The participants in Group C tended to use more sophisticated science terms and concepts when communicating ideas. They were good at clarifying terms to each other as well, rather than simply using the words without context. For example, Claire explained that “gases take up space, or gases have mass” (Photosynthesis Lesson, 4/13/15). Cady said, “And our evidence was that biomass is dry weight, and does not include water, which comes from the definition of biomass” (Photosynthesis Lesson, 4/13/15).

Group C rightly avoided relying too much on the tools of rhetoric in their argumentation. A few times they did over-rely on authority when seeking to provide reasons for their statements or simply when bemoaning their own confusion. There was no evidence of the participants from Group C examining the relevance, coherence, or sufficiency of evidence during this lesson. They accepted the evidence they had and did not seek to evaluate its merits in any way.

Case Summary

The previous sections described the results from Group C, the constructivist case. The participants of Group C began the experience with a mixture of alternative and accurate conceptions about the processes of photosynthesis and cellular respiration. Over the course of the study, their alternative conceptions improved the most of all three group cases. Individual alternative conceptions dropped more precipitously than the individual alternative conceptions in the other group participants (Figure 4.72). Unlike other groups, all members of Group C showed a reduction in alternative conceptions after the treatment lessons as compared to before. Additionally, all members of Group C showed additional reduction in their alternative conceptions on the delayed post-treatment survey, given two weeks later. They clearly retained their improved individual conceptual understanding from the post- to the delayed post-treatment survey.

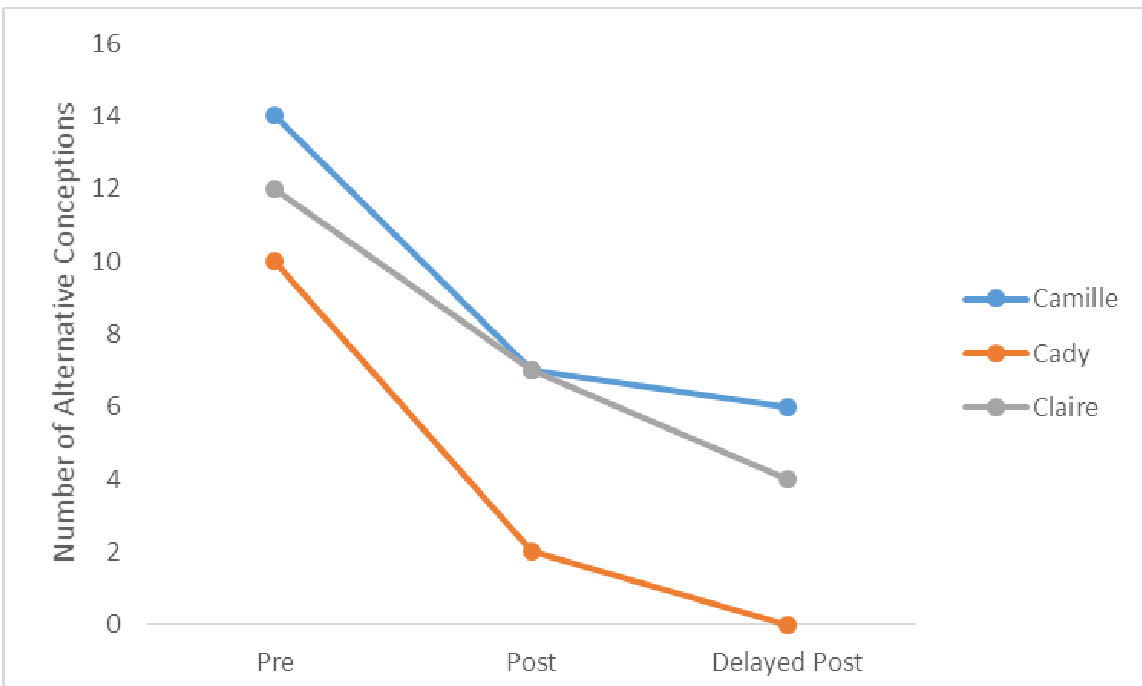

Figure 4.72. Comparison of Group C members' total alternative conceptions at pre-, post-, and delayed post-treatment.

Collectively, Group C exhibited two group alternative conceptions prior to the treatment lessons and ended with two different group alternative conceptions after the lessons (Figure 4.73). During the argumentative discourse-based lessons, they collectively agreed upon six alternative conceptions. One of those, that cellular respiration and physical respiration were analogous processes, was retained after the lessons. The others did not appear in the group discussion following the lessons.

A graphical representation (Figure 4.73) shows the number of alternative conceptions that were identified before, during, and immediately following the treatment lessons. Also, the figure shows when and how many newly expressed group alternative conceptions were revealed during and after the lessons. The initial purple bar denotes how many alternative conceptions were identified before the treatment lessons. Additional purple on bars at later time periods indicate the number of those same alternative conceptions that had been retained and were still present. Yellow indicates alternative conceptions that first appeared during the treatment lessons. Yellow on the last bar shows the number of those alternative conceptions retained immediately after the treatment lessons. Green indicates any collective alternative conceptions that were newly expressed following the treatment lessons.

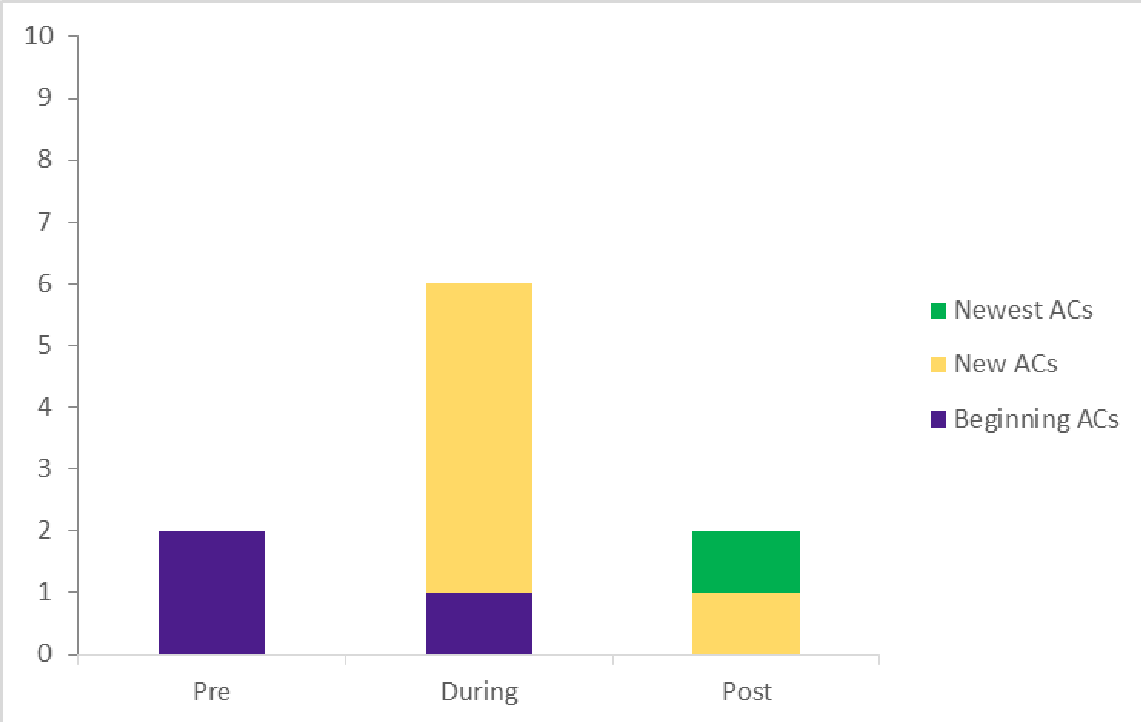

Figure 4.73. Group C's number of alternative conceptions at pre-, during, and post-treatment (ACs = alternative conceptions).

Cross–Case Analysis

According to Yin (2014) cross–case analysis of multiple case studies is a robust analytic technique for qualitative case studies. The comparison of multiple case studies can provide greater insights and lend more trustworthiness to the results and conclusions. The following section presents a summary of the three group cases and ways they compared and contrasted with one another.

The individual members (embedded cases) of each group that composed the three case studies approached the treatment lessons with their own unique mix of alternative and accurate conceptions. Their prior beliefs, attitudes, expectations, relationships to classmates, communication style, and myriad other factors affected the way the individuals interacted and the groups functioned. That ultimately influenced the effectiveness of the lessons. Effectiveness of the lessons was evaluated based on the conceptual change that occurred as a result of the treatment. One of the propositions of this study assumed that the amount and quality of conceptual change might vary depending on the participants' underlying epistemic beliefs about science. To address that proposition, the groups were purposely formed to place participants with similar levels of epistemic sophistication together.

Participant Backgrounds

To better understand the results of the study, it was important to learn about the participants' backgrounds. Thus, I gathered information about them such as their age, major, attitude toward learning science, and attitude toward teaching science. These are all summarized in Figure 4.74. Note that the participants are clustered according to their group cases to provide an overview of the makeup of each epistemic case group.

	Name	Age	Major	Attitude toward Learning Science	Attitude toward Teaching Science
Group T: Traditionalists	Tess	35	Interdisciplinary Studies, English (grades 4-8)	• Strongly dislikes • Too much memorizing • Not much retained • Prefers it taught by authoritative experts • More knowledge reduces her appreciation of nature	• Absolutely will not teach it
	Tory	Not given	Early Childhood Education (grades preK-3)	• Likes • Too much memorizing • Not much retained • Remembers hands-on experiences best	• Doesn't plan to teach it much
	Tia	20	Interdisciplinary Studies (grades K-6)	• Likes a lot • Didn't feel well-prepared in science knowledge • Too much information to learn	• Thinks it will be fun to teach • Looking forward to it
Group M: Moderates	Mari	20	Interdisciplinary Studies (grades K-6)	• Likes • Finds it challenging but attainable with study	• Expects to teach it • Confident, as long as she prepared well
	Morgan	21	Interdisciplinary Studies (grades K-6)	• Struggles • Hardest subject to learn	• Expects to teach it • Lacks confidence • Worries about her ability to teach it well
	Meg	32	Early Childhood Education (grades preK-3)	• Strongly dislikes • Too much memorization • Doesn't understand it • Extremely low confidence in her ability to learn it • Many negative experiences, poor teachers	• Expects to teach it • Thinks teaching it will be easier than learning it • Wants to be a better science teacher than she had
	Macy	22	Interdisciplinary Studies (grades K-6)	• Likes • Loves life science • Finds physical science and chemistry challenging • Poor chemistry teacher in her past	• Thinks it will be fun to teach • Looking forward to it • Confident, as long as she prepared well
Group C: Constructivists	Camille	20	Interdisciplinary Studies (grades K-6)	• Likes • Understands, but struggles to explain • Too much information • Hates chemistry • Enjoys hands-on science experiences	• Not interested in teaching it • Struggles to explain well • Moderately confident, but prefers to be a learner instead of a teacher
	Cady	20	Changing to Business	• Likes • Finds it challenging • Poor science teachers in past • Confident in her understanding, believes she knows more than average person	• Thinks it will be fun if taught right • Thinks it's beneficial to students
	Claire	19	Special Education (grades K-12)	• Likes • Good science teachers in past • Enjoys hands-on experiences	• Expects to teach it • Thinks it will be fun • Plans to use hands-on activities

Figure 4.74. Summary of the backgrounds and science attitudes of participants.

All the members of Group T lacked confidence in their understanding of science. Tess exhibited an extremely strong dislike and avoidance of the discipline of science. In fact, she was the most outspokenly negative of all the group members in the entire study. Only one member, Tia, was looking forward to teaching science someday.

Group M contained members with varied feelings about learning and teaching science. Mari and Macy had positive feelings about learning and teaching it, clearly expressing enjoyment of science. Morgan felt that it was difficult and lacked confidence, but she did not express a strong dislike of the subject in general. Meg, however, strongly disliked science. She was similar to Tess in her level of negative feelings toward science but was perhaps a little less vocal about it than was Tess. Meg had extremely low confidence in her ability to understand and retain science concepts. Unlike Tess, however, she expected to teach it, thought it would be easier to teach than it was to learn it herself, and hoped to be a better teacher than the ones she had experienced.

All members of Group C expressed positive attitudes toward science. They were not all confident in their ability to learn it though, and Camille did not plan to teach it in the future. Both Cady and Claire expressed excitement about teaching science one day and wanted to include many fun and hands-on activities in their instruction.

Group-Level Conceptual Change Results

The focus of this qualitative embedded case study was to examine how alternative conceptions about photosynthesis and cellular respiration may or may not be positively impacted by engagement in argumentative discourse for explanation building within a sociocultural context. Corollary to this overarching goal, the investigation sought to determine if there was support for the proposition that participant epistemic beliefs about science would influence the effectiveness of the lesson in encouraging conceptual change. This inquiry is partially addressed by examining the conceptual change outcomes of the three group cases and comparing them to one another.

The collectively agreed upon alternative conceptions of each individual (embedded cases) before, during, and after the treatment lessons were identified, compiled, and counted. The specific results of each individual within each group case were provided earlier in this chapter. These results detailed which alternative conceptions were extinguished by the lessons, which ones were retained, and which were newly identified after the lessons.

A detailed discussion of the conceptual changes that occurred at the group case level were also provided earlier in this chapter. The overall number of collective group alternative conceptions before, during, and after the treatment lessons are summarized on Figure 4.75. The following paragraphs will compare and contrast the results of the three group cases with one another.

