**Science and Mathematics Education Centre**

# The Effectiveness of Interactive Multimedia on Student's Comprehension of the Process of the Light Independent Reaction of Photosynthesis

**Soha Sobhanian**

**This thesis is presented for the Degree of**
**Doctor of Philosophy**
**of**
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## Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number # SMEC-02-13

Signature: 

Date: August 8, 2017

**ABSTRACT**

The complexity of photosynthesis challenges both teachers and students at every level of education. Consequently, the main purpose of this study was to evaluate the role that multimedia and interactive activities may play in students' understanding and retention of this complex scientific concept of the Calvin cycle in photosynthesis and how students perceived the implementation of such technology in their classrooms. The study focused on students enrolled in an introductory biology course in a four-year bachelor degree institution.

Three research questions guided the study and both quantitative and qualitative data were collected. During two semesters, a total of 352 students were initially assessed for prior knowledge and then divided into either a comparison or treatment group based on laboratory section number. To help students better understand the Calvin cycle, they observed a short narrated animation. The comparison group only viewed the narrated animation while the treatment group viewed the animation and completed an interactive activity quiz. Quantitative data were collected three and six weeks after the teaching intervention to assess students' understanding and retention, respectively. Qualitative data were collected over three semesters during which a total of 60 students were individually interviewed. Interviews supplemented the quantitative data to determine how students' perceived the addition of narrated animation and interactive activity quiz to their understanding of the Calvin cycle and its influence on their understanding and retention of complex concept.

The four multiple-choice questions of the first assessment evaluated understanding of the Calvin cycle three weeks after the teaching intervention implementation. Both groups scored similarly in three questions while the treatment group outperformed the comparison group in one question. So, while interactive activity was useful in teaching aspects of the Calvin cycle, its role in improving mental models or addressing the existing misconceptions was limited. Students' general

and specific retention patterns were assessed six weeks after the intervention through written statements and drawing and responses were evaluated using 5-point scales. Evaluation of the written statements displayed similar distribution pattern for scores of 5, 4, 3, and 2, though a slight deviation were observed in lower end where 59% of the treatment group scored 0 or 1 out of 5 compared to 66% of the comparison group. The recollection of certain aspects of the cycle were also improved after the intervention, lending support to the interactive activity influence, though minor, in improving retention and aiding lower achieving students. Both groups scored better in the second question, though, no significant deviation was noted between the groups, indicating that interactive activity was not as successful in internalizing the concept as was hoped.

The qualitative data demonstrated students' positive perception toward animation and its constructive role in their learning that was further enhanced through subtitles. Based on the collective analysis of the responses, combined with optimistic view of animation, and accessibility for both groups, the narrated animation was valuable in learning about a complex scientific concept like the Calvin cycle. Interview responses, showed high level of interest for the interactive activity in their courses, though additional modifications and improvements are needed.

Tools such as animations and interactive computer activities that attempted to actively engage students in their learning process can supplement traditional teaching. This study utilized both an animation and an interactive activity to enhance students' understanding of the Calvin cycle. The results of this study demonstrated the value of the role of the animation; however, the influence of the interactive activity was less pronounced. Some of the limitations of the study that may have hindered the effectiveness of the outcomes included the short duration of the animation and the design of the interactive activity quiz, the student population that was relatively high achieving, and the laboratory setting with potential deviation in teaching styles among teaching associates.

## DEDICATION

I thank God for giving me a wonderful family that supported me through every step of my journey. My work is dedicated to my mom, dad, grandma, brother, and sister who encouraged me to be the best I can be. Your patience and encouragement made a world of difference.

I also express my sincerest thanks to my mentor, Dr. David Treagust, who worked diligently and patiently with me throughout this process. I have gained valuable experience from working with you. I thank you for your time and efforts contributed to this study.

I also want to thank my husband, Jashim, my friends and colleagues who aided me over the past few years to be the best I can be and never to give up.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Overview of Chapter and Introduction to the Study

This chapter, which is divided in six sections, provides background about the current research. Sections 1.2, 1.3 introduce the research problem and discuss the rationale for the study, respectively. Section 1.4 provides the necessary background in the support of the presented study and section 1.5 outlines the research question. Section 1.6 briefly discusses the instruments utilized and section 1.7 considers the limitations of the research. Lastly, section 1.8 presents a summary of the chapter.

This section considers the college students' preparedness and skills to study science at a higher education institution. According to the report collected by American College Testing, ACT (2012), only 31% of all 2012 high school graduates taking the ACT examination were academically ready to complete college science courses). A year later, the number increased to 36%, which is still below the accepted range (ACT, 2013a). What is of concern to educators was that these students must have completed the two-year science requirement to successfully graduate from high school. However, many students test scores suggested that they have not gained an adequate amount of knowledge during the two years of high school science. Consequently, many students were required to take remedial courses in at least one subject because, they lacked the necessary skills for enrolling in a standard credit course (Adelman, 1998; ACT, 2004). Furthermore, a survey completed by ACT (2013b) showed that while 89% of high school teachers reported their students as being well prepared for college, college professors placed the number at 26%. Consequently, college instructors find themselves in situations where they must cover basic content before discussing the core concepts set for the course college curriculum (Adams, 2013). An outcome of such dilemma is that instructors have been working diligently to find avenues to best aid students succeed in their courses. This study was also initiated with the same goal in mind.

A main difference between students enrolled in college in 21st century verses those of the late 20th century is the adaptation of technology into people's daily lives. The rapid adaptation of technology such as personal computers, Internet access, video games, YouTube and Instagram have created a dependency in the current student population. Simultaneously, educational institutions in many countries, including the United States of America, have started to dedicate a large portion of their yearly budget on strategies that moved away from the traditional teaching styles of the past and toward a more modern education system. Consequently, a system was created that increasingly depended on computers and ever-so-advancing software supplements that in some cases replaced the old-style of teacher-student interaction. Many research studies have been conducted to better understand how the implementation of these transforming teaching instruments influenced the overall student performance at all levels of education (Ainsworth, Prain, & Tytler, 2011; Dori & Belcher, 2005; Harris et al., 2009; Gilbert & Treagust, 2009; Mayer, 1994; Wu & Shah, 2004). However, one point remains pivotal in these studies that regardless of the instructor's opinion about technology, its implementation and contribution to learning is inevitable. So, it is essential for instructors to learn how to use the technology effectively to maximize its benefits, while ensuring that it will not rule their classrooms.

### 1.2 The Research Problem

Keeping in mind the situation described before, this study examined the effectiveness of implementing interactive multimedia technology as a supplementary tool to assist college students with their learning and understanding of complex scientific.

The main goal of this study was to assess the effectiveness of implementing multimedia and interactive activity as teaching tools in college science classes to enhance students' learning experience and to enable students to develop a deeper and long lasting understanding of complex scientific concepts such as photosynthesis.

### 1.3 Rationale for the Study

Being an instructor is more than simply following a curriculum set by the department and teaching the same content to groups of students, semester after semester. An educator must reflect on his/her teaching style to ensure that an engaging learning environment has been created, enabling students to thrive and prosper in their academic setting. Such reflections should thoroughly examine the student population and teaching tools to identify the most effective methods for each learning environment.

In a society in which the new student population's focal attention is on technology, it is inherent for the instructors to utilize technology to better engage their students. Today's technology allows for a natural collaboration between spatial and verbal representation of the information. However, as discussed above, educators must become acquainted with and be cautious as to what particular combination is best suited for their teaching and/or department curriculum objectives. When designing an engaging learning environment, the educator must also understand the cognitive levels and learning orientations of their student population. Based on published STEM statistics, United States ranks 20th among the industrialized nations in high school science attainment (OECD, 2012). A study conducted by Anderson (1989) with Michigan State University students who had taken two years of high school biology, suggested that up to 75% of this student population did not gain valuable biology knowledge during their high school years. Therefore, when students start their higher education, many find their science courses challenging, even when they had successfully completed high school science requirements. Thus, it is reasonable to conclude that if students had difficulty acquiring basic knowledge in high school, they would have an even harder time understanding the same processes in more detail and in intense teaching periods during college. This study endeavored to find new avenues to aid college students in their learning process when studying complex science concepts.

Understanding the student population is an essential step in selecting the proper teaching tools. As Ecrama-Robinson (2011) explained, students acquire knowledge through multiple channels including but not limited to verbal, linguistical narration, images, and visual imagery (viewing figures, diagrams, and watching animation). Multiple representations supported students' learning by allowing learners to construct targeted knowledge using representation that was best suited to their learning styles, while capturing their interest in the subject matter (Ainsworth, 1999). Ainsworth et al. (2011) stated that when content was presented in different representations, it created meaningful connections within given information and therefore promoted a deeper understanding of knowledge. These studies add support to Piavio's dual coding theory (1986) where he suggested that information presented in verbal (i.e. spoken or written words) and non-verbal (i.e. images, graphics, illustration, animations, and video) forms can be integrated effectively for a more complete understanding of the concept. Moreover, in the majority of cases, educators found that implementation of visual representation together with other representations improved students' retention abilities and therefore enhanced learning outcomes (Dori & Belcher, 2005; Harris et al., 2009; Gilbert & Treagust, 2009; Mayer, 1994; Wu & Shah, 2004).