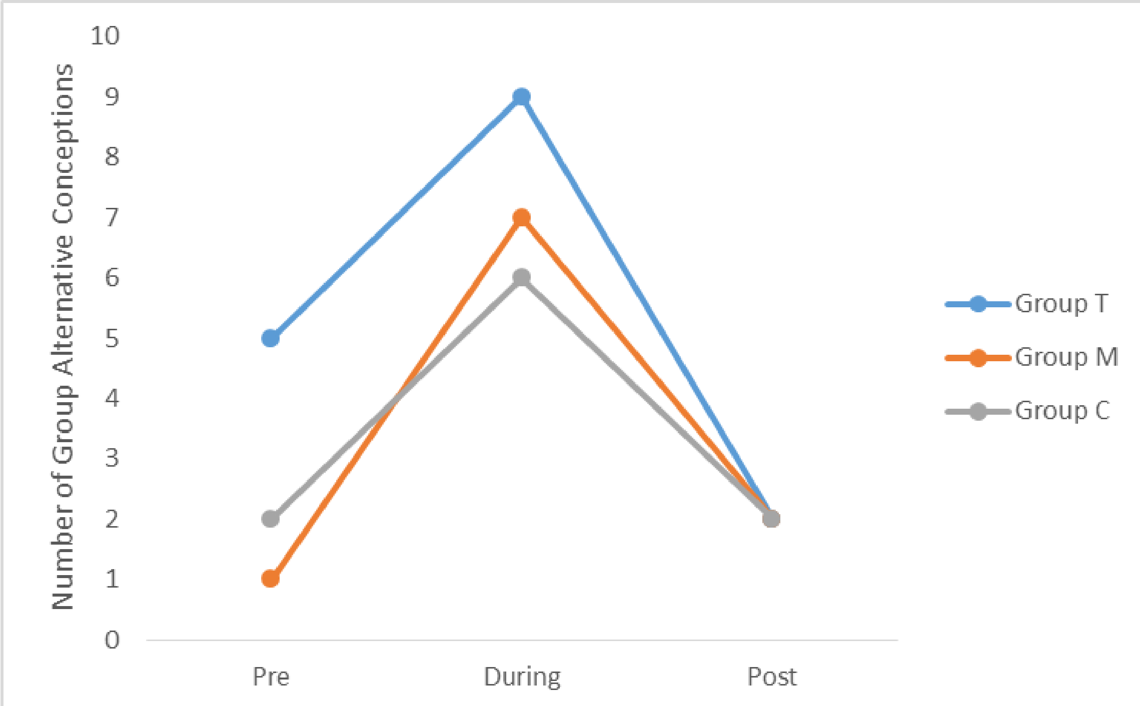

Figure 4.75 Comparison of the three groups' total alternative conceptions at pre-, during, and post-treatment.

Group T discussed and agreed upon more alternative conceptions at the start of the study than did Group M or Group C. All three groups then experienced a sharp increase in the number of alternative conceptions they discussed and agreed upon during the lessons. This was expected since the lessons were designed to force the group members to discuss conceptions related to the topics being studied. Also, the lessons were of a much longer duration and allowed for more and deeper conversations than the pre- and post-data collection discussions. Following the treatment lessons, the collective alternative conceptions of all groups dropped. Group M ended with one more collective alternative conception than they had discussed at the start of the study. Group C ended with the same number with which they began. Group T held two alternative conceptions at the end of the study, three less than their pre-treatment number. It should be noted that although all groups each ended with two collective alternative conceptions, they were not the same two alternative conceptions. Thus, the lessons did not cause all three groups to end the study with the same collective alternative conceptions. In comparing just the number of group alternative conceptions discussed before with those discussed after the study, Group T appeared to have had the most positive conceptual change as a result of the treatment lessons.

Argumentation Quality Results

The first two sections of the Assessing Scientific Argumentation in the Classroom observation protocol (Sampson et al., 2012) were completed on each of the groups. A side-by-side comparison of the groups' scores on each item is provided next. This is divided into the two subsections of the survey: conceptual and cognitive aspects of argumentation (Figure 4.76) and epistemic aspects of argumentation (Figure 4.77). The third subsection, social aspects of argumentation, was not included in this analysis.

	Items	Group T	Group M	Group C
Conceptual and Cognitive Aspects	1. The talk of the group was focused on solving a problem or advancing understanding.	1	2	1
	2. The participants sought out and discussed alternative claims or explanations.	2	1	1
	3. The participants modified their explanation or claim when they noticed an inconsistency or discovered anomalous data.	2	1	2
	4. The participants were skeptical of ideas and information.	1	1	2
	5. The participants provided reasons when supporting or challenging an idea.	1	1	2
	6. The participants based their decisions or ideas on inappropriate reasoning strategies (reverse scored).	1	3	2
	7. The participants attempted to evaluate the merits of each alternative claim or explanation in a systematic manner.	3	1	1
	Conceptual and Cognitive Subtotal	**11**	**10**	**11**
	Total Percent	**52%**	**48%**	**52%**

Figure 4.76. Comparison of the three groups' scores on conceptual and cognitive aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

	Items	Group T	Group M	Group C
Epistemic Aspects	8. The participants relied on the “tools of rhetoric” to support or challenge ideas (reverse scored).	2	3	2
	9. The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	1	2	1
	10. The participants examined the relevance, coherence, and sufficiency of the evidence.	0	0	0
	11. The participants evaluated how the available data was interpreted or the method used to gather the data.	1	0	1
	12. The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	1	1	2
	13. The participants made distinctions and connections between inferences and observations explicit to others.	0	0	1
	14. The participants used the language of science to communicate ideas.	1	2	2
	Epistemic Subtotal	**6**	**8**	**9**
	Total Percent	**29%**	**38%**	**43%**

Figure 4.77. Comparison of the three groups’ scores on epistemic aspects of scientific argumentation. A total of 21 points was possible (three points per item). Higher scores indicated better quality and more sophisticated performance.

In general, the scores were low for all groups on both aspects of argumentation. Figure 4.78 provides an additional graphical representation of the scores. There were 42 total points possible for the observation protocol (21 points per subsection). Group C had the highest cumulative score of 19, Group M scored 18 in all, and Group T scored 17. All these were less than half of the possible score.

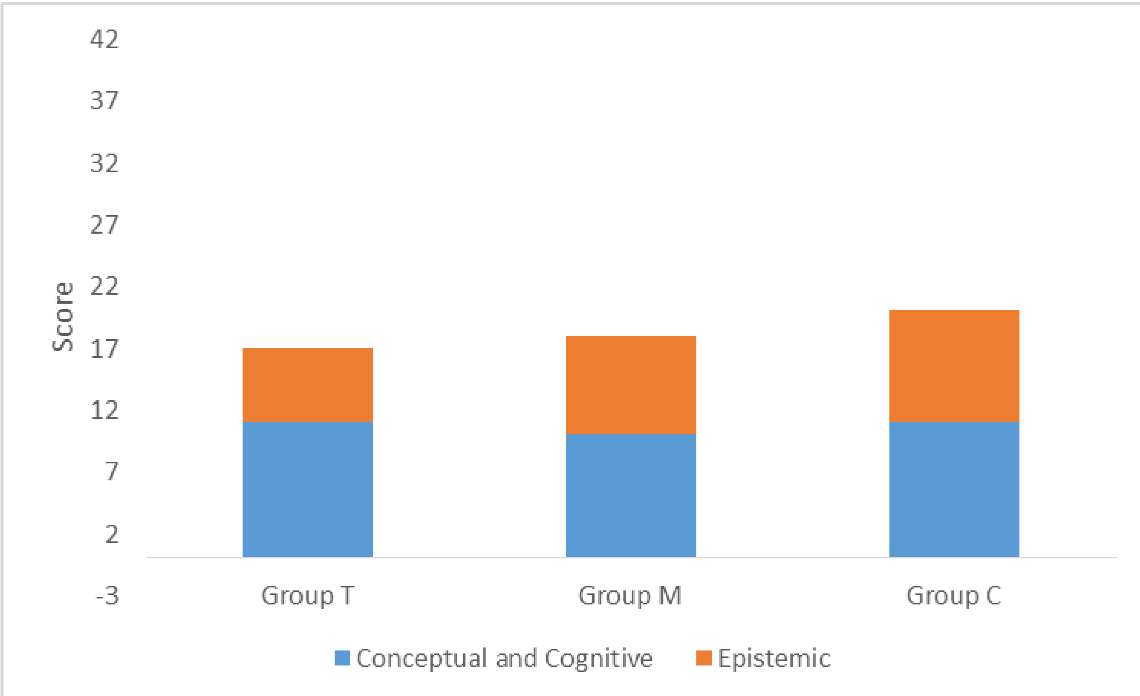

Figure 4.78. Comparison of the three groups' combined scores for aspects of scientific argumentation.

In comparing just the conceptual and cognitive aspect of argumentation subsection, the scores indicated that all three groups were similarly poor in their abilities to think and speak in disciplinary-specific ways during the lesson experiences. On the epistemic part, there was a slight difference in scores. Group T had the lowest score, and Group C had the highest score. This supported the credibility of the epistemic beliefs grouping, as it would be expected that Group T would have less sophisticated beliefs about science than would Group C.

Cross–Case Summary

The preceding section summarized the results of the groups in comparison with one another. This was presented primarily in word tables, a method recommended for the reporting of cross–case analysis results (Yin, 2014). The three groups shared some similarities and exhibited some differences in their results.

One similarity in the conceptual change results was that all the groups exhibited a high number of collectively agreed upon alternative conceptions during the lessons. This was to be expected since the four hours' worth of class time spent analyzing and discussing the concepts created a longer opportunity for alternative conceptions to be discussed. They had less time to discuss things in detail before and after the treatment lessons. Another similarity was that all groups showed a large reduction between the number of alternative conceptions they adopted during the lessons and how many they truly retained after the lesson. Interestingly, all three groups ended up each exhibiting only two collective alternative conceptions following the treatment lessons. A difference in the groups is how Group T began with notably more collective alternative conceptions than the other two groups.

There was varying impact of the lessons in eradicating alternative conceptions pre- to post-treatment in each of the groups. Group T ended with less group alternative conceptions than they began with, displaying some of the best group-level results. Group C ended with the same number of group alternative conceptions. Group M ended with two alternative conceptions, which was one more than which they began. In general, the argumentative discourse-based lessons helped correct most original group alternative conceptions, as well as the alternative conceptions that had been agreed upon during the lessons. The treatment lessons did not eradicate all group-level alternative conceptions.

The argumentation quality of the three cases varied only slightly. None of the groups functioned at a high level in either the conceptual and cognitive aspects of argumentation, or the epistemic aspects. Group C revealed a slight edge over Group T as far as employing more epistemic aspects of argumentation in their discourse.

Chapter Summary

The overarching purpose of this qualitative case study was to describe the influence of argumentative discourse-based experiences on PSTs' alternative conceptions regarding photosynthesis and cellular respiration. I also wanted to explore whether the epistemic beliefs of the participants influenced the effectiveness of the lessons for encouraging positive and lasting changes to their alternative conceptions. A thorough analysis was conducted and the resulting thick, rich narrative provided above detailed the results.

This chapter presented the results of this qualitative study of three group cases and their embedded participant cases. First, the results of Group T, the group with the most traditional and least constructivist epistemic beliefs was provided. Next, Group M, the moderates, was discussed. Finally, Group C, the group with the most constructivist epistemic beliefs, was shared. Each group case was developed by first reporting on the individual results from the embedded cases, the three to four participants in the group. After presenting individual results, group-level results were then discussed. The changes in alternative conceptions were comprehensively presented, and multiple quotations from the groups' discourse were provided. In addition to the changes in alternative conceptions, results regarding the quality of the groups' argumentation were provided.

The overall results showed that all the participants began the study with alternative conceptions about photosynthesis and cellular respiration. Some began with more alternative conceptions than others. By the end of the study, most participants' alternative conceptions were reduced. The exceptions were Tess, Morgan, and Meg, who exhibited an increase in the number of alternative conceptions, either from pre- to post-treatment or from post- to delayed post-treatment. A discussion of these results and implications will be provided in the next chapter.

CHAPTER V: CONCLUSIONS

Introduction

Learners typically bring many alternative conceptions with them in the acquisition of new science knowledge (e.g., Ahopelto et al., 2011; Alparslan et al., 2003; Anderson et al., 1990; Brown & Schwartz, 2009; Bursal, 2012; Haslam & Treagust, 1987; Krall et al., 2009; Miller, 1998; Özay & Öztaş, 2003; Öztaş & Öztaş, 2012; Svandova, 2014). These alternative conceptions may prevent students from appropriately assimilating or retaining scientifically accepted conceptions and can negatively influence future learning (Chi et al., 1994; Driver & Easley, 1978; Michael, 1998; Wandersee et al., 1994). Alternative conceptions in science can be extremely resistant to change (Brumby, 1984; Songer & Mintzes, 1994). Research has shown they can be difficult to influence through traditional instructional methods such as direct instruction (Anderson et al., 1990; Demircioğlu et al., 2005; Kibirige et al., 2014).

Unfortunately, elementary PSTs also hold numerous alternative conceptions and often lack a deep and connected understanding of scientific concepts (e.g., Abell & Smith, 1994; Cakiroglu & Boone, 2002; Davis et al., 2006; Harrell & Subramaniam, 2014; Köse, 2008; Stevens & Wenner, 1996; Trundle et al, 2002). Many PSTs feel underprepared and anxious about teaching science (Kazempour, 2014; Mallow et al., 2010; Yuruk, 2011), partially due to their recognition of their lack of conceptual knowledge. Ensuring elementary PSTs conceptual knowledge is well–developed can minimize the perpetuation of alternative conceptions in their future students.

Student-centered, reform-oriented science teaching methods have shown promise in prompting and supporting better learning outcomes in learners (e.g., Granger et al., 2012; Orbanić et al., 2016; Springer et al., 1999). Specifically, engaging in scientific argumentation and argumentative discourse in the classroom to learn concepts closely aligns with many of the principles that appear to support conceptual change (Dole & Sinatra, 1998; Nussbaum & Sinatra, 2003). The incorporation of student argumentative discourse as an instructional approach has encouraged positive learning results in students (e.g., Hardy et al., 2010; Venville & Dawson, 2010). It has been shown to promote reasoning and problem-solving abilities (Gillies & Khan, 2008; Gillies et al., 2011), as well as increased science achievement (Mercer et al., 2004). Although argumentative discourse has proven successful with K-16 students, its benefits for PSTs have not been established.

The purpose of this qualitative case study was to examine in detail how PSTs' alternative conceptions were impacted through engagement in two science lessons that included episodes of argumentative discourse. In addition to revealing more about the way argumentative discourse may or may not encourage conceptual change, this study explored the possible influence of the participants' underlying epistemic beliefs about science on their conceptual change outcomes. The specific research questions were:

1. How were life science alternative conceptions of PSTs influenced, if at all, by participation in two lessons incorporating argumentative discourse?

2. What, if any, influence did the participants' epistemic beliefs about science have on their conceptual change outcomes following the two lessons incorporating argumentative discourse?

A brief review of the study's methodology will be presented first in this concluding chapter. Then a summary and discussion of the results will follow. Finally, implications for educational practice and implications for future research will be suggested.

Review of Methodology

The purpose of this qualitative multiple case study with embedded cases was to examine how alternative conceptions about photosynthesis and cellular respiration were influenced, if at all, by engagement in argumentative discourse. The study participants consisted of 10 PSTs specifically chosen from a class of 22 undergraduates. The PSTs were in a college course designed to convey science content knowledge for elementary teachers.

I divided the class into six small groups of three to four participants each based on their responses to a survey intended to detect epistemic beliefs about science, whether they were more traditional or more constructivist in approach. These are core beliefs participants hold related to knowledge and ways of knowing in the discipline of science (Hofer & Pintrich, 1997; Schommer, 1990). Those who believe science knowledge is certain and fixed hold more traditional epistemic beliefs, while those who recognize the dynamic and fluid nature of scientific knowledge hold more constructivist epistemic beliefs (Muis & Franco, 2009).

I grouped the three participants who scored toward the more traditional end of the epistemic beliefs spectrum and designated them as Group T, Traditionalists. The individual members of this group were given pseudonyms of Tess, Tory, and Tia. I also grouped the three participants who scored the highest on constructivist epistemic beliefs and designated them as Group C, Constructivists. Those three participants were Camille, Cady, and Claire. I grouped four participants from the middle of the spectrum together and designated them as Group M, Moderates. Those participants were Mari, Morgan, Meg, and Macy. These three groups were the multiple case studies, and the individuals within each group were the embedded cases. I grouped the remaining class members into additional small groups. I collected data from these groups but did not include them in the analysis for this study.

The study treatment consisted of two consecutive science lessons intended to provide multiple opportunities for peer discussions, including argumentative discourse. The first lesson focused on the concept of photosynthesis, and the second was on cellular respiration. Both lessons required the small groups to compile and discuss evidence (provided at information stations around the room), develop a scientific claim, formulate an argument for why their claim was correct, share their claim and argument with other groups, critically evaluate others' arguments, and defend and refine their own. The instructor facilitated the lessons by asking questions, initiating tasks, and guiding the flow of the lesson. She refrained from direct instruction as well as from confirming or denying groups' chosen claims until the end of each lesson.

I used multiple data sources to answer the research questions and address the propositions. These included pre-, post-, and delayed post-treatment alternative conception surveys, pre- and post-treatment artifacts (both individual and group generated), transcripts of participant dialogue, and pre- and post-treatment group interviews. Data sources were analyzed to identify individual- and group-level alternative conceptions held prior to the study. I then gathered data during, immediately after, and two weeks after the treatment lessons to identify what alternative conceptions were retained, extinguished, or re-emergent at each of those time periods. I also noted any newly expressed alternative conceptions. The quality of the groups' argumentation was evaluated in two areas: conceptual and cognitive aspects, and epistemic aspects. Triangulation of the data sources lent credibility to the results. The detailed results were presented in Chapter 4. A summary and discussion of these results follows.

Summary and Discussion of Results

I was interested in how the participants' original alternative conceptions about photosynthesis and cellular respiration were influenced, if at all, by the argumentative discourse-based lessons. I also sought to determine if the individuals' epistemic beliefs about science might mediate their conceptual change outcomes. Based on my propositions, I anticipated that the participants would experience generally positive conceptual changes due to the treatment lessons. Additionally, I posited that Group T's alternative conceptions would show less positive change than would Group C's alternative conceptions. Group T's more traditional epistemic beliefs about science were expected to negatively impact their engagement in the reform-oriented argumentative-discourse lesson. Conversely, Group C, with more constructivist epistemic beliefs, was expected to engage more meaningfully with the treatment lessons and thus experience better conceptual growth.

It is important to interpret the upcoming summary and discussion in light of the fact that the treatment lessons contained a variety of instructional elements and were not solely composed of argumentative discourse. The lessons were planned with the expectation that argumentative discourse would emerge as a result of the structure of the main tasks in which participants were required to gather and share evidence, choose a claim, develop an argument, and defend that argument to others. Although some argumentative discourse episodes transpired, it was not the only type of discourse that occurred. A considerable amount of the discussions could be characterized more generally as collaborative discourse rather than strictly argumentative discourse. The participants engaged in conversations aimed at explanation building and collaboration as part of their evidence sharing, claim selection, and sense-making processes. Thus, the claims made about the conceptual change outcomes should be interpreted as the results of treatment lessons incorporating both argumentative discourse and collaborative discourse experiences.

There is some complexity in the varying ways the conceptual changes have been compared and discussed in the upcoming sections. Two summary figures are provided for reference. Figure 5.1 summarizes the number of alternative conceptions identified in individual participants at pre-treatment, post-treatment, and delayed post-treatment. Figure 5.2 provides similar information regarding the number of alternative conceptions identified at the collective group level at pre-treatment, during the lessons, and at post-treatment.

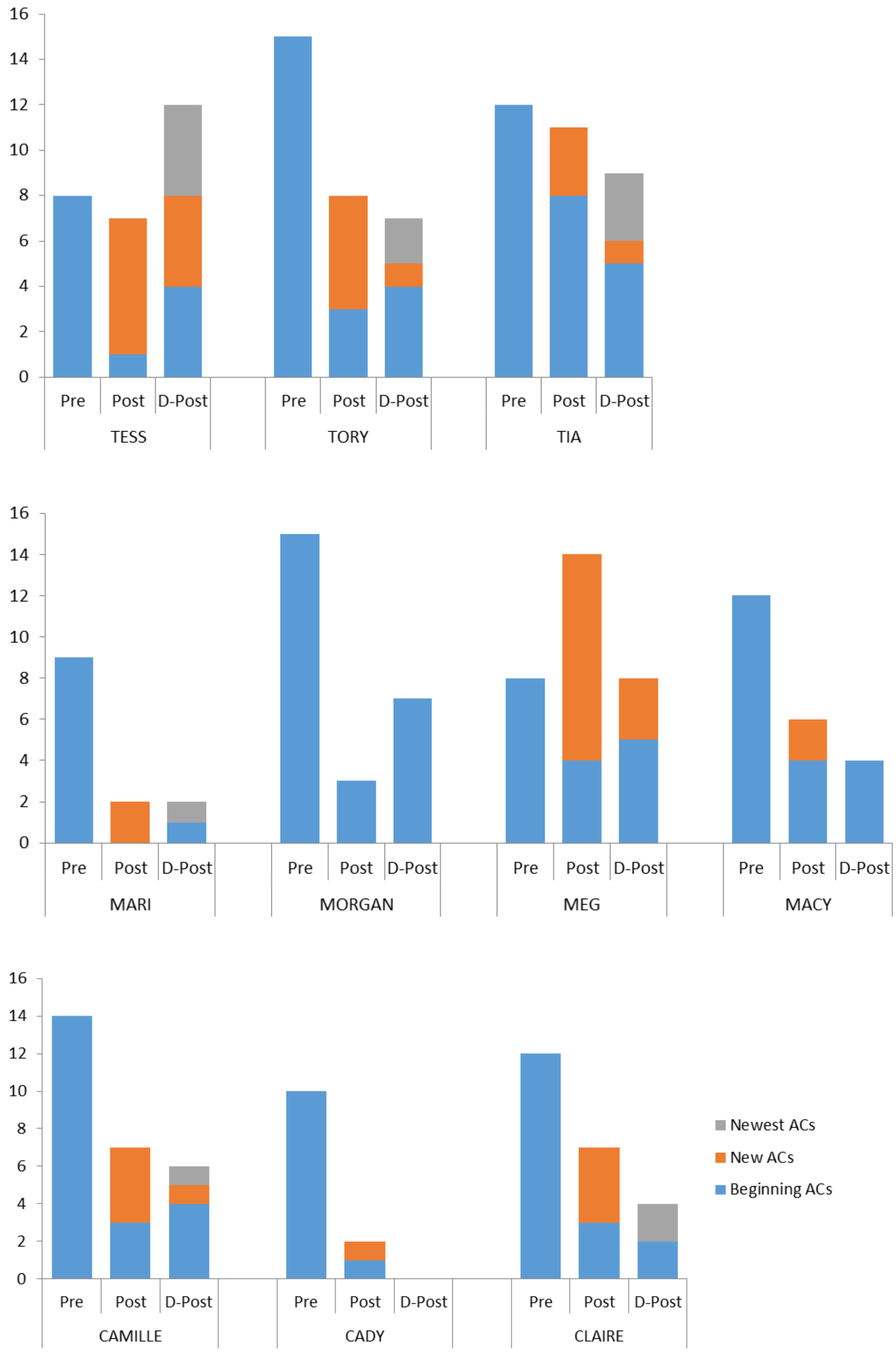

Figure 5.1. Comparison of all participants' number of alternative conceptions at pre-, post-, and delayed post-treatment.

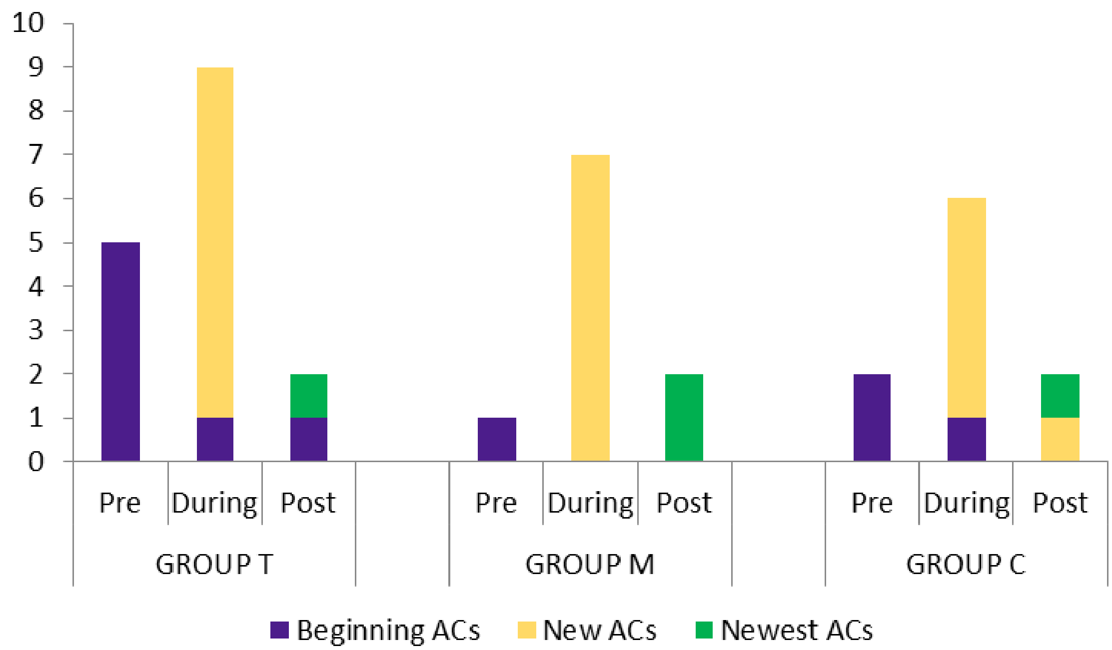

Figure 5.2. Comparison of the three groups' alternative conceptions at pre-, during, and post-treatment.

A summary and discussion of the results of the study is presented in the upcoming sections. First, there will be a section addressing the first research question regarding how the alternative conceptions of the participants were influenced by the treatment lessons. Then, the results that address the second research question regarding the influence of epistemic beliefs on the conceptual change outcomes occurred will be shared.

Conceptual Changes

The primary research question inquired into how the argumentative discourse lessons influenced the alternative conceptions of PSTs in the topics of photosynthesis and cellular respiration. The results indicated that the treatment lessons influenced the participants' alternative conceptions in predominantly positive ways. The evidence supports the following findings regarding the first research question.

Alternative conceptions decreased. The weight of evidence indicated that the argumentative discourse lessons decreased the number of alternative conceptions that participants held beforehand. This positive effect was evident in both the individual- and group-level results, which are summarized and discussed in the upcoming paragraphs. Although most of the evidence indicated that alternative conceptions decreased in the majority of participants, there were a few exceptions. Those exceptions will be highlighted and discussed.

All 10 participants experienced a decline in their original alternative conceptions immediately after the lessons (Figure 5.1). This provides strong support that engagement in the argumentative discourse lessons promoted positive conceptual change. Some participants had substantial decreases. For example, Mari had nine original alternative conceptions before the treatment lessons, none of which were exhibited afterward. Cady also had strong results, going from 10 original alternative conceptions to only one. Meg and Tia experienced the least amount of change, though still a reduction. Meg went from eight to four, and Tia dropped from 12 to eight original alternative conceptions.

Nine of the 10 participants also experienced a reduction in the total number of alternative conceptions they held before and after the treatment lessons (Figure 5.1). This means that even with the identification of some newly expressed alternative conceptions, the majority of participants still exhibited less overall after the lessons. Most members of Group C and Group M exhibited steep reductions in their total alternative conceptions from pre- to post-treatment. For example, Morgan began with 15 identified alternative conceptions and had only three after the lessons. Similarly, Cady had strong results, going from 10 to two in total. Group T experienced less promising results, although all three members did have a reduction. Tess went from eight to seven, Tia went from 12 to 11, and Tory went from 15 to eight total alternative conceptions.

The only exception to the reduction in total alternative conceptions was Meg. In startling contrast to the other participants, she experienced a large increase from eight at pre-treatment to 14 total identified after the treatment lessons. Although her original alternative conceptions decreased from eight to four, many newly expressed alternative conceptions were identified. This increased her total at post-treatment to nearly twice that of pre-treatment.

Like the individual-level results, the group-level results showed a decrease in original alternative conceptions. All three groups experienced a reduction in their original alternative conceptions following the treatment lessons (Figure 5.2). Group T had begun with the most, a total of five identified before the treatment lessons. That number dropped to only one at post-treatment. Group M began with one collective alternative conception and ended with none. Group C had two original alternative conceptions that were not identified at post-treatment.

When examining the change in total alternative conceptions at the group level, the results are less promising. Group T alone experienced a decrease immediately following the treatment lessons (Figure 5.2). They began with five and ended with two (one retained and one newly expressed). Group M's total alternative conceptions actually increased following the treatment lessons. They began with one identified alternative conception, which was not present following the treatment lesson. However, it was replaced with two newly expressed ones. Group C began with two alternative conceptions and ended with two different ones identified.

That there was no change or a slight increase in the number of total group-level alternative conceptions is of less relevance than all the decreases that occurred at the individual level. First, the increase was minimal. Group M increased by only one, and Group C simply had the same number post-treatment as when they began. Second, the amount of discussion that occurred and information included on the pre-treatment group knowledge structure was much less than the amount that occurred after the lessons. Thus, there was minimal content from which to identify alternative conceptions at the start of the study. Because there was little structure or directives imposed on the groups during the pre-treatment data collection time, they were allowed to discuss as little or as much as they wanted. The results were that little content, accurate or alternative, was mentioned at that stage. In contrast, after the study the groups engaged in more and deeper discussion and included much more content on their group knowledge structure, the majority of which was all accurate conceptions. This context is important when considering how Group M and Group C did not experience a decrease in their total number of identified alternative conceptions. That there were one or two newly exhibited alternative conceptions present in the large amount of accurate content the groups collectively held following the treatment lessons is understandable. The more pertinent evidence is that the number of their original alternative conceptions had been notably decreased by the treatment lessons.