Another example in support of dual-coding theory is the research by Mayer and Sims (1994). College students were first assessed for their spatial visualization ability (i.e. creating mental images). Computer generated animation was utilized to teach inexperienced students about the working of the bicycle tire pump. One group consisted of high- and low-spatial ability students, who watched a narrated animation (concurrent group) while a second group with similar student population watched the animation followed by narration (successive group). Generally, students in the concurrent group performed better in assessments compared to the successive group. Thus, in this study simultaneous visual and verbal presentation of information improved inexperienced learners' understanding of the content. Furthermore, students with high visual-spatial abilities benefited from the simultaneous presentation of information, which enabled them to form effective mental models and therefore enhanced their cognition. A similar conclusion was drawn from a second group of students learning about the human respiratory system using either successive or concurrent learning technique. Overall, this research demonstrated that multiple representations can have a positive influence on students' understanding of concepts, including those associated with natural sciences (Mayer & Sims, 1994).

Mayer and Chandler (2001) presented two distinct learning views. The first is known as information acquisition where learners increase their knowledge through memorization. The second is knowledge construction where the learners receive, organize, and integrate new knowledge with previously learned information. Many science instructors prefer the knowledge construction view, enabling educators to guide students to actively make sense of the presented information. Consequently, multimedia with an interactive component could be used as an effective teaching tool to promote the construction of new knowledge among science students. As will be explained (section 2.7 and 2.8), this study attempted to understand whether implementing interactive multimedia in one of the core science classes benefited students' learning outcomes, related to the multistep scientific concept of photosynthesis. Moreover, if there were benefits, how these learning outcomes could be eventuated.

The result of this study could encourage colleges and universities to incorporate effective technology in their course curriculum to better fit today's technology-savy student population, creating a more effective learning environment for science students.

### 1.4 Background of the Study

Many concepts in cellular and molecular biology are multi-step processes (i.e. photosynthesis, cellular respiration, replication, etc.). Because of the complexity of these biological systems, students must create strong and dynamic mental models that connect the steps and create an overall understanding of systems.

In cellular biology, the concept of photosynthesis has been identified as important and yet difficult to understand (Eisen & Stavy, 1988, Marmaroti & Galanopoulou, 2006; Yenilmez & Tekkaya, 2006). Aware of the conceptualization challenges, the cellular biology instructors of the institute where this research took place spent a full week of instruction on photosynthesis process (i.e. 3 instruction hours). Additionally, students also participated in 6 hours of laboratory work that reinforced the lecture information and reviewed additional handouts provided by the instructor. However, students' responses in examinations and laboratory reports suggested that the majority did not have a clear understanding of the concept of photosynthesis. Course instructors suggested that the lack of understanding stemmed from both the complexity of this multi-step system and the presence of misconceptions from prior education.

Educators are continuously searching for innovative ways to effectively engage their students in courses and improve learning outcomes. Consequently, many instructors across the globe have taken steps in large-scale implementation of multimedia technologies in their classrooms (Eison, 2010; Jhurreev, 2005; Kwando 2007; Ullrich, Shen, Tong, & Tan, 2010). But, what does the word "multimedia" mean? Multimedia is the presentation of information using multiple media such as audio, animation, video, diagram, and/or text. Multiple representations could be redundant (i.e. closed captioning of a narrated animation) or present additional information (Ainsworth, 2006; Rose & Meyer 2002; Schwartz & Beichner 1999). In recent years, multimedia has also been grouped with interactive applications to enhance learning. Interactivity in the terms of learning environment implies two-way action with the goal of fostering the learning process being in line with the instructional goals (Groff, 2013; Moreno & Mayer, 2007; Wagner, 1994). Interactive multimedia relies heavily on the actions of the learners, enabling them to take control of their own learning process (Moreno & Mayer, 2007).

However, the outlook toward new technology has not always been encouraging. In the late years of the 20th century, many studies suggested that implementation of new technology did not significantly influence the learning environment in terms of student achievement (see for example, Cuban 1986). Such inadequacies were either the result of infrequent use of the technology or lack of its effectiveness compared to more traditional teaching styles (Cuban, 1986; Vanderbilt, 1996). Since then, many educators have focused on ensuring that new age technologies have been extensively assessed prior to their large-scale implementation (Mayer & Moreno 1998). Such research, have rooted in cognitive psychology, analyzing how students acquire, process, and retains information (Neisser, 1967).

This study examined the effectiveness of implementation of animation and interactive activity on student comprehension and retention of photosynthesis processes, namely the Calvin cycle, throughout the semester. Statistical analyses were completed on pre- and post-test scores, examination scores, and students' demographical data to determine if utilization of the activity had any effect on students' understanding. In addition, the study analyzed qualitative data to identify possible benefits of the implementation of the multimedia and the interactive activities on addressing students' understanding of the concepts. Furthermore, the qualitative data was used to evaluate students' attitude toward implementation of such technologies in their classrooms especially science courses.

### 1.5 Research Questions

Three research questions guided this study, dealing with comprehension (research question 1), retention (research question 2), and perception (research question 3) after implementation of the teaching intervention. These questions were:

1. Does implementation of the Calvin cycle animation complemented with an interactive activity quiz positively influence students' understanding of concept of the photosynthesis in a core undergraduate biology course?
2. How does the use of interactive activity quiz in a core undergraduate biology course influences students' retention of the Calvin cycle?

3. What are students' perceptions toward implementation of multimedia and interactive multimedia in their learning environment?
    a. What features and attributes of the animation are deemed constitutive and fundamental verses unimportant and trivial?
    b. How does such implementation influence participants' comprehension and retention of the concept?
    c. What are students' perception toward implementation of the multimedia in their science classes and
    d. How do students perceive the interactive multimedia and its unique features?

**1.6 Research Design**

A science education study typically follows one the three common research designs of post-positivist, interpretivist, or critical theories (Treagust, Won, & Duit, 2014). However, many present-day educators who collect both qualitative and quantitative data have difficulties fitting their research into one of the established research designs, simply refuse to choose a particular design, and find the dichotomic nature of design distracting and futile (Creswell, 2012; Ercikan & Roth, 2006; Treagust et al., 2014). Therefore, the best method for such a scenario involves mixed methods that allow for proper understanding of their finding and make a stronger research case compare to the use of only one approach (Creswell, 2012; Reeves, 1997).

The mixed methods design provides a better understanding of the research problem, enabling researchers to collect and analyze data using different approaches, rather than being restricted to one (Creswell, 2003; 2012). Therefore, a mixed-method design was strongly recommended by many researchers as it enables the researcher to better understand the quantitative data and how students have reached the conclusion (Creswell & Clark 2011; Tobin & Fraser, 1998). There are six major designs for the mixed method research (Creswell, 2012). The best design for this study is convergent parallel design where the qualitative and quantitative data were collected concurrently; data sets were then analyzed separately, and were merged together for a comprehensive analysis of the research question (Creswell, 2003; 2011; 2012). Such an approach in this study enabled the researcher to collect quantitative data from post-assessment while interviewing a smaller group of students to provide a more detailed analysis of the research problem.

Qualitative data has been identified as an important way of collecting research data. Graneheim and Lundman (2004) highlight the importance of verbal communication, while Seidman (2013) identifies the process of interviewing as the basic mode of inquiry, allowing the interviewee to express and recount his/her experience. Furthermore, Gruenewald (2003) states that education is a social abstraction and the best way to investigate such institution is through the experience of individuals who make up the organization. Research that focuses on individual's experience and what they make out of the experience is referred to as "subjective understanding" (Schutz, 1967). In such occasions, the interview is the best tool of inquiry (Seidman, 2013). Therefore, implementation of qualitative data becomes essential because it enables this study the opportunity to assess students' attitude and understanding at a deeper level.

The student population for both semesters was randomly assigned to either an experimental or comparison group based on their laboratory section number. Students' achievement on the concepts of photosynthesis was evaluated through the comparison of by pre-assessment (prior knowledge) and two post-assessments composed of short answer, multiple-choice, and open-ended questions, respectively. In addition, a series of questions further evaluated the role that the multimedia (interactive or non-interactive) may have played in the student learning process.

## 1.7 Limitations

This study was limited to students enrolled in second year biology class at one university. In this course, students are exposed to a detailed and step-by-step representation of photosynthetic process including chemical reactions that make the process possible. Consequently, students in this class are an ideal population for this research which centered on students' understanding of photosynthesis. It must be noted that because of the curriculum set by the biology department of the university, all students enrolled in the course were presented the same content with limited deviation in the course instruction and assessments.

Another limitation of this study was the lack of control on variables that may affect the outcome of the research, including students' accessibility to additional resources during their studies and distribution of students' population between the comparison and treatment groups. Another significant limitation was the short timetable for conducting interviews (2 weeks), which led to a relatively low turnout of volunteers who partook in the interview process.