Furthermore, group-level alternative conception data were interesting, but not as informative or relevant as the individual-level. First, the conceptual changes of individuals are what is most salient to educators. The discussed and agreed-upon group conceptual knowledge is pertinent only in how it influenced or did not influence the individual learners. Second, the group alternative conception data were flawed in that they were not consistently representative of individual understanding. One clear example was how Cady had agreed with her group and refrained from correcting an alternative conception that she later said she knew was incorrect at the time. Therefore, although the group-level results show Group T having better results in some ways than the other groups, the evidence from the individual learners was quite positive for the participants in Groups C and M, Meg notwithstanding. Group T individuals for the most part had poorer individual outcomes in spite of their ostensibly better collective group outcomes.

The treatment lessons were effective in promoting the reduction of previously held alternative conceptions regarding photosynthesis and cellular respiration in a group of PSTs. These findings are aligned with the substantial number of studies that have shown positive conceptual changes and learning advances that have occurred in other groups of learners at various levels (e.g., Acar, 2015; Adúriz-Bravo et al., 2005; Aydeniz et al., 2012; Eryilmaz, 2002 Gillies & Khan, 2008; Gillies et al., 2011; Hardy et al., 2010; Jiménez-Aleixandre & Pereiro-Munhoz, 2002; Mason & Santi, 1998; Mercer et al., 2004; Niaz et al., 2002; Venville & Dawson, 2010; Zohar & Nemet, 2002). These results also align with expectations based on conceptual change theory. The argumentative and collaborative discourse episodes provided participants with the conditions and impetus for grappling with their conceptual understanding of photosynthesis and cellular respiration (Chi et al., 1994; Duit & Treagust, 2003; Hewson & Hewson, 1984; Posner et al, 1982; Vosniadou, 1994). These lessons encouraged the PSTs to activate their prior knowledge, develop dissatisfaction with their alternative conceptions, and seek and adopt conceptions that were more intelligible, plausible, and fruitful (Posner et al., 1982).

Accurate conceptions increased. As alternative conceptions decreased, it was expected that accurate conceptual knowledge would increase. This positive outcome occurred in this study. The treatment lessons promoted the replacement of alternate conceptions with accurate ones. The participants' individual knowledge became more extensive and detailed following the argumentative discourse lessons. Most participants' post-treatment individual knowledge lists had more quantity and quality of accurate concepts than their pre-treatment ones. This was especially true in regard to the topic of cellular respiration. The participants' increased accurate conceptual knowledge was also evident in their post-interviews. In general, they had more content knowledge to share and expressed more eagerness and confidence in their understanding.

Predictably, the group-level conceptual knowledge was also deeper and more detailed. All three groups' post-treatment knowledge structure graphics were much more complex and included more depth of conceptual understanding than their pre-treatment graphics. Although alternative conceptions were present too, there was substantially more information presented, an increased amount of scientific concepts explained, and a greater number of accurate conceptions displayed.

As the participants delved deeper in the topics and applied critical thinking in a sociocultural context during the lessons, their knowledge increased, and their conceptual understanding coalesced toward accurate conceptions. This result can be interpreted in light of sociocultural learning theory (Vygotsky, 1978) which posits knowledge is not conveyed from the teacher directly to the pupil, but it is strongly influenced by peer communication. The peer and social influence was primarily positive in this study, resulting in groups that had more accurate and more complex conceptual understanding after the experience.

Some lasting conceptual change experienced. An important aspect of true conceptual change is that the improvements in knowledge are retained over time. To determine how well the participants retained their conceptual changes, I purposely required the participants to take the alternative conceptions survey again a little over two weeks after the lessons ended. This assessment, designated as the delayed post-treatment survey, was for identifying which, if any, of the alternative conceptions remained at that time.

The results provided evidence of lasting conceptual change following the treatment lessons. All participants held fewer of their original alternative conceptions at the delayed post-treatment time point than they had before the lessons (Figure 5.1). This means that all experienced improvement in their conceptual understanding that lasted for more than two weeks after the lessons.

The strength of this positive outcome was slightly dimmed, however, by examining the results in a different way. In comparing the number of original alternative conceptions that participants had right after the lessons to how many original ones they had at the delayed post time, it was clear that some originally identified alternative conceptions had returned in the majority of participants. A few of the original alternative conceptions that were not present after the lessons ended had returned in six of the 10 participants. The number that had returned was low (only one to three), and all participants held fewer overall than they had at the beginning. Four of the 10 participants held the same number or fewer than they had at post-treatment time.

Reverting almost immediately to some previously held alternative conceptions after instruction was to be expected. Previous research has noted that alternative conceptions can be resistant to change (Brumby, 1984; Driver et al., 1985; Harrell & Subramaniam, 2014; Helldén & Solomon, 2004; Songer & Mintzes, 1994). However, that most participants in this study had maintained most of their conceptual gains and had reverted to only a few previous alternative conceptions was promising.

Positive conceptual change occurred despite poor argumentation skills. All the groups exhibited poor argumentation quality as measured by their Assessing Scientific Argumentation in the Classroom (ASAC) observation protocol scores. For the cognitive and conceptual aspects of argumentation, Group C and Group T tied with scores of 52%. Group M scored 48%. These scores indicated that the content of all the groups' argumentation lacked a strong focus on essential argumentation practices such as being skeptical of ideas, seeking alternative explanations, and providing reasons when supporting or challenging ideas. They scored even worse on their epistemic aspects of argumentation. Group C scored 43%, Group M scored 38%, and Group T scored 29%. These indicated that all the groups were extremely poor in their abilities to engage in argumentation skills such as using the language of science, analyzing the relevance of the evidence, and employing scientific theories or models in their argumentation.

Low quality of argumentation was not unexpected, considering other researchers have reported a similar situation in their studies of argumentation (e.g., Watson, Swain, & McRobbie, 2004). That factor, however, did not prevent most participants from experiencing substantial gains in their conceptual understanding. This study demonstrated that positive conceptual change could result from argumentative discourse-based instructional tasks even if the participants have not yet become experts at the practice of argumentation.

New alternative conceptions were identified after the lessons. Although the treatment lessons led to a decrease in alternative conceptions overall, it was also true that some newly expressed alternative conceptions were identified in most individuals immediately afterward. Nine of the 10 participants exhibited at least one new individual-level alternative conception as revealed on their post-treatment data. Morgan was the only participant who did not express any new ones at that time. Most exhibited only a small number of new ones. For example, Cady only had one, and Mari and Macy only expressed two new ones each. Meg and Tess, however, expressed a large number of previously unidentified alternative conceptions immediately after the treatment lessons.

Meg provided evidence of holding 10 new ones, and Tess had six. Both Meg and Tess had noticeably poorer conceptual change results than the other participants overall.

In addition to exhibition of newly identified individual-level alternative conceptions, there were also new collective-level ones that appeared in all the groups following the treatment lessons. Group T expressed one new alternative conception. Groups M and C each exhibited two new ones.

The treatment lessons may have directly caused the development of new alternative conceptions in the participants. It is more probable, however, that the lessons may have simply served as an environment and opportunity in which already held alternative conceptions were allowed to emerge and be identified. Prior to the lesson, all groups spoke about photosynthesis and cellular respiration in unsophisticated and surface-level ways. Their original knowledge structure graphics were simple and the ideas discussed were superficial. Then the treatment lessons forced them to delve deeper and discuss concepts at length, causing alternative conceptions to emerge during and afterwards that had probably been present at the beginning, though not initially revealed. The value of this type of discourse was recognized by Nussbaum (2008), who termed it “critical, elaborative discourse” (p. 349).

The revelation of new alternative conceptions after the treatment lessons may also have been a consequence of the data collection procedures. For the collective conceptions, I identified the various alternative conceptions that were revealed and appeared to be accepted by the group prior, during, and after the lessons. The group members were completely free to bring up and discuss any conceptions about photosynthesis and cellular respiration they chose during the pre- and post-treatment knowledge structure graphic constructions. During the pre- and post-treatment interviews, I had the freedom to prompt the groups to discuss concepts of my choosing. However, I purposefully sought to limit those prompts as much as possible as I did not want to unduly influence the participants. I instead wanted their conceptions to emerge organically through group communication and their own choices as to what might be important and relevant to mention. Thus, there were likely numerous additional alternative conceptions the members would have agreed upon before the treatment if those concepts had happened to arise organically at that time. It may be inevitable that over time and with probing, additional already held alternative conceptions would continue to be revealed.

Summary. The first research question focused on how the argumentative discourse lessons influenced, if at all, the alternative conceptions of the participants regarding photosynthesis and cellular respiration. The results revealed that the treatment lessons reduced alternative conceptions in the majority of the participants. In addition, accurate conceptual knowledge was increased. The majority of participants retained most of their conceptual gains for more than two weeks following the treatment, although some of their original alternative conceptions reappeared. These positive conceptual changes occurred despite poor quality argumentation skills exhibited by the groups. Most participants expressed some alternative conceptions at the end of the treatment lessons that they had not revealed prior.

Influence of Epistemic Beliefs

In addition to examining how the treatment lessons influenced the PSTs' alternative conceptions, I sought to determine whether the underlying epistemic beliefs of the participants about science had an influence on the effectiveness of the lessons for promoting positive conceptual change. This study was unique in that the participants with similar epistemic beliefs were grouped together for most of the instructional tasks in the lesson. Thus, much of their discourse was with those who had similar beliefs. Note that there were also times during the lessons in which they engaged in discourse with those holding other epistemic beliefs. This occurred during the rotations for presenting, critiquing, and defending the arguments they had developed with their homogeneous group.

To address the second research question regarding the influence of epistemic beliefs, I examined the evidence for differences among the three epistemic groups. I looked for differences among the three groups' conceptual change outcomes at both the individual and group level. The preponderance of evidence provided support for the proposition that participants with stronger constructivist epistemic beliefs about science experienced better conceptual change results from the treatment lessons.

Epistemic beliefs influenced effectiveness of lessons in promoting conceptual change. The evidence from this study suggested that better conceptual change aligned with stronger constructivist beliefs. In general, the participants in Group C exhibited more positive individual-level conceptual change results than those in Group T. For example, most of the individuals in Group C had consistently positive results when examining how their original alternative conceptions changed over the course of the study. This was also true of their total alternative conceptions results. Cady, from Group C, had the best outcomes of all the participants. Group M participants also had better results than those in Group T, except for the notable outlier of Meg. Three of their four members had very good outcomes, exhibiting reduced alternative conceptions and increased accurate conceptions. In fact, Mari from Group M had the second best conceptual change results of all the study participants.

The participants holding the most traditional epistemic beliefs generally experienced the least reduction in alternative conceptions at both the post- and delayed post-treatment times. Tess even exhibited a larger number of alternative conceptions at the delayed post-treatment time than she did pre-treatment, the only participant to have such a result. Tia also had generally poor results. Tia and Tess both consistently exhibited less positive conceptual changes than did the other individuals in the study.

There were inconsistent results, however. For example, Tory and Meg's individual-level results represented contradictions to the generalization that those with more constructivist beliefs had better outcomes that those with more traditional beliefs. Tory, a strong traditionalist, had relatively good conceptual change results (similar to the results exhibited in most of Group M). Meg, moderate in her epistemic beliefs, had extremely poor results. More regarding this disparity will be discussed in the next section.

At the group level, there was both supporting and opposing evidence for the proposition that the stronger constructivists would have better outcomes than would the traditionalists. In support, there was the fact that all of the beginning group-level alternative conceptions of Group C and Group M had disappeared after the treatment lessons (Figure 5.2). Some newly expressed alternative conceptions were identified, but the original ones were gone. In contrast, Group T retained one of their original alternative conceptions throughout the entire study. Group T's engagements in the treatment lessons did not help them eradicate all of their original group-level alternative conceptions as it did in the other groups.

The opposing group-level result was that Group T experienced a reduction in their total group-level alternative conceptions (five reduced to one), while Group C and Group M did not. Group C ended with the same number of total alternative conceptions with which they began (two). Group M had the least positive results when examining the data in this way. They ended with one more alternative than with which they began (one increased to two). This makes it appear that Group T had better conceptual outcomes than the other groups.

This finding is partially explained by the fact that Group T was more talkative with one another during the initial data collection and revealed many more beginning collective alternative conceptions than did other groups. As a consequence, they exhibited a greater reduction after the lessons than did other groups. As mentioned previously, the alternative conceptions in Groups C and M were newly revealed ones, and none of their original ones were retained as had occurred in Group T. The individual-level results are also considered more representative than the group-level results in demonstrating actual conceptual change. Thus, the evidence as a whole supports the conclusion that the epistemic beliefs of the participants influenced the effectiveness of the lessons in promoting positive conceptual changes.

Definitive reasons for the marginally better conceptual change results from the stronger constructivists were outside the scope of this investigation. Many complex factors may be instrumental in this effect. For example, previous studies (Noroozi, 2016; Nussbaum & Bendixen, 2003; Nussbaum et al., 2008) have demonstrated a link between the epistemic beliefs of participants and the manner in which the participants interacted with one another throughout the lessons. The evidence from this study hints that social functioning and personality interactions may have played a role, as well as background knowledge and interest and confidence in learning science. However, these were not examined in the analysis of the data. This would be an area for more research.

Epistemic beliefs did not explain all variation in conceptual change outcomes. As explained in the previous paragraphs, it was apparent that epistemic beliefs had an influence on the success of participants in experiencing conceptual change as a result of the treatment lessons. However, the influence of the epistemic beliefs was not sufficient to explain all of the variation in the individuals' conceptual change results.

For example, Meg experienced the least positive conceptual change results of all the study participants. However, her epistemic beliefs were squarely in the middle of the group according to her scores on the epistemic beliefs survey. She was in Group M with others who had similar levels of epistemic beliefs. The rest of Group M's participants had strong positive conceptual outcomes. For example, Mari exhibited some of the best of the entire study. Yet, Meg herself experienced little growth in her conceptions. In fact, unlike all others in the study, she actually exhibited a large increase in alternative conceptions immediately following the treatment lessons.