## 1.8 Summary of Chapter

High school students in the U.S. complete a two-year science requirement before graduating. However according to recent statistics, they are not prepared for the rigor and intensity of the college sciences. Educators' goal is to improve students' learning environment and enhance their understanding of concepts using technology such as multimedia and interactive multimedia. Many students enrolled in science courses struggle with biological concepts that encompass complex and multistep processes. Therefore, it is important to use proper instructional tools to aid students create dynamic mental models of these processes to enhance their understanding. This study attempted to evaluate the role of multimedia and interactive multimedia on students' understanding and retention of complex process of the Calvin cycle and analyze student's perception toward the use of technology in in their learning environment.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview of the Chapter

This chapter reviews and presents a detail analysis of the literature relevant to this study. Section 2.2 provides an introduction overview of multimedia involvement in science education. Section 2.3 describes the primary and secondary education (K-12) in the United States, while section 2.4 examines higher education in the states with the focus on institutions of state of California. Section 2.5 explains the significance of multimedia in today's educational systems. Sections 2.6 and 2.7 examine the role of animation and interactive activities respectively to better understand how these two technologies transform the educational system. Lastly, section 2.8 reviews prior research on how multimedia with or without its interactive components influences students' understanding of photosynthesis process.

## 2.2 Introduction

Researchers have distinguished long term and short term human memories. Long term memory stores large amounts of information on a permanent base while short term memory (also called working memory) stores only limited amount of information on a temporarily basis (Cowan, 2001; de Jong, 2010; Dosher, 2003; Miller, 1956). Defining characteristics of working memory has instructional design implications and therefore has been studied extensively since the late 1980's (Chandler & Sweller, 1991; de Jong, 2010; Paas, Renkl, & Sweller, 2004; Sweller, 1988, 1989, 2008; Sweller, Ayres, & Kalyuga, 2011). From the work of Sweller and colleagues the idea of cognitive load theory arose which stated that learning processes were hindered when the presented information exceeded the capacity of the working memory (Chandler & Sweller, 1991; Sweller, 1988, 1989, Sweller, Chandler, Tierney, & Cooper, 1990).

Research suggested that cognitive overload could be addressed if information was coded by more than one modality; this is the notion supported by Paivio's dual coding theory (Paivio 1986, Perkins & Unger, 1994, Sunyono, Yunaita, & Ibrahim, 2015). Studies in the late 20th and early 21st centuries signified that information presentation in multiple modalities (i.e. words and pictures) was more effective than presentation in words only because it improved students' understanding, retention capacity, and working memory (Brener et al. 1997; Lemke, 1998; Mayer & Moreno, 2002). Therefore, while certain information was best presented using specific representations, the utilization of multiple representations would be the key to creating a deeper understanding of the scientific phenomena (Ainsworth, 1999; Ainsworth, Prain & Tytler, 2011; de Jong et al. 1998). Ainsworth (1999) identified three key elements to ensure the effectiveness of multiple representations 1) when represented information was complementary, 2) one representation constrained the second representation's understanding, and 3) deeper understanding was constructed using the multiple representations. The mentioned studies emphasized the importance of multiple modalities adaptation to enhance learners' cognitive abilities.

In today's technology-driven world, adaptation of computer-based multimedia provides an encouraging prospect, in which multiple modalities are utilized (i.e. pictures/animation with words/narration) to create a familiar and yet effective environment for learners of all ages and subjects (Allen, 2015; Angeli & Tsaggari, 2016; Ginns, 2005; Guan, 2009; Mayer & Moreno, 2002; Tudor, 2013). The use of multimedia introduced a new theory known as cognitive theory of multimedia (Mayer, 2002, 2003; Mayer & Moreno, 2002). This theory centered around the notion that relevant connections were built when information was presented in words and pictures rather than words or pictures (Mayer, 2009). Furthermore, for an in-depth understanding of the presented information, learners must engage in cognitive processes related to each modality, organize the received knowledge, and integrate them to make connections between given representations (Irby, Brown, Lara-Aiecio, & Jackson, 2013; Mayer, 2002, 2003; Mayer & Moreno, 2002). Since visual and verbal information are processed in two different systems, therefore, an effective multimedia delivers information as to prevent cognitive overloading of learners (Chandler & Sweller, 1991; Clark & Paivio, 1991, Paivio, 1986 Cook, 2006; de Jong, 2010; Horz & Schnotz, 2010). Furthermore, the instructional tool should be designed to effectively use the passive media (multimedia) to actively engage the cognitive processes of the learner, creating an interactive and effective learning tool (Herold, 2016; Mayer, 1996; Mayer & Moreno, 2002, Roscorla, 2016; U.S. Department of Education, 2016). The next few sections investigated prior research on student population and the influence of multimedia and interactive multimedia on their learning environments.

## 2.3 K-12 Education in the United States of America and State of California

Based on codes set by education department of state of California, students graduating from high school must have successfully completed two science courses, one in biological science and one in physical science (California Department of Education, 2014). Physical science includes physics, chemistry, or earth science. However, statistics collected by STEM (Science, Technology, Engineering, & Mathematics) suggested that 64% of students entering college did not have an adequate background knowledge to advance in their college science curriculum (ACT, 2014).

Research conducted in the later years of the 20th century indicated that 7th graders outperformed 3th graders in scientific terminology; however, 11th graders performed similarly to 7th graders (Yager & Yager, 1985). Furthermore, no correlation was observed between the number of completed science courses and students' performance (Anderson, 1989). Since the adaptation of technology in 21st century classrooms, it was probable that students' performance improved naturally across the board. A report that compared 4th, 8th, and 12th graders' science performance in 1996 and 2005 showed that in 1996, 37%, 41%, and 43% of elementary, middle, and high schoolers, respectively scored below basic achievement level (Grigg, Lauko, Brockway, 2006). Grigg and colleagues (2006) further reported that by 2005, the percentage of 4th graders who scored below basic level decreased while the percentage of middle schoolers remained constant. Sadly, the percentage of 12th graders that scored below basic achievement level increased by 3%. A more recent analysis compared the same age populations from 2009 to 2015 (National Center for Educational Statistics, 2016). The percentage of students who scored below basic level skills for both 4th and 8th grade populations declined compared to the prior data. However, 40% of 12th grade population scored below basic science achievement level for both years (National Center for Educational Statistics, 2016). The result was troubling because high school science education prepared students for college courses.

Students' performance has been linked to their level of interest. Lack of interest in biological concepts can stem from an inability to connect the topic to real world experiences (Seiler, 2006). Therefore, teacher's awareness of learners' interest and fluency in self-generated questions related to the topic could piques students' curiosity, and thus improve their performance in the subject matter (Baram-Tsabari, Sethi, Bry, & Yarden, 2010).

Teaching a subject is a highly cognitive process (Leinhardt & Greeno, 1986; Wilson, Tabbers, & Pass, 1987) and as such a teacher's credentials on a specific subject (i.e. biology) affect students' achievement (Boyd, Grossman, Lankford, Loeb, & Wyckoff, 2008; Clotfelter, Ladd, & Vigdor, 2007; Hashweh, 1987; National Research Council, 2010). Therefore, teachers with prior knowledge of the subject matter are likely to be more competent in creating effective learning plans that could in turn aid students in developing a deeper understanding of the concepts (Davis, Petish, & Smithey, 2006; Magnusson et al., 1999). A recent report indicated that while elementary teachers taught life, earth, and physical sciences, only 36% had completed courses in all three areas (Banilower et al., 2013). Bainlower and colleagues' (2013) also reported that only 5% of elementary science teachers had earned a bachelor's degree in science, engineering, or science education and 41% of elementary teachers had not had any science-focused professional development in the past 3 years. A better trend was reported for middle school science teachers, where 41% of teachers had completed a bachelor's degree in one of the listed majors (Bainlower et al., 2013). Though the majority of high school science teachers had proper training and a degree to teach sciences, 29% did not major in the subject in college and/or were not certified to teach it (Aud et al. 2010; Bainlower et al., 2013). These statistics suggested that lack of science preparedness among students may be related the proficiently of their K-12 science teachers.

Other concerns that may explain the unpreparedness of students included relaxed academic settings of high school, over-emphasization of standardized testing, and lack of proper study habits (Hansen, 2013). Any one of a combination of these issues could explain the lack of students' preparedness for course at higher education institutions.

### 2.4 Higher Education in the United States of America and State of California

In the United States, students continuing their higher education after high school graduation are presented with multiple options. For instance, their enrollment in a two-year college earns them an associate degree, while completion of a program in a four-year university warrant them a bachelor degree. Many students choose to further their education by enrolling in a graduate program. Most higher education institutions in the United States are funded by the public with a smaller number of private universities and colleges. With the advancements in technology, economically priced computers, and accessible Internet nationwide during this past decade, new opportunities have been presented to students seeking higher education. Such opportunities include distance education where accredited on-line based universities offer quality education to their students (Casey, 2008; McIsaac & Gunawardena, 2001).