Another case that did not align with expectations was Tory. Tory had scored as the second strongest traditionalist of the class on the epistemic beliefs survey. However, her conceptual change results were as positive as most of those in Group M. She experienced noticeably better overall results than did her other two Group T partners, Tess and Tia.

The cases of Meg and Tory illustrate the insufficiency of epistemic beliefs in explaining all the variation in conceptual change outcomes. As mentioned earlier, the evidence from this study suggested that the quality of argumentation skills was not influential in the conceptual change outcomes. All groups had low quality of argumentation, yet many participants experienced substantial conceptual changes. Although this evidence does not rule out the possibility of argumentation skills having an effect in other situations and with other populations, its influence was minimal to nonexistent with this sample. Some other factors that may have been pertinent were background science knowledge or feelings of self-efficacy and confidence in learning science. However, it was outside the scope of this study to determine the influence of those factors. Figure 5.3 summarizes the influencing factor of epistemic beliefs and the lack of influence of argumentation skills on the participants in this study.

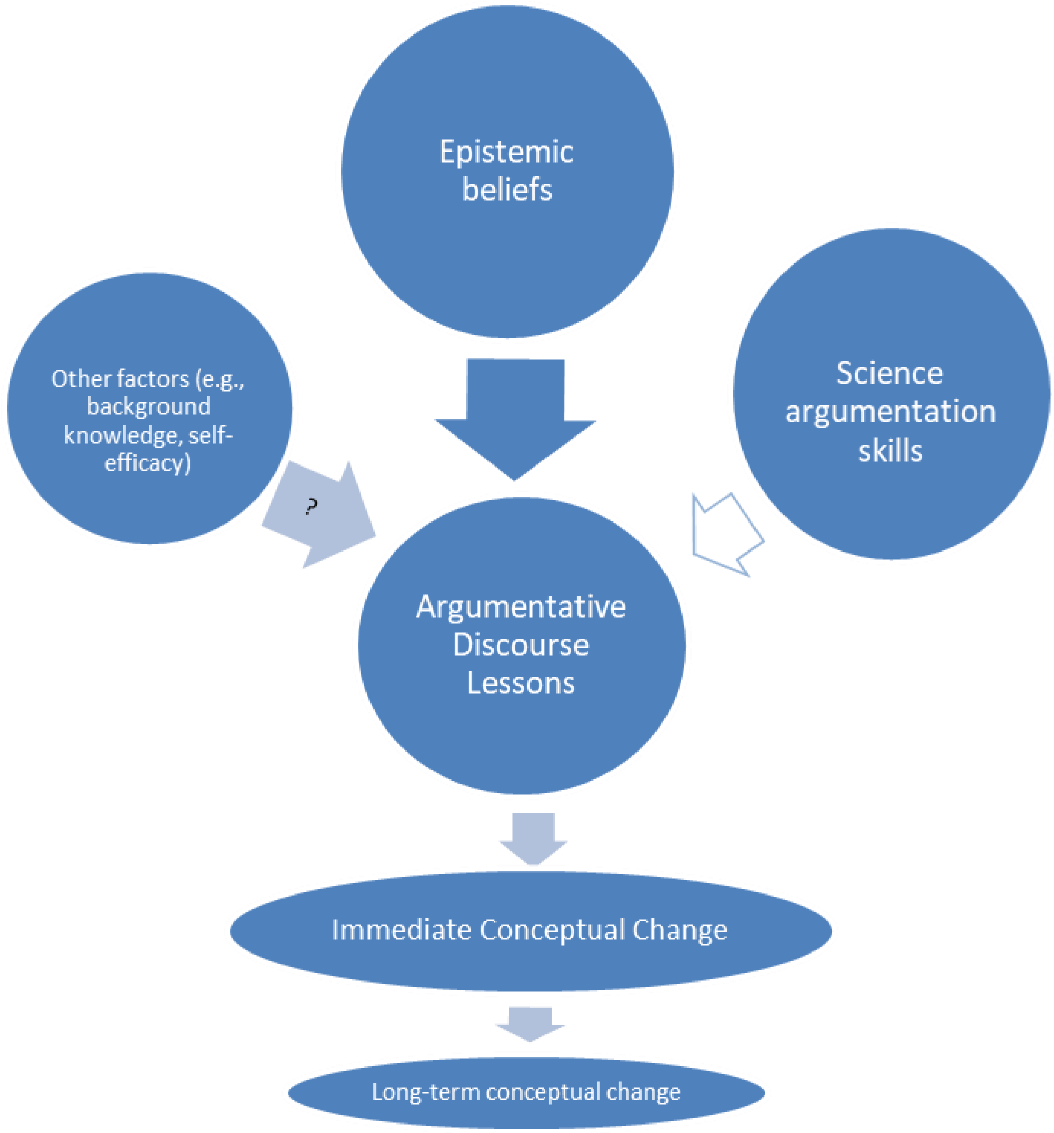

Figure 5.3. Some factors influencing conceptual change results.

Summary. The evidence indicated that those with more sophisticated constructivist beliefs about science experienced better conceptual change results following the argumentative discourse-based lessons. The influence of epistemic beliefs was apparent; however, there were some unexpected conceptual change results that were not consistent with the participants' epistemic beliefs. Thus, that factor did not entirely explain the variation in all the participants' results. Those other factors and the strength of their influence were outside the purview of this study.

Implications and Future Research

These findings have theoretical and practical relevance. I discuss two notable implications in the upcoming section. In addition, I provide suggestions for future research that could extend and enhance our understanding of how to use argumentative discourse to encourage conceptual change in science learners.

Useful for Promoting Conceptual Change

There were many positive conceptual changes that occurred following the treatment lessons. The majority of participants experienced a decrease in their alternative conceptions and an increase in their accurate conceptions. Additionally, there were lasting conceptual changes exhibited by most participants. For practitioners, the implication of these findings is that engaging students in this type of argumentative and collaborative discourse experiences is a viable means to encourage their conceptual growth.

Another positive outcome of the study that lends support to these lessons' usefulness in promoting conceptual change was that participants became more willing to share and discuss their conceptions after the lesson. This lends support to the lessons' usefulness in promoting conceptual change. The participants discussed a greater quantity of accurate conceptions as well as some newly revealed alternative conceptions following the treatment lessons. New alternative conceptions were expressed by nearly all participants. This seemingly concerning outcome was ameliorated by the increased talkativeness and sharing of ideas the majority of participants exhibited afterward as compared to beforehand. They began the study sharing little information regarding what they thought about the topics of photosynthesis and cellular respiration. By the end of the study, they exhibited more eagerness to discuss the concepts in depth.

Therefore, this study provides a documented means for encouraging PSTs to feel enabled to share more about their conceptions, both accurate and alternative. This can promote their conceptual change by helping them activate their prior knowledge and experience dissatisfaction with their alternative conceptions per conceptual change theory (Chi et al., 1994; Duit & Treagust, 2003; Hewson & Hewson, 1984; Posner et al, 1982; Vosniadou, 1994). The implication is for practitioners to consider using this type of instructional approach as a means of encouraging more open sharing of conceptions as a means for advancing conceptual change.

Taken all together, the findings regarding conceptual changes in participants should alleviate concerns some instructors may have in using argumentative discourse as an instructional strategy. Some have expressed a worry that allowing students to engage in discussions in which inaccurate conceptions may be voiced and considered might lead to the unintentional reinforcement of misconceptions (Sampson & Blanchard, 2012; Simon, Erduran, & Osborne, 2006). This study shows that positive learning can result from the opportunity to wrestle with concepts and critically evaluate evidence, even if alternative conceptions are expressed and given attention during that process. In fact, taking an opportunity for alternative conceptions to be heard can be argued as a vital part in promoting the conditions necessary for the process of conceptual change (Chi et al., 1994; Duit & Treagust, 2003; Hewson & Hewson, 1984; Posner et al, 1982; Vosniadou, 1994).

Rather than seeking to prevent the appearance of alternative conceptions in the classroom, teachers should create situations for them to emerge and be heard. This is in line with conceptual change theory in that learners must confront their alternative conceptions to begin the process of reducing them (Posner et al., 1982). They must be allowed to think and reason deeply about ideas (Vosniadau, 1994). The episodes of argumentative discourse can provide the impetus and productive atmosphere for that to occur (Nussbaum & Sinatra, 2003).

These positive results were limited to a small sample of PSTs learning about two limited life science topics. Thus, there is a need for future research using larger sample sizes, other sample groups of learners, and other science concepts. This would provide insights regarding its effectiveness in other learning situations. Additional research might explore precise reasons for why this experience fostered dialogue and increased the willingness of participants to share their conceptual understanding.

Effectiveness was Influenced by Varying Factors

The underlying epistemic beliefs of participants had some influence on the effectiveness of the treatment lessons in promoting conceptual change. In general, those with traditional beliefs had less positive conceptual growth than did those with stronger constructivist beliefs. One implication is that practitioners who choose to use argumentative discourse with PSTs may need to provide differentiation based on epistemic beliefs. Learners with traditional epistemic beliefs about science will need more support.

Teachers should be cognizant of student differences and ensure they provide support to those who struggle with learning the concepts through the chosen instructional approaches. Additional research beyond the scope of this study might explore specific ways educators could provide support for learners such as Meg who experienced poor conceptual changes from the argumentative discourse-based lesson experience. For example, researchers might examine whether grouping participants in more heterogeneous epistemic groups would provide better outcomes than were experienced in this study using homogeneous groups. Additional future research should explore other supports that might help science learners of all levels advance their scientific epistemic beliefs. Furthermore, a larger quantitative study might reveal more about what percentage of learners might be expected to have little to no positive conceptual outcomes as a result of this type of instructional experience.

With the result that epistemic beliefs did not account for all the variation in the conceptual outcomes of the participants, other factors must also have had an influence. Argumentation quality was one factor that was explored in this study. The evidence suggested that the argumentation quality did not account for variation in the PSTs' conceptual growth. The data showed the argumentation quality was consistently poor across all groups, yet some experienced much better conceptual changes than did others.

The poor argumentation quality did not prevent substantial conceptual changes in many participants in this study. However, since there was no group who had high quality argumentation skills with which to compare, it is impossible to know what greater gains might have been possible. Other studies have demonstrated that with more training and exposure to appropriate scientific argumentation techniques, greater learning gains were achieved (e.g., Nussbaum et al, 2008). Additional research is warranted.

In conclusion, that most participants experienced positive conceptual change even with poor argumentation skills implies that educators need not fear that the science learning of their students will be derailed by engagement in novice argumentation. Learners do not have to be expert constructors and disseminators of scientific arguments before they can benefit conceptually from the practice.

Since insights into additional factors that may or may not have influenced the participants' conceptual change outcomes was outside the scope of this study, future research is needed to identify and examine additional possibilities. Future research into factors such as participants' background knowledge, their self-efficacy toward learning science, and group social dynamics may provide more insights. With the exploration of additional factors influencing the outcome, questions about why the lessons were not effective for participants like Meg may be more fully explored.

Chapter Summary

To support learners in obtaining complex and sophisticated conceptual understanding that aligns with currently accepted scientific evidence, teachers must implement effective instructional methods. National educational policy documents promote the use of scientific argumentation in the K-12 curriculum (NGSS Lead States, 2013; NRC, 2012). Numerous research studies have demonstrated positive learning outcomes following the use of argumentative discourse in elementary through college level students (e.g., Acar, 2015; Adúriz-Bravo et al., 2005; Aydeniz et al., 2012; Eryilmaz, 2002 Gillies & Khan, 2008; Gillies et al., 2011; Hardy et al., 2010; Jiménez-Aleixandre & Pereiro-Munhoz, 2002; Mason & Santi, 1998; Mercer et al., 2004; Niaz et al., 2002; Venville & Dawson, 2010; Zohar & Nemet, 2002). Being able to create, evaluate, revise, and defend an argument based on objective evidence is a key scientific practice in which scientists engage, yet is often absent in science learning experiences. In addition to the benefits of learning key processes of science, argumentative discourse experiences support positive conceptual changes in learners.

The results of this qualitative study lend support to that assertion. Although the sample size was small, this in-depth look at how undergraduate PSTs' alternative conceptions were influenced by argumentative discourse-based lessons provides useful and detailed insights that add to the current literature. The conceptual understanding of most participants increased and became more complex and detailed, with the argumentative discourse-based lessons encouraging the eradication of naïve alternative conceptions and the adoption of more accurate and sophisticated conceptual knowledge.

By engaging in critical thinking and peer discussions to develop, analyze, critique, and debate claims and evidence, most learners in this study improved their conceptual understanding of the topic of photosynthesis and cellular respiration. Educators are advised to incorporate argumentative discourse learning experiences with other instructional strategies to support not only student skill development but also complexity and sophistication of conceptual understanding.

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APPENDICES

APPENDIX A: Epistemic Beliefs Survey

STUDENT BELIEFS ABOUT SCIENCE

Instructions: Please answer the following questions as best you can on a scale from **1** to **4**, with 1 being **strongly disagree** and 4 being **strongly agree**. There is no right or wrong answer; we are only interested in your opinion.

	Strongly Disagree				Strongly Agree
1. Truth is unchanging in science.	1	2	3	4	5
2. In science, most work has only one right answer.	1	2	3	4	5
3. Sometimes you just have to accept answers from the professional scientists, even if you don't understand them.	1	2	3	4	5
4. What we accept as knowledge in science is based on objective reality.	1	2	3	4	5
5. All professors in science would probably come up with the same answers to questions in science.	1	2	3	4	5
6. The most important part of work in science is coming up with original ideas.	1	2	3	4	5
7. If you read something in a textbook for science, you can be sure it is true.	1	2	3	4	5
8. A theory in science is accepted as true and correct if professional scientists reach consensus.	1	2	3	4	5
9. Most of what is true in science is already known.	1	2	3	4	5
10. Ideas in science are highly connected and related.	1	2	3	4	5
11. In science, it is good to question the ideas presented.	1	2	3	4	5
12. Correct answers in science are more a matter of opinion than fact.	1	2	3	4	5
13. If scholars try hard enough, they can find the answers to almost anything.	1	2	3	4	5
14. The most important part of being an expert in science is accumulating a lot of	1	2	3	4	5

facts.					
15. I know the answers to questions in science because I have figured them out for myself.	1	2	3	4	5
16. One expert's opinion in science is as good as another's.	1	2	3	4	5
17. Professional scientists can ultimately get to the truth.	1	2	3	4	5
18. Principles in science are unchanging.	1	2	3	4	5
19. Principles in science can be applied in any situation.	1	2	3	4	5
20. If my personal experience conflicts with ideas in the textbook, the book is probably right.	1	2	3	4	5
21. There is really no way to determine whether someone has the right answer in science.	1	2	3	4	5
22. Expertise in science consists of seeing the interrelationships among ideas.	1	2	3	4	5
23. Answers to questions in science change as professional scientists gather more information.	1	2	3	4	5
24. All professional scientists understand the field in the same way.	1	2	3	4	5
25. I am more likely to accept the ideas of someone with first-hand experience than the ideas of researchers in science.	1	2	3	4	5
26. I am most confident that I know something when I know what the professional scientists think.	1	2	3	4	5
27. First-hand experience is the best way of knowing something in science.	1	2	3	4	5

APPENDIX B: Alternative Conceptions Survey

Modified from Photosynthesis and Respiration in Plants Diagnostic Instrument (Haslam & Treagust, 1987)

Directions: *Please circle the letter of the answer for each multiple choice question. Then circle the number of the reason that best matches why you chose that answer. If your reason is not listed, please write down your exact reason(s) on the blank lines.*

1. What gas is given out in the LARGEST amounts by plants in the presence of sunlight?

A. Carbon dioxide
B. Oxygen

The reason for my answer is because:

1. This gas is given off in the presence of light energy because plants only respire during the day.
2. This gas is given off by plants because plants only photosynthesize and do not respire in the presence of light energy.
3. There is more of this gas produced by the plant during photosynthesis than is required by the plant for cellular respiration and other processes, so the excess is given off.
4. This gas is a waste product given off by plants after they photosynthesize.
5. ____

____

2. Which gas is taken in by plants in LARGE amounts when there is no light energy at all?

A. Carbon dioxide
B. Oxygen

The reason for my answer is because:

1. This gas is used in photosynthesis which occurs in plants all the time.
2. This gas is used in photosynthesis which occurs in plants when there is no light energy at all.
3. This gas is used in cellular respiration which only occurs in plants when there is no light energy to photosynthesize.
4. This gas is used in cellular respiration which takes place continuously in plants.
5. ____

____

3. Which gas is given off by plants in LARGE amounts when there is no light energy at all?

    A Carbon dioxide
    B Oxygen

The reason for my answer is because:

1. Plants stop photosynthesizing when there is no light energy available but they continue to respire and therefore they give off this gas.
2. This gas is given off by the plant during photosynthesis which takes place when there is no light energy.
3. Since plants respire only when there is no light energy they give off this gas.
4. ____

____

4. What gas is taken in by plants in the LARGEST amounts in the presence of light energy?

    A. Carbon dioxide
    B. Oxygen

The reason for my answer is because:

1. Plants make their food from this gas in the presence of light energy.
2. Animals need this gas to respire in the presence of light energy.
3. ____

____

5. Cellular respiration in plants takes place in:

    A. The cells of the roots only.
    B. Every plant cell.
    C. The cells of the leaves only.

The reason for my answer is because:

1. All living cells need energy to live.
2. Only leaves have special pores (stomates) to exchange gas.
3. Only roots have small pores to breathe.
4. Only roots need energy to absorb water.
5. ____

6. Cellular respiration is:
   A. A chemical process which occurs in all living cells of plants and animals.
   B. A chemical process which occurs in plant cells but not in animal cells.
   C. A chemical process which occurs only in animal cells but not in plant cells.

The reason for my answer is because:
   1. Only plant cells obtain energy to live in this way.
   2. All living cells of plants and animals obtain energy to live through this process.
   3. Only animal cells need energy to live as they cannot photosynthesize.

   4. ____

   ____

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

The reason for my answer is because:
   1. Plants never respire, they only photosynthesize.
   2. Plants take in carbon dioxide and give off oxygen when they respire.
   3. Cellular respiration provides the plant with energy to live.
   4. Cellular respiration only occurs in plants when there is no light energy.

   5. ____

   ____

8. When do plants respire?
   A. Only at night (when there is no light energy).
   B. Only during daylight (when there is light energy).
   C. All the time (whether there is light energy or no light energy).

The reason for my answer is because:
   1. Cells of plants can photosynthesize during the day when there is light energy and therefore they respire only at night when there is no light energy.

2. Plants need energy to live and cellular respiration provides energy.
3. Plants do not respire they only photosynthesize, and photosynthesis provides energy for the plant.

4. ____

____

9. Which of the following equations BEST represents the process of cellular respiration in plants?

A. Glucose + oxygen → energy + carbon dioxide + water.

B. Carbon dioxide + water → energy + glucose + oxygen.

C. Carbon dioxide + water $\xrightarrow[\text{light energy}]{\text{chlorophyll}}$ oxygen + glucose.

D. Glucose + oxygen → carbon dioxide + water.

The reason for my answer is because:

1. During cellular respiration plants take in carbon dioxide and water in the presence of light energy to form glucose.
2. Carbon dioxide and water are used by the plant to produce energy during which time glucose and oxygen waste is produced.
3. During cellular respiration, plants take in oxygen and give off carbon dioxide and water.
4. During cellular respiration, plants derive energy from glucose using oxygen.

5. ____

____

10. Which of the following equations BEST represents the overall process of photosynthesis?

A. Glucose + oxygen $\xrightarrow[\text{light energy}]{\text{chlorophyll}}$ carbon dioxide + water

B. Carbon dioxide + water $\xrightarrow[\text{light energy}]{\text{chlorophyll}}$ glucose + oxygen + water

C. Carbon dioxide + water + energy → glucose + oxygen

The reason for my answer is because:

1. The pigment called chlorophyll combines with the carbon dioxide in the presence of light energy and produces glucose and water.
2. The energy from sunlight is used by plants containing chlorophyll to combine carbon dioxide and water to form glucose and oxygen and water.
3. Glucose and oxygen are combined in the presence of chlorophyll and light energy to form carbon dioxide and water.

4. ____

____

11. Which of the following factors is NOT important for the process of photosynthesis?

A. Amount of oxygen.
B. Amount of carbon dioxide.
C. Amount of chlorophyll.
D. Amount of light.

The reason for my answer is because:

1. Photosynthesis can take place with no light energy.
2. Non-plants like fungi which do not contain chlorophyll or similar pigments can also photosynthesize.
3. Photosynthesis cannot take place without carbon dioxide.
4. Oxygen is not required for photosynthesis; it is a by-product of photosynthesis.

5. ____

____

12. The MOST important benefit to plants when they photosynthesize is:

A. Removal of carbon dioxide from the air.
B. Conversion of light energy to chemical energy.
C. Production of energy.

The reason for my answer is because:

1. Photosynthesis provides energy for plant growth.
2. During photosynthesis, energy from the sun is converted and stored in glucose molecules.
3. Carbon dioxide is taken in by the leaf through the stomates during photosynthesis.

4. ____

____

13. Which of the following comparisons between the processes of photosynthesis and cellular respiration in plants is correct?

	Photosynthesis	**Cellular respiration**
A.	Takes place in plants only	Takes place in animals only
B.	Takes place in all plants	Takes place only in all animals
C.	Takes place in plants in the presence of light energy	Takes place in all plants and in all animals at all times.
D.	Takes place in plants in presence of light energy	Takes place in all plants only when there is no light energy and all the time in all animals

The reason for my answer is because:

1. Plants photosynthesize and do not respire at all.
2. Plants photosynthesize during the day and respire at night (when there is no light energy at all).
3. Because cellular respiration is continuous in all living things. Photosynthesis occurs only when light energy is available.
4. Plants respire when they cannot obtain enough energy from photosynthesis (e.g., at night), and animals respire continuously because they cannot photosynthesize.

5. ____

____

14. The MAIN source of a plant's biomass is:

A. Water
B. Soil
C. Oxygen
D. Carbon dioxide

The reason for my answer is because:

1. Plants use nutrients in water to create their cells.
2. Plants use nutrients from the soil to create their cells.
3. Plants use molecules from oxygen to create plant cells.
4. Plants use molecules from carbon dioxide to create plant cells.

5. ____

____

APPENDIX C: Instructions for Generating Artifacts

Instructions for the Individual Knowledge Lists:

1. Provide each PST with one half-sheet of paper with *Photosynthesis* written on it.
2. Say, "I want to know what you know right now about the topic of photosynthesis. I am going to give you three minutes to write down everything you know about it on the paper. You may use pictures, diagrams and charts as well as words and sentences. This is not for a grade! There is no need to feel anxious about what you know or don't know. I only want to see what your knowledge is right at this moment. No checking your phone, talking to your neighbors, or peeking at their papers. Any questions?"
3. After approximately three minutes, pass out the other half-sheet of paper with *Cellular Respiration* written on it. Repeat the same process, but ask them to write down everything they know about cellular respiration.
4. Collect the individual knowledge lists.

Instructions for the Group Knowledge Structure Graphics:

1. Provide each table group with two large blank sheets of paper.
2. Say, "Now, please represent your entire group's knowledge structure graphic of both photosynthesis and cellular respiration on the large sheets of paper. You may choose to keep the papers separate or link the two sheets together in some way. You may use pictures, diagrams and charts, as well as words, symbols, and sentences. You will have about seven minutes. Any questions?"

3. After approximately seven minutes, collect the groups' knowledge structure graphics.

APPENDIX D: Semi-Structured Interview Protocol

1. Describe what you have written/diagrammed in your group's knowledge structure graphic.
2. What did you mean by each of the concepts that you as a group have chosen to include in your diagram?
3. Why did you choose to include each of them?
4. What do these lines (or arrows, etc.) between the concepts represent?
5. (To each individual) Was there any concept that ended up on this group knowledge structure graphic that was not on your original knowledge list? If so, where did the idea come from?
6. Why did you choose to keep photosynthesis and cellular respiration separated (or why did you choose to link your knowledge structure graphics of photosynthesis and cellular respiration)?
7. Were there any concepts that were discussed/suggested, but did not make it into the final knowledge structure graphic? If so, why?
8. (To each individual) How would you characterize your attitude toward learning science and teaching? What experiences have you had that contributed to that attitude?

Questions adapted from Abd-El-Khalick (2006)

APPENDIX E: ASAC Observation Protocol

Assessing Scientific Argumentation in the Classroom (ASAC) **(**Sampson, Enderle, & Walker, 2012)

Time	Description of Event

CONCEPTUAL AND COGNITIVE ASPECTS OF SCIENTIFIC ARGUMENTATION

HOW THE GROUP ATTEMPTS TO NEGOTIATE MEANING OR DEVELOP A BETTER UNDERSTANDING

(THESE ITEMS TARGET HOW THE GROUP ATTEMPTS TO MAKE SENSE OF WHAT IS GOING ON)

1. The talk of the group was focused on solving a problem or advancing understanding.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: The emphasis on advancing understanding indicates that there were some significant claims or explanations at the heart of discussion. Groups that score high on this item maintain the focus of their talk and efforts on understanding or solving the problem rather than the best way to finish their work quickly or with the least amount of effort. *Note:* Groups that stay on topic but never go engage in an in-depth discussion about what is happening should be scored low on this item.				

2. The participants sought out and discussed alternative claims or explanations.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: Divergent thinking is an important part of scientific argumentation. A group that meets this criterion would talk about more than one claim, explanation, or solution. Individuals that valued alternative modes of thinking would respect and actively solicit new or alternative claims, explanations, or solutions from the other participants. *Note:* Groups that discuss multiple types of grounds or support for a claim, explanation, or solution but only one claim, explanation, or solution should be scored low on this item.				

3. The participants modified their explanation or claim when they noticed an inconsistency or discovered anomalous data.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: Inconsistencies between claims or explanation and the phenomenon under investigation are common in science. A group that modified their claim or explanation when they noticed inconsistencies or anomalies would not ignore "things that do not fit" or attempt to discount them once they are noticed by one of the participants. Groups that score high on this item try to modify their claim or explanation (not just their reasons) in order to account for an inconsistency or an anomaly rather than attempting to "explain them away".				

4. The participants were skeptical of ideas and information.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: During scientific argumentation, allowing a variety of ideas to be presented, but insisting that challenge and negotiation also occur would indicate that group members were skeptical. Accepting ideas without accompanying reasons would result in a low score because it is a sign of credulous thinking. In other words, students must be willing to ask, "how do you know?" or "Are you sure?" Groups that respond to the ideas of others with comments such as "ok", "that sounds good to me", or "whatever you think is right" would score low on this item.				

5. The participants provided reasons when supporting or challenging an idea.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: Providing reasons to support or challenge a claim, conclusion, or explanation is a crucial characteristic of argumentation. Claims must have some support provided for them beyond simply restating the claim itself. Making claims without support would result in a low score on this item and including any reason like "that's what I think", "it doesn't make sense", "the data suggests…" or "but that doesn't fit with…" would result in a higher score. *Note:* Personal or past experiences count as a reason for this item.				

6. The participants based their decisions or ideas on inappropriate reasoning strategies.	**3**	**2**	**1**	**0**
	Not at all	Once or Twice	A few times	Often
Description: When people are trying to support ideas they often: (a) jump to hasty generalizations, (b) attribute causality to random events, (c) insist that a correlation is evidence of causality, and (d) exhibit a confirmation bias (for example saying, "now we need some data to prove this"). Groups that avoid inappropriate reasoning strategies or recognize them when they occur would score high on this item. Groups where these types of reasoning strategies are common would score low on this item.				

7. The participants attempted to evaluate the	**0**	**1**	**2**	**3**

merits of each alternative claim or explanation in a systematic manner.	Not at all	Once or Twice	A few times	Often

Description: This addresses the tentative or responsive nature of science. The idea that there is often more than one way to interpret data or evidence and that only through careful analysis can an idea be accepted or eliminated. This gets at the "gut" response factor. Conclusions are not based on opinion or inference.

EPISTEMIC ASPECTS OF SCIENTIFIC ARGUMENTATION

HOW CONSISTENT THE PROCESS IS WITH THE CULTURE OF SCIENCE

(THESE ITEMS TARGET HOW THE GROUP DETERMINES WHAT COUNTS AS VALID OR ACCEPTABLE)

	3	**2**	**1**	**0**
8. The participants relied on the "tools of rhetoric" to support or challenge ideas.	Not at all	Once or Twice	A few times	Often

Description: "Tools of rhetoric" refer to tricks or strategies used to win a debate. Tool of rhetoric include: (a) claiming that if someone cannot disprove a claim it must be true, (b) using emotive words and false analogies, (c) directing the focus of the discussion from thinking about a claim or an explanation to thinking about the person holding or proposing a claim or an explanation, (d) over-relying on authorities, (e) dichotomizing issues so that if you discredit one position, then the observer is forced to accept the other view, and (f) making claims that are a simple restatement of one of the premises. Groups that avoided using the tools of rhetoric would score high on this item. *Note:* This item focuses on how the content of a discussion is presented or supported (i.e., how they are saying it) rather than the content of the discussion (i.e., what they are saying).