The Babson survey research group has been tracking online education in the United States for over a decade. Comparing these reports, a steady increase in student population was observed. For instance, in the fall of 2009, 5.9 million students were enrolled in at least one online course which was an increase of almost 1 million students since 2008 (Allen, & Seaman, 2010). Furthermore, over the past decade, there has been a push in institutions to implement distance education as part of their growth. Accordingly, to Allen and Seaman (2010), up to 63% of higher education institutions were developing strategies to implement distance education to support the demand. Moreover, the same report indicated that 66% of chief academic officers did have a positive perception on the quality of the online education when compared to face-to-face instruction. However, a more recent report released in by the research group showed a slow growth rate for students enrolled in an online program, and there has even been a decline in enrollment in the for-profit institutions (Allen & Seaman, 2015). In the survey, Allen and Seaman (2015) also observed a slight decline in university faculties' positive perception of online instructions compared to the face-to-face instruction. Faculty members responded more positively to a "blended instruction" where learning environment was a product of cohesive immersion of both online and face-to-face instructions (Allen & Seamen, 2010, 2015). So, adaptation of a hybrid instructional setting that combines the qualities of face-to-face and online instructions might be most appropriate path. Existence of such a curriculum is multimedia-dependent to bridge gaps between traditional and technology-driven teaching approaches.

Community college system in the state of California composed of 113 campuses, offering on-campus courses as well as distance education (Community College League of California, 2015). While California community college system is comparable to other states, the university system offers two different paths. Unlike many states with one 4-year university system, the state of California is composed of 2 separate four-year universities system, University of California (UC) and California State University (CSU) system. While most universities in both systems are internationally renowned, their approach to teaching is believed to be different.

Special emphasis is placed on research among the 10 universities within the UC system as they thrived to create a rich academic setting and integrated skills to "unlock the secrets and mysteries of the universe" (The UC system, 2014). The CSU system was comprised of 23 campuses throughout California and provided professional training to over 470,000 students (The CSU Statistical Reports, 2015). CSU universities focused on developing professional training and granting related degrees (International Office of the Chancellor, 2010). For instance, in 2010, California's state universities granted 62% of bachelors' degrees in agriculture, 54% in business, and 64% in hospitality and tourism. Moreover, 52% (6,500) of teachers in the state of California received their credentials either in single/multiple subject or in educational specialist from a CSU campus (The CSU Academic Affairs, 2014).

Regardless of campus, all students who sought a career in the health professions or in the natural sciences were required to complete a series of core courses. Such curriculum provided a broad exposure to key concepts and biological principles, guiding students to acquire the skills, and choose the appropriate educational path that best suited their interests and career goals. CSU Fullerton (CSUF), where the study took place offered an undergraduate bachelor of science (B.S.) degree in biological sciences with four concentrations of 1) cell and developmental biology, 2) ecology and evolutionally biology, 3) marine biology, and 4) molecular biology and biotechnology (CSUF, 2013, p. 194). Per guidelines provided in CSUF catalog (2013), students interested in earning their B.S. in biology, started their program by completing a series of four core courses. Each course was five units and included lecture and laboratory components with a minimum of six hours and maximum of nine hours/week for laboratory. Per program standards set by the college, students who majored in biology completed the four courses in sequence and could only enroll in the future courses if they earned a grade of "C" or better in their prior course (CSUF, 2013, p. 194). Upon satisfactory completion of these courses, students could choose one of the four concentrations offered by the college.

The CSUF catalog (2013) provided brief description of each of the four core courses. The first class of the series was evolution and biodiversity that introduced scientific processes and biological methods and discussed principles of evolution, biodiversity, and conservation biology. The second class, cellular basis of life, built on previously gained knowledge and provided an in-depth comparison of prokaryotic and eukaryotic organisms, including their evolutionary relationships and reproduction. Genetics and molecular biology, the third course of the sequence, explained population evolution utilizing principles of inheritance and genetics and discussed the influence of biotechnology (gene manipulation) on society. The series was concluded by principles of physiology and ecology course that discussed physiological and evolutionary adaptation of organisms as well as human ecology principles (i.e. energy flow, organismal impact on environment).

Regardless of the students' enrollment in a two or four-year higher education institution, the challenges of learning environment remain. While every field of has its own obstacles, this study focused on students interested in sciences, specifically biology. A most recent report indicated that 28% of bachelor degree candidates declared a STEM major, however 48% left the program and half the students left college without earning a degree, while the remaining percentage changed major (U.S Department of Education, 2014). The low rate of graduation might be linked to either students' lack of interest in the subject matter, from prior education, demographic characteristics, precollege academic preparation, and/or teacher's limited background on the subject being taught (Hashweh, 1987; Seiler, 2006; U.S. Department of Education, 2014).

Recent statistics indicated that the national high school graduation rate was 82% and of those who graduated only 40% were ready to enroll and succeed in the college-level course work (National Center for Educational Statistics, 2016). Another report indicated that states' focus had been on successful enrollment of students in higher education institutions rather than ensuring that they were well prepared and skilled to successfully complete their programs (Shulock, 2011). The Author also indicated that many of students were placed in remedial courses and found themselves unprepared for the rigor of college courses even though they were eligible to attend college. Students' unpreparedness was related to the lack of joined efforts between K-12 and postsecondary institutions to standardize their expectations (Shulock, 2010). In support of the mentioned statistics, a faculty focus survey conducted in 2013 identified instructors were challenged with students' lack of preparedness for rigors of college courses and lack of active participation in class

(Alford & Griffin, 2013). Therefore, instructors of postsecondary institutions, particularly those teaching introductory courses, focused on identifying learning tools and approaches that enhanced students' learning environment and properly prepared them for a higher level thinking, their future college courses, and careers.

### 2.5 Multimedia Role in Students' Learning Process and Achievement

Prior to digital age, instructional tools such as blackboard, slides, and overhead projectors sufficed in teaching static concepts. However, such instrument proved insufficient in representing movement of component or passage of time and therefore modifications were required to enhance the learning environment (Slish, 2000). Slish's move toward creating basic graphics to help students was based on prior research conducted by Glynn (1998) who showed that cartoons (today's animation) can be used as an effective tool in teaching non-static concepts. Glynn's (1998) study showed that students used cartoons to create appropriate mental models to further facilitate their learning process. Cartoons also offered students' freedom to review the information repeatedly and at their own pace until they felt competent (Nantz & Lundgren, 1998; Slish, 2000).

Now nearly two decades later, educators and researchers alike have followed the footsteps of Glynn, and Slish and their colleagues. Over the years, it has become clear that while the basic concepts remained the same, learners have changed. Consequently, the learning process has been modified, thus transforming instruction to ensure the needs of learners were met (Stith, 2004); therefore, classrooms could no longer be monopolized by traditional instruction. Change in the learning process and addition of novel learning resources (i.e. computer-base technology), innovative instructional opportunities were being created to enhance and optimize the learning system (Aleman & Porter, 2016; Gyambrah, 2007; Handal, MacNish, & Petocz, 2013; Mukhopadhyay & Parhar, 2001; Kearney, Schuck, Burden, Aubusson, 2012; O'day, 2006, 2007).

The new generation, born with phones in their hands, look for flexible methods of knowledge delivery at schools and universities (Al-Fahad, 2008; Handal et al., 2013; Kearney et al., 2012; Ryan, Scott, Freeman, & Patel, 2000). So, as the student population has changed, new teaching methods should be employed to better engage students (Aloraini, 2012; DeRouin, Fritzsche, & Salas, 2005; Handal et al., 2013). Such modalities included auditory and pictorial representations of information (i.e. animations, games, virtual realities, and special effects). Recent research has investigated the importance of multiple external representations (MER) on student learning outcome. Such research has shown a positive correlation between MER and students' conceptual learning environment (Ainsworth et al., 2011; Cerghit, 2008; Dori & Belcher, 2006; Treagust & Tsui, 2013).

Aloraini (2012) utilized computer presentation and multimedia treated curriculum to teach a group of students in college of education, while a second group was taught using traditional teaching (i.e. lectures, group activities, and class discussions). Students' achievement was measured using pre- and posttest assessment in which the multimedia group showed a measurable improvement in their overall grade. The result of this and other studies (Aloraini, 2012; Low & Sweller, 2005; Moore & Miller, 1996; Özmen, 2008; Sadaghiani, 2011; Walsh, Chih-Yuan Sun, & Riconscente, 2011), suggested that when multiple instructional tools harmoniously worked together (i.e. print and electronic media), they created a powerful supplement to classroom process and consequently augmented learning (Mukhopadhyay & Parhar, 2001; Tudor, 2013).

According to Buckley and colleagues (1999), the new world, driven by technology, continues to grow, evolve, and become more complex. Therefore, society requires its members to think like scientists so they can understand the intricacy of the environment. This multiplicity also exists in the science world, such as biological science. Such intricacy in the sciences has created demands that can no longer be sustained using traditional instruction and emphasized the pivotal role of multimedia in education. Supplementation of traditional teaching with technology provides opportunities to match the tools with which students learn (Mayer, 2005b; O'day, 2007; Roschelle, Pea, Hoadley, Gordin, & Means, 2000; Su, 2008; Taşçı & Waugh, 2008). Though studies have mixed results on the role of technology in classrooms, the improvement in students' understanding was still evident in mathematics and science, with the listed research providing supporting examples (Roschelle, Kaput, Stroup, 2000; Roschelle et al., 2000; Taşçı & Waugh, 2008; Treagust & Tsui, 2013; Thatcher, 2006).

There were several research studies in recent years that highlighted the role multimedia in improving students' cognition. One such study conducted by Ecrama-Robinson (2010) in an introductory biology course at a postsecondary institution showed that the multimedia implementation in the course curriculum created a positive cognitive dissonance in students' mental model of plasma membrane and improved their performance.

The effectiveness of multimedia in teaching science was also demonstrated in a geology class, where utilization of technology decreased students' contact time by 55% with similar or better examination scores compared to the traditional course (Van der Westhuizen, Nel, & Richter, 2012). Qualitative data from interviews further supported the new adaptation of the course since students preferred a more technology directed course to the more traditional setting. Furthermore, accessibility to the resources prior to the exam provided additional review time, which would have been impossible in a traditional classroom setting. Walsh and colleagues (2011) designed an online multimedia teaching tool that supplemented an undergraduate neuroscience course. Both students' and teachers' perception of the technology implementation was positive. Moreover, students showed a higher level of interest for the presented content and were actively engaged in their learning process. This supplementation enhanced students' understanding of the concept and enabled them to make connections between gained knowledge and the course curriculum. Additional research further supported the positive role of multimedia in secondary schools.

Research on college students enrolled in an introductory physics course showed that addition of multimedia modules to their regularly scheduled lectures and discussions improved their examinations scores and enhanced their performance in discussion questions (Sadaghiani, 2012). Other physics-focused research supported Sadaghiani (2012) result and suggested the that multimedia modules reduced the level of course difficulty ranking for students (Chen, Stelzer, & Gladding, 2010; Smetana & Bell, 2012; Stlezer, Gladding, & Mestre, 2010). Tan and Waugh (2013) demonstrated that the implementation of computer based visualization in a molecular biology class in an all-male secondary school in Singapore increased the achievement scores for students, helped clarify the concept, and enhanced students' interest and engagement. There are number of addition research that demonstrated the successful and effective adaptation of multimedia in STEM courses (Kiboss Ndirangu, & Wekesa, 2004; Rutten, Van Joolingen, & Van der Veen, 2012; Shegog et al., 2012). However, Roschelle and colleagues (2000) cautioned instructors when choosing their multimedia tools to ensure that the technology best complement their teaching style, course curriculum, and students' needs.

In choosing multimedia that best suited the needs of the learning environment, the modality principle should be considered. The modality principle states that because of limited capacity of visual and verbal channels, designed multimedia activities must avoid overloading the senses or creating spilt attention effect (Moreno & Mayer 2007a; Mousavi, Low, & Sweller, 1995; Van Merriënboer, & Sweller, 2010). Consequently, it is best to present verbal material using auditory modality and non-verbal material using visual modality (Low & Sweller, 2005; Mayer, 2005a; Moreno & Mayer, 2007a, b). A study conducted by Mousavi and colleagues (1995) assessed the importance of the modality principle on geometry content. They found that textual information (diagrams) presented through auditory modality were more effective than when textual information was presented in visual (written) modality. A recent study also emphasized the importance of split-attention principles in instructional design to improve performance of learners with lower working memory (Fenesi, Kramer, & Kim, 2016). Other research conducted by Mayer and Moreno (1998) presented two processes (lightning formation and car's breaking system) using animation. Some students received the information as narrated animation while others were presented with an animation and on-screen text. Students in the narrated animation group outperformed the other group in recalling information, retention, or a matching test, providing support for the modality principle. More recent research further supported the suggested that prior knowledge also eased students' interpretation and understanding though visual input (Cook, 2006).

While the modality principle cannot be stressed enough, it must be noted also that the principle does not apply when one of the sources provides redundant information (present the information in a different form) (Craig, Gholson & Driscoll, 2002; Low & Sweller, 2005, Mayer & Moreno, 2002). Craig and colleagues (2002) conducted research with three groups of learners, where information was presented as printed text, printed text with narration, and narration only. Students in the narration only group outperformed the other two groups, with no significant difference in students' performance between printed text and printed text with narration (a redundant feature). A meta-analysis of studies and educational instruments also supported Craig and colleagues (2012) result (Adesope & Nesbit, 2012).

Another essential element that must be considered when teaching sciences is students' ability to visualize the concept being presented at the chemical level, which is not accessible for direct observation (Gabel, 1998; Tasker, 2014, 2015; Tasker & Dalton, 2006). To understand of chemical phenomena, students must have an in-depth understanding of the concepts presented at the macro, sub-micro (molecular), and representational (symbolic) levels of presenation (Chittleborough & Treagust, 2007; Johnstone, 1993; Sanger, 2000; Tasker & Dalton, 2006; Treagust & Tsui, 2013; Yakmaci-Guzl & Adadan, 2012). Students need to use atoms and molecules (molecular) level to explain what is perceived by their senses (macro) and then present the knowledge in chemical notations and formulas (representational) (Gabel, 1998; Johnstone, 1993). Gilbert and Treagust (2009) suggested that conceptual understanding of sciences including chemistry not only requires the understanding of each level, but also ability to translate between levels of representation, and construct representation to explain various phenomena. Since macro and symbolic levels dominate the laboratory experiments, many students fail to comprehend, visualize, and/or connect their knowledge to the sub-micro level. Therefore, molecular-level animation that is at the sub-micro level can be an effective and powerful learning tool (Ardac & Akaygun, 2005; Tasker & Dalton 2006; Yezierski & Birk, 2006). However, Tasker and Dalton (2006) noted that the animation should be designed to avoid creating or reinforcing misconceptions.

Research by Adadan, Irving, & Trundle (2009) emphasized the importance of frequent use of multiple representations on students' ability to bridge content between the macroscopic and microscopic levels in chemistry. Conceptual understanding of the particulate nature of matter was assessed among 42 high school students enrolled in an introductory chemistry course following the implementation of reform-based teaching with multiple representations (RBTw/MR). Information was presented as a combination of verbal and audio (static particle models) and textual information for RBTw/MR, while the second group received textual depiction of the content (RBT). Qualitative data indicated that the RBTw/MR group was more proficient in their understanding of the particulate nature of matter compared to the RBT group. Adadan and colleagues' (2009) research further supported by a body of knowledge, stressing the role that multiple representations in improving conceptual understanding of chemistry and utilization of the given knowledge by students to make sense of the given phenomena (Ardac & Akaygun, 2005; Chandrasegaran, Treagust, & Mocerino, 2007, 2008; Stieff, Hegarty, & Deslongchamps, 2011; Sunyono, Yuanita, & Ibrahim, 2015; Tasker & Dalton, 2006). All the above studies established a connection between multimedia role in establishing successful instructional designs in science classes.

Molecular biology shares similarities with chemistry in content representations, as both require students to gain a comprehensive knowledge through connection of the three levels. For instance, molecular biology courses explain the intricacy of the photosynthesis process using chemical representations and reactions to show the transformation of reactants (CO2 and H2O) into products (C6H12O6 and O2). Furthermore, molecular biology describes how molecules in the air and soil are utilized to form fruits and vegetables, therefore bridging molecular concepts to macroscopic level. Connecting these three levels to create a coherent representation of the photosynthesis process is not an easy task. However, it is thought that the effective utilization of multiple representations using multimedia could drastically improve students' understanding of complex scientific concepts, such as photosynthesis (Barker & Carr 1989; Bell, 1984, 1985; Carr, 1989; Hazel & Prosser, 1994, Russel, Netherwood, & Robinson, 2004; Schwartz & Brown, 2013).

**2.6 Role of Animation as a Teaching Tool**

Role of computer stimulation in improving scores among chemistry students was demonstrated as early as early 1990's (Geban, Askar, & Özkan, 1992). With time, more studies were conducted. For instance, one of the earlier research by Williamson and Abraham (1995) demonstrated the positive impact of animation on students' learning. Their research assessed students' test scores in a chemistry course after receiving short (1 to 2mintues) supplemental animations in addition to their lecture material. While changes in lecture duration were insignificant after addition of the animation, the improvement in test scores was noteworthy. The average examination scores for students with access to traditional teaching was recorded as 59% and 50%, while for students with supplemental animation examination scores averaged at 70% and 63%.

Another research study conducted by Wu, Krajcik, and Soloway (2001) also indicated a similar pattern of improvement among 71 high school students enrolled in chemistry. A computer-based program enabled students to simultaneously build and observe multiple representations. Consequently, this 6-week program created a highly engaging environment and improved students' average score from 31.1 for pretest to 59.5 for the posttest.

A more recent study conducted by Al-Balushi and Al-Hajri (2014) assessed 11th grade students' understanding of organic chemistry content when animation was utilized. Twenty-two students were taught using concrete models while 28 students had access to concrete models and an interactive animation in which they could rotate, inspect, and interact with multiple representations simultaneously. Comparison of pre- and post-test data between the two groups indicated that exposure to the interactive animation significantly improved student's conceptual knowledge. These examples as well as other research in the field emphasized the pivotal role of animation in chemistry courses (Appling & Peake, 2004; Ardac & Akaygun, 2004; Kelly & Jones, 2007). Now the question is does animation play a significant role in other sciences such as biology?