	0	**1**	**2**	**3**
9. The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	Not at all	Once or Twice	A few times	Often

Description: A goal of scientific argumentation is the use of data as evidence to defend a claim, conclusion, or explanation. This item implies that students were attempting to use evidence in their arguments. This should more than an opinion; they must include data. Statements like "that's what I think" or "it doesn't make sense" would result in a low score. Statements like "the data we found suggests that …" or "our evidence indicates…" would result in a higher score.

	0	**1**	**2**	**3**
10. The participants examined the relevance, coherence, and sufficiency of the evidence.	Not at all	Once or Twice	A few times	Often

Description: This item draws attention to the amount and kinds of evidence used to support a claim or explanation. Groups that attempt to (a) determine the value of a piece of evidences (e.g., "does that matter?"), (b) look at links or the relationship between multiple pieces of evidence (e.g., "This supports X and Y but this only supports X"), or (c) attempt to determine if there is enough evidence to support an idea (e.g., "We do not have any evidence to support that") would score higher on this item.

	0	**1**	**2**	**3**
11. The participants evaluated how the available data was interpreted or the method used to gather the data.	Not at all	Once or Twice	A few times	Often

Description: The evidence provided for a claim or explanation should be evaluated based on how well the data was gathered and interpreted. A question such as "Why is that evidence included?" or "How did they gather their data?" or "Where did that data come from?" indicates that the participants are assessing methods or an interpretation of data and would result in a higher score.

	0	**1**	**2**	**3**
12. The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	Not at all	Once or Twice	A few times	Often

Description: Science is theory-laden. In other words, scientists rely on broad, well-supported organizing ideas to frame their arguments and claims. Students should also employ these paradigmatic ideas in providing warrants for the evidence and claims they make or use to refute others' claims. Explicit reference to these "big ideas" will result in a higher score on this item.

	0	**1**	**2**	**3**
13. The participants made distinctions and connections between inferences and observations explicit to others.	Not at all	Once or Twice	A few times	Often

Description: The structure of scientific arguments includes evidence involving both empirical (such as quantitative measurements and systematic observations) and inferential (noting of trends and logical connections among observations) aspects. Making these distinctions and their connections explicit to others enhances the quality of the argumentation and thus results in a higher score.

14. The participants used the language of science to communicate ideas.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: This item stresses the importance of the accurate use of scientific language by students. The adoption and use appropriate terms (e.g., condensation, force, etc), phrases (e.g., "it supports" rather than "it proves") or ways of describing information is a characteristic of argumentation that is scientific. *Note:* Ideas may be explicated before being labeled with the correct terminology.				

SOCIAL ASPECTS OF SCIENTIFIC ARGUMENTATION

HOW THE PARTICIPANTS INTERACT WITH EACH OTHER
(THESE ITEMS TARGET GROUP DYNAMICS)

15. The participants were reflective about what they know and how they know.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: It is important for members of the group to agree on what they know and to be specific about how they know. Statements such as, "do we all agree?" or "is there anything else we need to figure out?" or "can we be sure?" indicate that participants are monitoring their progress and have an end goal in mind.				
16. The participants respected what each other had to say.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: Respecting what others have to say is more than listening politely or giving tacit agreement. Respect also indicates that what others had to say was actually heard and considered (e.g., "that is a good point", interesting idea", or "I hadn't thought of that"). A group that scored high on this would allow everyone to present their ideas and express their opinions without censure or ridicule.				
17. The participants discussed an idea when it was introduced into the conversation.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: To be a participating and contributing member of the group, it is important to feel valued. Ideas and opinions need to be critically acknowledged. This means they are considered and given weight by the group. Groups that ignore ideas when they are proposed (results in the same idea being mentioned over and over) would earn a low score on this item.				
18. The participants encouraged or invited others to share or critique ideas.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: Good argumentation comes from considering and comparing competing ideas from multiple individuals to construct the most robust explanation of the phenomenon under study. Groups that consist of individuals that invite others to share (e.g., "what do you think"), critique (e.g., "do you agree" or "it is ok to disagree with me"), or discuss an idea (e.g., "let's talk about this some more") would score higher that a group with an alienating leader that dominates the conversation and the work of the group.				
19. The participants restated or summarized comments and asked each other to clarify or elaborate on their comments.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: The depth of discussion will be enhanced by not making implicit judgments or assumptions about another person's ideas or views, and it demonstrates that their point of view is valued and is furthering the discussion. Communication provides students with opportunities to identify the strengths and weaknesses of their understanding.				
20. There was equal participation from all members of the group.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: The degree to which in member contributed to the argumentation impacts the depth and breadth of the discourse. Also, one or two high performers may result in a high score on some items, but not be representative of the actual argumentation event. Groups where some members are not engaged would score low on this item.				

APPENDIX F: IRB Approval Letter

4/1/2015

Investigator(s): Heather L. Barker, Cindi Smith-Walters and Angela Barlow
Department: Mathematics and Science Education
Investigator(s) Email: hlb3g@mtmail.mtsu.edu; cindi.smith-walters@mtsu.edu; angela.barlow@mtsu.edu

Protocol Title: "The influence of argumentative discourse on pre-service teachers' alternative conceptions in life science "

Protocol Number: 15-229

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 and 21 CFR 56.110, and you have satisfactorily addressed all of the points brought up during the review.

Approval is granted for one (1) year from the date of this letter for 30 (THIRTY) participants.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918. Any change to the protocol must be submitted to the IRB before implementing this change.

You will need to submit an end-of-project form to the Office of Compliance upon completion of your research located on the IRB website. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions. Failure to submit a Progress Report and request for continuation will automatically result in cancellation of your research study. Therefore, you will not be able to use any data and/or collect any data. Your study expires 4/1/2016.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete the required training. **If you add researchers to an approved project, please forward an updated list of researchers to the Office of Compliance before they begin to work on the project.**

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

Sincerely,

Institutional Review Board
Middle Tennessee State University

APPENDIX G: Photosynthesis Enacted Lesson Plan

Task 1: Introduction of the Guiding Question

Dr. Pepper showed the class a small seed and a large tree cookie (a thin cross-section of a tree trunk) She talked about how the large tree grew from a tiny seed. Dr. Pepper then asked the PSTs to individually consider the question, "From where does a plant get its biomass?" and directed them to write their initial answer on a sticky note.

Task 2: Selecting a Claim

Dr. Pepper showed the class a cartoon drawing consisting of four panels. Each panel showed a boy musing about from where the biomass of a plant originates. The first panel showed him saying that he thinks most of the biomass comes from nutrients from the soil that the plant absorbs. The second panel showed him supposing that perhaps instead the biomass mainly came from the water taken up by the plant. In the third panel, the boy surmised that the mass is primarily formed from the air molecules that a plant absorbs. The final panel showed the boy suggesting that the biomass comes directly from the sun's energy.

Dr. Pepper explained that there were four different claims made in the cartoon regarding from where the majority of a plant's biomass comes. She asked the PSTs to discuss the four claims and select the one their group agreed was the most accurate. Then she instructed them to write down the claim they chose. This provided the first opportunity for participants to engage in argumentative discourse based on their existing background knowledge.

During this task and all other portions of the lesson, save the final teacher-directed instruction at the end, Dr. Pepper floated around to all the table groups and made herself available for questions. She did not directly answer most questions that were asked of her. Instead, Dr. Pepper would engage in questioning to help scaffold the participant in reaching the correct understanding on their own. Also, while she moved around the groups, Dr. Pepper paid attention to the group talk, pointed out interesting things she wanted them to notice, and made comments on what they were doing and/or discussing when she dropped by.

Task 3: Modeling the Photosynthesis Equation

Dr. Pepper passed out an envelope to each group. The envelope contained various words and symbols, each written on small squares of paper. These were referred to as the equation component cards (Table G1).

Table G1

Type and Number of Equation Component Cards

Word or Symbol	# of Cards Provided (Photosynthesis Lesson)	# of Cards Provided (Cellular Respiration Lesson)
ATP Energy	1	1
Chlorophyll	1	1
Chloroplast	1	1
$C_6H_{12}O_6$	1	1
CO_2	1	2
Enzymes	1	1
Fats	1	1
Heat	1	1
H_2O	1	2
Light Energy	1	1
Minerals	1	1
Mitochondria	1	1
Nutrients	1	1
O_2	1	2
Stomata	1	1
Soil	1	1
+	5	6
→	2	2
(blank card)	1	1

Dr. Pepper directed the groups to lay out the cards to model the equation for photosynthesis on their tabletops. She explained that they might or might not use all of the cards and they could also add their own words or symbols to the blank card if desired. This was another opportunity for argumentative discourse as the participants planned and negotiated with their group members based on their background knowledge and reasoning.

Task 4: Gathering and Sharing Evidence within the Group

Dr. Pepper then explained that the PSTs would be gathering evidence to help them in supporting the claim they had chosen regarding the source of a plant's biomass. She explained that the evidence might also lead them to choose a different claim. Posted on the walls around the room were nine different information sheets, referred to as evidence stations (see Appendix H for an example). Each evidence station provided specific information about an aspect deemed relevant to helping the PSTs determine the correct reactants and products of the process of photosynthesis, as well as the fact that carbon dioxide contributed the most to a plant's biomass and was absorbed from the air through the stoma. The PSTs were also provided with student evidence sheets, which included questions that were designed to guide them in discovering the necessary information from each station (see Appendix I for an example). Dr. Pepper asked that each group divide the nine evidence stations among their members to ensure that all the stations were visited by at least one of their group members. She then gave the class approximately 10 minutes to study the evidence stations and record what they learned on their evidence sheets. Then Dr. Pepper directed them to return to their tables and share what they learned with the rest of their group. She encouraged them to modify their claim or their equation as needed based on the evidence.

Task 5: Developing an Argument to Support the Claim

Dr. Pepper passed out a large sheet of blank paper and reminded the PSTs of previous lessons when they had developed scientific arguments using the Claims, Evidence, Reasoning (CER) framework (McNeill & Krajcik, 2012). She briefly reviewed each part of the framework. Dr. Pepper then asked each group to write down their preferred claim from the concept cartoon, as well as all the evidence they felt supported that claim. She instructed them not to write their reasoning piece yet. This task provided the first opportunity for participants to engage in argumentative discourse using the evidence they had gathered from the information stations.

Task 6: Rotations for Presenting, Critiquing, and Defending Arguments

Rotation one. Dr. Pepper told the class that they would be sharing their arguments with other groups. She asked each of the six groups to choose one person to remain at their table and be their presenter. Then she instructed the rest of the group members to disperse to other tables, each to a different table, to act as reviewers.

The presenter was to explain and defend, if appropriate, her group's argument (chosen claim and supporting evidence) to the visiting reviewers. The reviewers were instructed to evaluate the group's argument and engage in discourse regarding the ideas presented. This part of the lesson was intended to stimulate the participants' critical thinking, introduce new claims and/or previously unconsidered evidence, and require that all participants practice critiquing and defending the validity of the arguments as necessary. During his task, participants had the opportunity to engage in argumentative discourse with those from other groups who had different epistemic beliefs.

To support the generation of relevant discourse, Dr. Pepper posted suggested actions and prompts the presenters and reviewers should engage in during this part of the lesson (Figure G1).

Presenters:

- Present your claim and all your evidence
- Explain why you included each piece of evidence
- Explain how your thinking aligns with accepted scientific practices, assumptions, theories, laws, and/or models, etc.
- Respectfully defend your claim/evidence as you see fit. Be open to considering revisions as well.

Reviewers:

- Do you agree with the presenter's claim? Tell them why or why not. Be specific.
- Can you suggest any evidence they may not have considered?
- Evaluate their evidence. Is there anything that seems incorrect, weak, or irrelevant? If so, explain.
- Is there anything you can help them clarify?
- Share any knowledge you have learned from previous tables.

Figure G1. Prompts for presenting, critiquing, and defending arguments.

There was quite a lot of confusion among the participants regarding which table they were each supposed to go to first. Dr. Pepper gave the directions a few more times while the PSTs milled around. She also helped direct some individuals to a specific spot before everyone finally settled down to the task.

Rotation two. Once discussions waned at the tables, Dr. Pepper instructed the participants to rotate again so they went to the next table in a clockwise direction. She asked that the presenters again explain their arguments to the new visitors at their tables. The participants were required to again engage in discourse around the arguments presented at each table, evaluating, critiquing, and defending the claims and evidence as necessary.

Task 7: Changing, Revising and Expanding the Argument

Following the two rotations, Dr. Pepper had everyone return to their original groups and discuss what they had learned. She instructed them to change or revise their arguments and/or their photosynthesis models if they deemed it necessary. She also asked them to add their reasoning piece to their arguments once they were all agreed on their final chosen claim and pieces of supporting evidence. Participants had the opportunity to engage in additional argumentative discourse with their original small groups in order to revise, improve, and augment their written arguments.

Task 8: More Rotations for Presenting, Critiquing, and Defending Arguments

Rotation three. Dr. Pepper next asked the participants to return to the same table they visited during rotation one. She asked the same presenters to stay at their own tables to explain their possibly revised and augmented arguments to their visitors again. This was another opportunity for argumentative discourse with others who had different arguments and held different epistemic beliefs. Some of the participants became confused about where to go, and thus not all returned to the exact same tables they had been at during the first rotation.

Rotation four. The end of the class period approached, so Dr. Pepper did not give the groups too much time to talk before asking them to rotate for the fourth and final time. This rotation was short, only a couple minutes. Then Dr. Pepper asked everyone to return to their original groups.

Task 9: Final Argument Revision

Dr. Pepper gave the groups a few more minutes to make any additions or edits to their claim, evidence, or reasoning according to anything they had learned during rotations three and four. This was the last opportunity in the lesson for peer discussions and any final argumentation. By this point, all the groups were basically happy with their arguments and exhibited little interest in making revisions. There had been little discourse that occurred during the third and fourth rotations. Most groups had simply shared their argument, the visitors had agreed with little comment, and then the discussion had turned to off-task topics.

Task 10: Teacher Explanation and Questioning

Dr. Pepper asked the participants to return to their original groups. She then started questioning the class as a whole. She began by asking them what they wished they knew more about. Many participants responded with “ATP” and then Tess, a participant in Group T, said she wanted to know the process of photosynthesis itself. Dr. Pepper then directed someone from Group M to go to the board and write down their equation for photosynthesis. Macy went to the board and wrote their correct equation, with assistance from her other group members.