Educators and students involved in the field of cell biology identify animation as a valuable tool that multimedia offers (Kiboss et al., 2004; Reindl et al., 2015; Rutten et al., 2012; Smetana & Bell, 2012; Stith, 2004). In the past educators were limited to video microscopy to show cellular processes; however, with advancement in technology, reliance on computer base instruction has been increasing (Rutten et al., 2012). Animation offers instructors significant advantages (i.e. ability to magnify, modify, highlight, and/or adjust colors of images) (Stith, 2004). Research with medical school students showed that those who learned about DNA replication using animation performed significantly better compared to students with learned by reading the textbook chapter (Thatcher; 2006). Furthermore, studying text after viewing animation did not enhance students' test scores indicating that animation was indeed sufficient for students' comprehension. Similarly, a study by O'day (2007) supported the role of animation in improving college students' retention. Undergraduates enrolled in a cell biology course retained the information better when the mode of presentation was a narrated animation compared to those taught by diagrams accompanied with legends. There are number of research that further supported the role of animation in biology and biotechnology courses (Höffler & Leutner, 2007; Lin & Atkinson, 2011; Marbach-Ad, Rotbain, & Stavy, 2008; Nicholls & Merkel, 1996; Ryoo & Linn, 2012; Yarden & Yarden, 2010).

Research conducted by Sanger, Brecheisen and Hynek (2001) lent support to the impact of animation in addressing students' misconceptions. The study conducted with 149 students in a second-semester introductory college biology course evaluated if the implementation of two animations about diffusion influenced students' conceptions. Sanger and colleagues (2001) noted that animation was successful in addressing several misconceptions associated with the process; however, the animation created some content confusion as students tried to apply rules at macroscopic level to what they were being presented at the microscopic level. Therefore, researchers must be cautious in designing the animation, so as not to create additional misconceptions among learners.

Animation should not be viewed as an independent tool, rather it should complement the traditional curriculum by either providing a preview or review of material during the lecture (Munyofu et al., 2007; Schnepf, Mashayekhi, Riedl, & Du, 1994). Furthermore, the passive media (animation) could develop a more engaging tool through the addition of questions that can be answered by students through verbal communication or clicker. Learners could utilize animation outside the classroom as a study tool to review the material and prepare for the examination. However, students' performance was enhanced when animation was viewed repeatedly and in its entirety (Reindl et al., 2015).

Moreover, animation was a more effective instructional tool when teaching sequential processes (i.e. signal transduction) in cell biology (McClean et al., 2005; O'day, 2007). Similarly, Stith (2004) study assessed the role of animation in students' understanding of multistep process of apoptosis. Students' scores improved after watching a 1-minute apoptosis-related animation, three times in a row. Further analysis showed that the treatment group responded better to questions related to the sequence and location of the events, but fared similarly for definition-based questions. Stith's (2004) research suggested that visual representation of sequential event enabled learners to recognize and internalize the consecutive order of the process and therefore improved their conceptual understanding. Therefore, animation could be a suitable instrument in teaching cellular biology concepts such as photosynthesis. However, other approaches might be employed when teaching photosynthesis-related vocabulary.

Stith (2004) explains that steps could be taken when designing an animation to avoid oversimplification of the content or skipping of the steps, which may be misleading to students. Furthermore, interactive components (i.e. hot key, rollover controls) should be built into the animation to keep the learner engaged. Overall, Stith's research provides grounds for the study reported in this thesis, which was designed to understand how animation and interactive activities could be implemented in the curriculum to teach multistep processes of the Calvin cycle.

While science education research in general is supportive of animation implementation, the researcher should be cautious of learners' cognitive construction and its limitation (Chandler & Sweller, 1991). Lin, Shen, and Liu (2014) conducted research that adapted the cognitive load theory in fifth grade science classes in Taiwan. Students performed better when taught using narrated animation compared to students who learned through subtitled animation (no narration).

Lin et al., (2014) study result was in line with Mayer and Moreno's (2002) theory of multimedia cognition, because narrated animation employed both visual and auditory channels verses only visual channel for subtitled animation. So how does the addition of subtitles to the narrated animation affect students' learning?

According to learning preference theory, each student learns differently (Mayer & Moreno, 2002). Therefore, it was predicted that if the same information is presented in more modes (i.e. animation, narration, and subtitles), students have the option of choosing their preferred mode(s) and can enhance their understanding. However, a study showed that simultaneous presentation of narrated animation and written text did not foster learning, rather it reduced comprehension and retention among student population (Mayer, Heiser & Lonn, 2001). An early study suggested that addition of subtitles did not enhance the learning process rather it diminished learner's understanding of the concept (Kalyuga, Chandler & Sweller, 1998). Moreno and Mayer (2002) explained that addition of subtitles could cause visual working memory overload. Students must divide their attention between the animation and subtitles (split-attention effect), and possibly miss out on information (Ayres & Sweller, 2014; Chandler & Sweller, 1992; Leahy, Chandler, & Sweller, 2003; Mayer & Moreno, 2002; Moreno & Mayer, 2002; Sweller, 2005). Moreover, visual working memory overload inhibits the chance of forming proper connections between visual and verbal representations, and therefore students are unable to comprehend and retain the information.

While some research (Kalyuga, Chandler & Sweller, 1998; Leahy et al., 2003; Mayer et al., 2001) did not provide positive evidence on subtitles other than as a redundant form of information presentation, few research lend support to such addition when learners are receiving information in their non-native language. When English speakers used a computer program to read a story presented in the German language (Plass, Chun, Mayer, & Detlev, 1998), they had the option of seeing the translation, hearing the translation, or both options simultaneously. Students who chose to use both visual and verbal annotations remembered the word translation better when compared to those who chose only one of the two options.

Another research study (Krugar and Steyn, 2014) conducted on the role of subtitles with phycology students taught in English, their non-native language, showed that students who watched videos with and without access to subtitles performed similarly. However, a closer look at data showed that students who read the subtitles available to them performed better than those who did not read the provided subtitles. These data suggest subtitles can enhance the learning environment for the non-native speakers. So, it is possible that the addition of subtitles to a narrated animation might not benefit native speakers, but might enhance non-native students' comprehension and performance. Interestingly, Mayer and Johnson (2008) demonstrated that students' knowledge retention improved when narrated presentation included short redundant phrases; however, redundant and non-redundant groups performed similarly on knowledge transfer.

This chapter detailed the importance of narrated animation as an instructional tool to enhance learning environments irrespective of the content being presented or the learner's age. The next inquiry then focused on how did the addition of an interactive component to multimedia influenced students' learning.

### 2.7 Interactive Multimedia in Students' Learning

The previously mentioned research highlighted the significance of multimedia in training and improving the learning environment for primary, secondary, and postsecondary education. This next section emphasizes the role interactive multimedia (IMM) may play in enhancing students' learning experience.

Interactive multimedia relies on the knowledge construction view where learners take new information and organize and integrate it into previously acquired information to create a mental representation of the information (Moreno & Mayer, 2007a, b). Interactive multimedia is also well suited for explaining complex multidimensional, dynamic, chemical, and microscopic (i.e. reactions, cell activities, metabolism, muscle contraction) processes (McElhaney, Change, Chiu, & Linn, 2015; Phillips, 2014). In a sense, the interactive component of the multimedia empowers users in the learning process (Phillips, 2014). The goal of the approach is not to add information to the learner's memory, but to guide the learning process using instructional materials (Mayer, 2005b). Furthermore, IMM, combined with a range of narrative data, should provide opportunities for students to reflect, discover, and modify their mental model accordingly (Phillips, 2014). Such an approach was in line with cognitive psychologists' view that students' accumulation and integration of knowledge was enhanced when they were active participants in their learning process (Atkinson & Renkl, 2007; Clough, 2015; Colburn & Clough, 1997; Moreno & Mayer, 2005b).

Cheng, Basu, and Goebel (2009) described several changes expected across the field of education as multimedia becomes more accessible. In schools and higher education institutions, activities such as virtual dissection replaces real dissection in biology, while course-specific “drag and drop” exercises designed to entertain and engage students in any field of study become common educational tools. Moreover, educational games that simultaneously attract, amuse, and teach students become credible and popular resource across all fields of study. Therefore, adaptation of multimedia-driven activities with interactive components in various learning environment could help student learn, enhance, and deepen their knowledge (Frailich, Kesner, & Hofstein, 2009). Furthermore, interactive multimedia use in biology laboratories enables faculty members to enhance students’ learning while providing resolutions to issues such as a hazardous environment, high material cost, and/or ethical issues (Watanabe, 2002).