Using the example on the board, Dr. Pepper began talking about the process of photosynthesis. She interspersed her instruction with questions directed at the class. During this part of the lesson, Dr. Pepper explained how the plant obtains the water molecules (absorbed through the roots) and the carbon dioxide molecules (absorbed through the stoma from the atmosphere). She explained how the plant uses the sun’s energy to complete a series of chemical reactions that results in the products of glucose, oxygen and water vapor. Participants were attentive and most took notes during this part.

Dr. Pepper attempted to clarify the confusion she had noticed regarding the nutrients. She explained that the plant does use nutrients to build the majority of its biomass, but not nutrients from the soil. She reminded participants that the plant uses water, but biomass itself is the weight of the dry plant. Therefore, water cannot be contributing to the dry biomass. Dr. Pepper then explained that the majority of the mass came from the carbon dioxide, a nutrient. She showed them how the glucose molecule was made up mostly of carbon and oxygen, but did not explain that the hydrogen molecules are very small in comparison and thus do not contribute must to the mass. She completed her explanation with the question, “So does this make sense to you?” She was met with some nods and some quizzical looks, but no answers or questions. The time for the class period was up and Dr. Pepper dismissed them.

APPENDIX H: Photosynthesis Evidence Station Sheet

Evidence Station 1: van Helmont's Investigation

From 1642-1647, Jon Baptista van Helmont carried out an experiment to determine where a plant's biomass came from. He hypothesized that the plant obtained its mass from the soil. He grew a willow tree in a pot during the five-year experiment. He recorded the weight of the tree and the weight of the soil in the pot at the beginning and at the end of his experiment.

Look at the following table that shows the change in weight of the tree and the dried soil:

van Helmont's Data:

Year	**Weight of Tree**	**Weight of Dried Soil**
1642	5 pounds	200 pounds
1647	169 pounds, 3 ounces	199 pounds, 14 ounces
Total Weight Change:	Increased by 164 pounds, 3 ounces	Decreased by 2 ounces

van Helmont concluded from his experiment that almost all of their biomass must come from the water, since it apparently did not come from the soil.

APPENDIX I: Photosynthesis Evidence Gathering Student Sheet

Station 1: van Helmont’s Investigation

1. Is van Helmont’s conclusion justified by the results of his experiment? Explain why or why not.

2. If van Helmont's conclusion is not valid, state a more valid conclusion based on the results of his experiment. What is the only thing that his investigation proved?

APPENDIX J: Cellular Respiration Enacted Lesson Plan

Photosynthesis Lesson Reviewed

The class session began with Dr. Pepper showing some examples of plants and seeds (i.e., ivy plant, avocado pit) to generate interest. She then conducted a review of the photosynthesis lesson from the previous class session by first having the participants individually write the equation from memory. Next, Dr. Pepper asked them to work together in their small groups to model the equation for photosynthesis using the provided set of equation component cards (Table G1). Note that the participants were continuing to work in the same small groups they had been assigned for the entire study.

Dr. Pepper then asked guiding questions and provided information to review the class on the components of the photosynthesis equation and what occurs during the process. She also talked through the concept regarding the how most biomass originates from air and not the other source options provided in the previous lesson. Participants continued to express some confusion. Dr. Pepper spent some time emphasizing the seemingly incongruous fact that most of plant biomass come from air. She also prompted participants to take notes.

Task 1: Introduction of the Guiding Question

The cellular respiration lesson began with an introduction to the guiding question, “How and when does a plant use the food it makes to sustain life?” Dr. Pepper reminded the participants that during the previous lesson that she had asked them to choose a claim and then gather evidence. During this lesson, however, she explained that she would instead have them collect some evidence first, before seeking to make a claim to answer the guiding question.

Task 2: Gathering and Sharing Evidence within the Group

Dr. Pepper directed the participants to gather evidence regarding the process of cellular respiration. This evidence would help them in developing their claims to answer the guiding question. As in the previous lesson, evidence stations had been set up around the room. This time the stations were focused on information related to cellular respiration (see Appendix K for an example). Each evidence station provided specific information relevant to helping the PSTs determine the correct reactants and products of the process of cellular respiration, as well as other details regarding its purpose and when it occurs. The PSTs were provided with student evidence sheets, which included questions that were designed to guide them in discovering the necessary information from each station (see Appendix L for an example). The small groups divided up the 10 evidence stations so that all stations were visited by at least one of the group members. Dr. Pepper then gave the class approximately 15 minutes to study the evidence stations and record information on their evidence sheets before returning to their tables. Once back together again, the group members were asked to report on what they had learned to the rest of their small group so that everyone heard and understood the information from all the evidence stations.

Task 3: Modeling the Cellular Respiration Equation

Dr. Pepper passed out a set of equation component cards (Table G1) to each group and asked them to model the cellular respiration equation using the cards. This was the same task she had had the participants do during the photosynthesis lesson when she asked them to model the photosynthesis equation. She explained that they might or might not use all of the cards and they could also add their own words or symbols to the blank card if desired. Dr. Pepper directed the participants to think about the evidence from the evidence stations that supported the way they decided to model the cellular respiration equation. This was the first opportunity for argumentative discourse to occur regarding cellular respiration. Participants were able to reference evidence they had just gathered to support their arguments regarding the correct cellular respiration equation

Task 4: Compiling Evidence and Developing a Claim

Dr. Pepper reminded the participants that during the photosynthesis lesson she had asked them first to choose a claim and then to gather evidence. For this lesson, however, she asked them first to compile the evidence they thought seemed relevant to helping them answer the guiding question "How and when does a plant use the food it makes to sustain life?" Dr. Pepper instructed each group to obtain a large sheet of paper to write down the evidence. She reminded the participants of the CER framework (McNeill & Krajcik, 2012) and explained they would be adding the claim and reasoning later. Dr. Pepper asked that the participants reference the evidence station number for the pieces of evidence they recorded. She also told them that the equation for cellular respiration they had modeled would function as part of their evidence.

Dr. Pepper floated around to tables helping the groups determine what evidence might be helpful in answering the guiding question. She reminded them to reference the stations. She gave them about 15 minutes for this part.

Then Dr. Pepper asked the groups to each make a claim that answered the guiding question. She reminded them that the claim should be based on the evidence they had been discussing and recording. Groups had the opportunity to engage in more argumentative discourse with their homogeneous epistemic beliefs group members throughout the development of their claim, evidence, and reasoning

Task 5: Rotations for Presenting, Critiquing, and Defending Arguments

Rotation one. Dr. Pepper told the class that they would be sharing their arguments with other groups. She asked each of the six groups to choose one person to remain at their table and be their presenter. Then she instructed the rest of the group members to disperse to other tables, each to a different table, to act as reviewers.

The presenter was to explain and defend, as appropriate, her group's claim and supporting evidence to the visiting reviewers. The reviewers were instructed to evaluate the group's argument and engage in discourse regarding the ideas presented. This part of the lesson was intended to stimulate the participants' critical thinking, introduce new claims and/or previously unconsidered evidence, and require that all participants practice critiquing and defending the validity of the arguments as necessary. To support the generation of relevant discourse, Dr. Pepper posted suggested actions and prompts the presenters and reviewers should engage in during this part of the lesson (Figure G1). The participants had the opportunity to engage in argumentative discourse with those from other small groups who held different levels of epistemic beliefs and had different ideas regarding the claims, evidence and reasoning in the arguments.

Since this was the same procedure as the last class period, participants were much quicker at choosing a presenter and then dispersing to other tables. They quickly began presenting and discussing the claims and evidence. Dr. Pepper walked around and asked probing questions.

Rotation two. After a few minutes, Dr. Pepper instructed the participants to rotate again so they went to the next table in a clockwise direction. She asked that the presenters again explain their arguments to the new visitors at their tables. The participants were encouraged to again engage in discourse around the arguments presented at each table, evaluating, critiquing, and defending the claims and evidence as necessary.

Task 6: Changing, Revising and Expanding the Argument

Next, Dr. Pepper had the participants return to their home tables to report what they had learned to each other. She asked them to revise their claims and evidence according to any new insights they had gained. Dr. Pepper encouraged them to add to their evidence and to remember to reference the stations where the evidence had originated.

After giving the groups a few minutes to share, revise, and add to their evidence accordingly, Dr. Pepper next instructed them to add the reasoning section to their argument at this time. Dr. Pepper shared some optional sentence starters for helping the participants write their reasoning piece for their arguments. Additionally, she reminded them explicitly to identify and use scientific concepts and models that they got from the stations to use in explaining why their evidence supported their claim. This was the last opportunity in this lesson for participants to engage in argumentative discourse

Task 7: Teacher Explanation and Questioning

Next, Dr. Pepper asked the groups to wrap up their conversations and add the final changes to their completed written arguments. She then began questioning the whole class regarding the components and actions involved in the process of cellular respiration. She asked scaffolded questions that stepped the whole group through the basics of the cellular respiration equation, making sure that participants were listening and taking notes. Along the way, a few participants asked questions in order to clarify some points they were unsure about. Eventually, Dr. Pepper asked the guiding question and emphasized the correct concept that answered it: how the plant was using the products of photosynthesis in cellular respiration, and when that action occurred.

Finally, Dr. Pepper highlighted the cyclical connection between photosynthesis and cellular respiration. She explained how the carbon cycled through the environment due to the actions of photosynthesis, cellular respiration, and organic decay. She closed the lesson by emphasizing the interactions between people and plants and our dependence on the functioning of plants' photosynthesis and cellular respiration processes. The time for the end of the class period came and Dr. Pepper dismissed the PSTs.

APPENDIX K: Cellular Respiration Evidence Station Sheet

Evidence Station 1: Peanut Burning Experiment

During photosynthesis, a peanut plant creates glucose molecules. These macromolecules are often converted to other types of macromolecule such as carbohydrates (example: starches, sugars), fats (example: oils) and proteins. While some of those macromolecules are stored in all parts of the plant (i.e. in the stem, leaves, peanut shells), peanut plants tend to situate the majority of the storage in their underground fruits (the peanuts).

Anna, a biology student performed the following experiment:

She placed 50 mg of peanuts in a test tube. Then she set the peanut on fire beneath another tube containing 20 ml of water. She observed the burning peanut and she measured the maximum amount of degrees that the water increased in temperature. Then, Anna put 50 mg of peanut shells in another tube and burned it beneath a tube containing 20 ml of water. Again she observed the burning of the shell and measured the maximum increase in the water temperature. She did the same with 50 mg of sand.

Her results:

	Length of burning time	**Smoke**	**Flame**	**Initial Water Temperature**	**Final Water Temperature**
50 mg of peanuts	268 seconds	Large amounts of oily, black smoke	Tall, strong, bright, glowing, steady	20° Celsius	100° Celsius
50 mg of peanut shells	15 seconds	Little smoke	Faint, sputtering, hardly burning	20° Celsius	25° Celsius
50 mg of sand	0 seconds	none	none	20° Celsius	20° Celsius

Combusting Peanut

https://www.youtube.com/watch?v=Om30MM_E7Q0

APPENDIX L: Cellular Respiration Evidence Gathering Student Sheet

Station 1: Peanut Burning Experiment

1. How do you know there was energy stored in the peanut and in the peanut shells, but not in the sand?

2. Where did the energy stored in the peanut and the shell originally come from?

3. During what process was this energy stored in the peanut?

4. In this experiment, discuss what happened to the energy stored in the peanut.

5. Combustion is often used as a representation (metaphor) to help understand the process of cellular respiration. Why do you think that is (i.e. how are combustion and cellular respiration similar processes)?

APPENDIX M: Alternative Conceptions Identified in this Study

		Alternative Conceptions Identified
1.	P	Plant biomass originates from water
2.	P	Plant biomass originates from the sun
3.	P	Plant biomass originates from O_2
4.	P	Plant biomass originates from multiple sources (e.g., soil, water, air, sun)
5.	P	Plant biomass originates from soil
6.	P	Plants "eat" soil
7.	P	Nutrients for plants come ONLY from soil
8.	P	Occurs all the time in plants
9.	P	Only occurs in the dark
10.	P	Mostly takes place in the middle of the day
11.	P	P timing: light not required
12.	P	P equation: gas exchange is O_2 in, CO_2 out
13.	P	P equation: turns light directly into sugar
14.	P	P equation: sugar is a reactant
15.	P	P equation: chlorophyll is a reactant
16.	P	P equation: unspecified energy is a reactant
17.	P	P equation: unspecified energy is a reactant in addition to light
18.	P	P equation: ATP energy is a product
19.	P	P equation: chlorophyll is a product
20.	P	P chlorophyll is not required
21.	P	P oxygen is a waste product, ignoring its importance as a reactant for CR
22.	P	P sugar may be "given off" after produced
23.	P	P sugar is stored in chloroplasts only
24.	P	P produces energy directly
25.	P	P purpose: main benefit to the plant is to remove CO_2 from air
26.	P	P purpose: mainly to create O_2 for CR
27.	P/CR	P and CR equations are the exact reverse/opposite of each other
28.	CR	CR equation: gas exchange is CO_2 in, O_2 out
29.	CR	CR equation: water is a reactant
30.	CR	CR equation: do not recognize sugar is a reactant
31.	CR	CR equation: do not recognize energy is a product
32.	CR	CR timing: only occurs in light/day
33.	CR	CR timing: only occurs in dark/night
34.	CR	CR timing: only occurs when P is not happening
35.	CR	CR purpose: simply to exchange CO_2 and O_2
36.	CR	CR purpose: to provide energy when P is not occurring or has not made enough energy
37.	CR	CR purpose: to produce sugar
38.	CR	CR purpose: to store sugar
39.	CR	CR ATP energy is absorbed

40.	CR	CR ATP energy is a type of stored energy
41.	CR	CR sugar made during CR is stored in stoma
42.	CR	CR requires chlorophyll
43.	CR	CR animals do CR because they cannot do P
44.	CR	CR process only in animals
45.	CR	CR location: occurs in roots only
46.	CR	CR location: occurs only in leaf cells
47.	CR	CR only leaves have pores/stomata
48.	CR	CR plants lack mitochondria
49.	CR	CR related to exercising (in humans)
50.	CR	Similar to physical respiration in animals; plants do CR, but animals breathe
51.	CR	Gas exchange varies: plants respire O_2, but animals respire CO_2
52.	CR	Associated with blood flow
53.	CR	Happens in lung organs only

P = Photosynthesis CR = Cellular Respiration