Interactive multimedia is a combination of texts, graphics, animations, audio, and video technology that is “reader-centered” (Bass, 2000). The user-friendly nature of the video base IMM enables learners to control the appearance in respect to models (Wouters, Tabbers & Pass, 2007). Interactive multimedia enhances dynamic visualization for learners as it allows for the content to be manipulated, controlled, browsed, navigated, analyzed, searched, annotated, or possibly be personalized for individual users (Betrancourt, 2005; Cook, 2006; Moreno & Mayer, 2007a, b; Renkle & Atkinson, 2007; Scheiter & Gerjets, 2007; Tversky, Morrison, & Betrancourt, 2002; Wagner, 1994). Such an approach empowered individuals to control their own learning environment and thus find the most appropriate, personalized, and consequential path for learning. Number of studies highlighted IMM function in fostering active learning and engaging additional cognitive processes as well as its use in assessments to provide proper feedback to encourage learning and acts as a personalized tool, attending to individual’s learning needs (Ahmed & Pollitt, 2010; Atkinson, Derry, Renkl, & Wortham, 2000; Buckley, Coleman, Cohe, & Stewart, 1999; Mayer, 2002; Weintrop et al., 2014).

Menn (1993) emphasized the importance of interactive multimedia by stating:

> As humans, we seem hard-wired for multiple inputs. Consider that we remember only about 10% of what we read; 20%, if we hear it; 30%, if we can see visuals related to what we're hearing; 50%, if we watch someone do something while explaining it; but almost 90%, if we do the job ourselves-- if only as a simulation. In other words, interactive multimedia--properly developed and properly implemented-- could revolutionize education. (p. 35)

Hands-on experience or direct experimentation offers the most comprehensive method of learning. However, because of the nature of scientific phenomena (i.e. molecular/microscopic/chemical content), students' experiences are very limited. Consequently, dynamic representation of information would be a determining factor in students' learning (McElhaney et al., 2015; Buckley, 2000; Mayer, 2002; Menn, 1993). The positive influence of interactive multimedia has been demonstrated in physics (Clark et al., 2011; Dega, Kriek, & Mogese, 2013; Fadaei, Daraei, & Lay, 2013), validating the role of interactive physics activities in enhancing students' understanding of physical concepts. Furthermore, students' viewpoint about physics role in their daily life was improved through the implementation.

Lee and Osman (2012) investigated $6^{th}$ grade chemistry students understanding of electrochemistry and noted that it was hindered because of the abstract nature of content at all three representational levels (macro, micro, and symbolic). To enhance students' understanding, Lee and Osman implemented an interactive multimedia as part of the course curriculum and evaluated its importance in students' learning and motivation. The study data suggested that implementing interactive activities not only improved students' test scores but also heightened their motivation level. These positive results were also echoed in Moore, Herzog, and Perkins (2013), where they implemented an interactive stimulation as part of the guided-inquiry base activity. Students' perception was positive toward the implementation and their grade reflected the effectiveness of the interactive stimulation.

The positive impact that computer-assisted instruction (CAI) had on nursing students at a Californian university was noted almost four decades ago (Timpke & Jannay 1981). The basic program included diagnostic tests and information on basic mathematics skills designed based on the course curriculum. Prior to implementation of the CAI, only 61% of students (17 of the 28 students) passed the test, however all students who participated in the fully implemented CAI, successfully completed their assessment (32 students). Maag (2004) research also illustrated the successful role of interactive multimedia in teaching and learning sciences. A total of 96 undergraduate nursing students were randomly assigned to one of the four study groups of text only, text and image, multimedia, and interactive multimedia to learn about basic math skills and medication dosage calculation. This study measured students' achievement, effectiveness, and satisfaction of the teaching method. While the interactive group scored similarly to the other groups in achievement and self-efficacy, the interactive group had a more appealing and enjoyable experience and found the provided feedback more appropriate. Such results signified the role of interactive technology and empowered educators to adapt the technology to enhance learning environments.

In a study of pharmacy school students enrolled in university microbiology class, the implementation of laboratory-based multimedia interactive activities (virtual labs) were effective in students' learning (Sancho et al., 2006). Sancho and colleagues (2006) showed that students who learned through the fusion of traditional teaching with virtual laboratories did as well as those who participated in the regular laboratory meetings, and overall perceived the implementation as a positive addition. The use of this technology also provided immediate feedback which was not possible in the normal laboratory setting because of time constraints and usage instructor/student ratio and in addition, the multimedia saved resources and laboratory supplies. Yet, another investigation supported the implementation of IMM as an effective tool in nursing programs (Kaveevivitchai et al., 2009). Students' performance skills were enhanced through the implementation of the interactive multimedia. Moreover, students perceived the implementation as a positive addition to their course. Therefore, it is possible to use the interactive multimedia to replace demonstration and decrease the demand on the instructors, while enhancing the learning environment by enabling students to learn at their own pace (Beeson & Kring, 1999; Bloomfield, Roberts, & While, 2010; Bolwell, 1994; Kaveevivitchai et al., 2009; Sancho et al., 2006).

Other studies that showed the importance of interactive multimedia include improvement of medical student performance in cardiac examination following the implementation of a multimedia animation (Criley, Criley, & Criley, 2000; Criley, Keiner, Boker, Criley, & Warde, 2008). Other studies also suggested that students' conceptual understanding of physics improved when an interactive computer simulation was complemented their traditional course curriculum (Olympiou & Zacharia, 2011; Zacharia & Anderson, 2003; Zacharias & Olympiou, 2008).

Education research has also demonstrated the importance of IMM in enhancing math and language skills (Hur & Suh, 2012; Nasr, 2005; Nusir, Alsmadi, Al-Kabi, & Sharadgah, 2013; Thang et al., 2014). Interestingly, the interactive multimedia proved helpful in teaching good moral values to 8 and 9 year olds (Norhayati & Siew, 2004). Interactive learning environment also proved useful for individuals with autism or Asperger syndrome by enhancing their ability to recognize complex facial features and emotions (Baron-Cohen, Golan, Wheelwright, & Hill, 2004; Golan & Baron-Cohen, 2006).

Such display of examples strengthened the position of interactive multimedia as a successful tool in teaching regardless of content, disciplines, or learners' age. Most studies including one listed in this study highlighted, the role of interactive multimedia programs such as computer reinforced online multimedia education as tools to be used in large scale studies, enabling educators to reuse resources and material, allow for collaboration among student population, and improve learning outcomes (Buckley et al., 1999; Cheng et al., 2009, Sancho et al., 2006). So, how could animation and interactive multimedia be utilized to enhance student understanding of the concept of photosynthesis?

## 2.8 Role of Animation and Interactive Multimedia in Teaching Photosynthesis

Examples presented in the earlier sections express educators' largely positive view about multimedia (i.e. narrated animation) and interactive multimedia. These benefits included an enhanced learning environment, reduced teaching related challenges, and improved students' comprehension.

Phillips (2014) explains that interactive multimedia is an effective tool when teaching microscopic processes that are hard to visualize, or dynamic processes which require comprehension of associations and relationships between multiple moving objects. Considering the microscopic nature of photosynthesis process and its complexity, then it could perhaps benefit through interventions involving interactive multimedia. A survey of 104 high schools across the Czech Republic identified photosynthesis as the most difficult concept for students to comprehend and for the teacher to lecture on (Tepla & Klimova, 2011). Furthermore, the concept of photosynthesis is one of the main focuses of science education and is taught at all levels of education (Hazel & Prosser, 1994).

Based on several studies, students' difficulties in understanding the concept of photosynthesis is because while students may understand the involvement of light, in the process few students recognize concepts such as energy transfer (sun light to stored energy in glucose); role of carbon dioxide and oxygen, and the importance of water in photosynthesis cycle (Barker & Carr 1989; Bell & Brook, 1984; Ekici, Ekici, & Aydin, 2007; Haslam & Treagust, 1987; Hazel & Prosser, 1994; Wandersee, 1983). Other studies explained that the difficulty of the photosynthesis concept stems from the broadness and complexity of the topic, the cyclic representation, and crossing over of multiple disciplines because photosynthesis describes the movement of matter and energy at microscopic to organism and ecosystem (macroscopic) levels. (Hartley, Wilke, Schramm, D'Avanzo, & Anderson, 2011; Koba & Tweed, 2009; Russell et al., 2004; Tasker & Dalton, 2006). Biology students' limited chemistry knowledge further hinders the understanding of the photosynthesis because much of information is presented at the molecular level and are described as chemical interactions (Callaway, 1996; Duschl, Schweingruber, & Shouse 2007; Ekici et al., 2007; Ross, Tronson, & Ritchie, 2006; Russell et al., 2004).

Students also have many misconceptions about the process of photosynthesis that persist through school grades and stay with them as adults (Amir & Tamir, 1994; Anderson, 1994; Duschl, Schweingruber, & Shouse 2007; Haslam & Treagust, 1987; Wilson et al., 2006). Interviews with Harvard and MIT graduates evaluated their understanding of photosynthesis process (Harvard-Smithsonian Center of Astrophysics, 1995). Interestingly, carbon dioxide, an essential molecule utilized during the Calvin cycle of photosynthesis to make sugar, was not included in any of student's responses. Students' went as far as disagreeing when the role of carbon dioxide in photosynthesis, indicating that their misconceptions were deeply rooted (Koba & Tweed, 2009). Moreover, textbook graphics that are introductory rather than scientific and non-experts teaching of the concept continuously reinforced students' misconceptions about photosynthesis (Russell et al., 2004).

Clements and Jackson (1998) demonstrated that active participation of students' (high school or college) in a dynamic demonstration depicting reactions of photosynthesis, enabled students to learn more effectively and answer complex questions. In their demonstration, students acted as molecules and proteins involved in the process, providing a visual representation for the microscopic level. Though the result of this study supported the effectiveness of this approach for teaching the complex process of photosynthesis, the use of such a demonstration was not practical for high content/ enrollment courses (i.e. introductory college biology). So, what is the next best thing?

Trindade, Fiolhais, and Almeida (2002) understood the importance of visual representation of molecular information (i.e. photosynthesis) in students' understanding and so did Max (1992). Research conducted nearly 25 years ago indicated that animated representation of photosynthesis helped ease the difficulties of educators and students (Max, 1992), which is further supported by other studies (Beakes, 2003; Moore & Miller, 1996). Moore and Miller's (1996) believed that multimedia (i.e. dynamic pictures and animation) did indeed have the power to bring abstract, invisible concept to life and therefore enhanced understanding and retention. A more recent study also showed the positive perception of teachers and students toward the implementation of a dynamic animation in high school biochemistry courses to facilitate learning of photosynthesis (Tepla & Klimova, 2014).

Callaway (1996) was one of the first researchers who studied the impact of interactive multimedia on high school students' understanding of photosynthesis. Her research compared a group who were taught using videos verses the treatment group that utilized interactive multimedia package (IMP). Evaluation of the pre- and post-assessments showed a significant improvement in students' performance both in multiple choice and short answer questions following the IMP implementation. It should be noted that considering the two-decade-old technology, the 'interactive' aspect of this intervention was minimal. Nevertheless, the research does support that students' active engagement in their learning process improved understanding when compared to a passive use of video.

In a more recent research, Russell and colleagues (2004) designed a multimedia package encompassing five photosynthesis-related modules to enrich the curriculum, supplement lectures, and/or be used as tutorials. The flexibility of this multimedia package made it a unique package that could be utilized for various student population (i.e. high school, 1$^{st}$ year college, postgraduate levels). Implementation of this package was positively viewed by over 95% of student population. Students agreed on the helpfulness and functionality of the multimedia as a learning tool. Moreover, students' academic improvement was not only perceived but also was quantified in their assessment scores. The addition of modules improved students' average to short answers by over 30% (43% vs. improved 75%). Student responses to essay questions were also more developed following the module implementation. Another study with 11$^{th}$ grade high school students in Turkey, evaluated if their cognition and misconceptions about photosynthesis were influenced by the implementation of a computer-based program (Cepni, Tas, & Kose, 2006). There was improved understanding among the treatment group, however, the implementation was not able to address the misconceptions existing among student population.

Other studies have attempted to enhance students' understanding of cell functions such as the respiration pathway (Rice, 2013). Frustration associated with learning respiration was similar to that of photosynthesis because both concepts are dynamic and complex in nature. So, if interactive multimedia improved students' interest in the respiration pathway and reinforced subject content (Rice, 2013), then it also has potential to be used as an effective tool to influence the learning outcome of photosynthesis.

Past research demonstrated a great potential for interactive multimedia in the field science. This research attempted to better understand the influence of interactive multimedia intervention on students' understanding of dark reaction of the photosynthesis.

**2.9 Summary of the Chapter**

This chapter focused on the review of the literature that described the influence of the multimedia and interactive activities on students' learning environment. Studies showed that K-12 education did not necessarily prepare students for the rigor of the college courses. The unpreparedness of student was especially visible in sciences even though they have completed two years of science courses in high school. Therefore, instructors of introductory college courses were challenged to use resources and best prepare students for their future science classes.

Studies have demonstrated that students benefited from multiple representations in the form of pictorial and auditory stimulation. The new generations of students are technology-savy, so technology can be used to represent the information using different modalities (multimedia) and enhance the learning environment. Several research studies have shown improvement in the students' learning outcomes when multimedia was used in the classrooms. Furthermore, students' ability to create an appropriate mental model was enhanced following the implementation of multimedia. An effective multimedia was in a form of narrated animation that has been successfully used in science classes; however, the role of subtitles was debated. Studies suggested that non-native students identified the subtitles as beneficial while native speakers found it a distraction, possibly because of its split attention effect. Further research, highlighted the importance of interactive aspect of the multimedia. The interactive nature enabled learners to actively engage in their learning process, be provided with appropriate feedback to encourage learning, and acted as a personalized tool, attending to individual's learning needs.

Prior research identified the concept of photosynthesis as the hardest concept for students to comprehend. This difficulty stemmed from the fact that photosynthesis is a complex multistep process and expands through microscopic and macroscopic levels, making it difficult for students to grasp. Research has shown a positive correlation between multimedia and interactive activities and enhancing students' understanding of the photosynthesis.

Both the Williamson and Abraham (1995) and the Stith (2004) studies lend support to the importance of short animations in enhancing students' learning. Furthermore, research, including Callaway (1996) and Aloraini (2012) supported the role of interactive multimedia in the improvement of students' learning. Consequently, based on these studies and others reported in the literature review, the study in this thesis evaluated how students' comprehension, retention, and perception were affected following the implementation of an intervention that used short animation and an interactive activity quiz to learn about the complex process of the Calvin cycle involved in the light independent reaction of photosynthesis.

## CHAPTER 3

## RESEARCH METHODOLOGY

### 3.1 Introduction

This chapter outlines the research questions, research procedures for collecting quantitative and qualitative data, the interview questions for collection of qualitative data, and the procedures for data analysis.

Section 3.1 provides the introduction to this chapter, section 3.2 presents the research questions, and section 3.3 outlines the research design. Section 3.4 attempts to provide an overview of student population at both the campus and at the course level. The implementation of teaching intervention in the classroom is outlined in section 3.5, while quantitative and qualitative data collection procedures are detailed in sections 3.6 and 3.7, respectively. Lastly, section 3.8 describes the demographic survey that collected additional data on gender and age distribution within student population, study and work habits, preferred method of study, educational background, and prior exposure to the scientific concept of this study. These data were used to further enhance the quantitative and qualitative analyses of data.

This study was designed to investigate how the implementation of an interactive multimedia program influences college students' learning in a first-year biology course. The research primarily focused on how viewing the Calvin cycle animation (multimedia component) and implementation of the relevant interactive activity quiz (interactive component) influenced students' understanding of the concept and retention of the given knowledge. Additionally, students' perspective and impressions on the role of such implementation in their classrooms was evaluated at multiple levels.

### 3.2 Research Questions

A main component of the research design was the animation that presented the Calvin cycle process through visual and auditory channels- the multimedia component. The treatment group's learning environment was further enhanced by an interactive quiz that provided suitable feedback that was dependent on students' responses to each question- the interactive component. Therefore, the focal points of the study were to examine the importance of interactive multimedia on students' comprehension, retention, and perception. The following questions describe the pivotal goals of the study.

1. Does implementation of the Calvin cycle animation complemented with an interactive activity quiz positively influence students' comprehension of concept of photosynthesis?
2. How does the use of interactive activity quiz in a core biology course influence students' retention of the Calvin cycle?
3. What are students' perceptions about the implementation of multimedia and interactive multimedia in their learning environment?
    a) What features and attributes of the animation are deemed constitutive and fundamental verses unimportant and trivial?
    b) How does such implementation influence participants' comprehension and retention of the concept?
    c) What are students' perceptions about implementation of the multimedia in their science classes and
    d) How do students perceive the interactive multimedia and its unique features?

### 3.3 The Research Design

To collect data, the researcher could utilize quantitative, qualitative, or mixed methodology. The quantitative research utilizes rubrics and statistical techniques to understand participants' understanding, preference, and behavior categorize differences (i.e. gender role in achievement in math) (Ercikan & Roth, 2006; Jeager, 1997, Treagust et al., 2014). Furthermore, quantitative data should be checked for reliability, validity and statistical accuracy (Cohen, Manion, & Morrison, 2011). The qualitative research design are typically narratives, case studies, etc., in which the researcher collect data through interviews, observation of individuals or classroom, and document analysis (Erciknon & Roth, 2006; Saidman, 2013; Treagust et al., 2014). Moreover, the setting for data collection is “naturalistic” and analysis depends on the “researcher’s subjective perspective”(Carlone, 2004; Ercikan & Roth, 2006; Treagust, Jacobowitz, Gallagher, & Parker, 2001). For instance, for the research to answer why girls’ performance is lower than boys, the researcher may spend a significant amount of time observing her study subjects and based on her insightful and perceptive draw conclusions to explain the difference. Therefore, in a sense, quantitative data can register the difference within the study population and qualitative data can answer the ‘how’ and the ‘why’ the difference exist.

This study employed mixed methods, applying both qualitative and quantitative approaches for data collection. The combined strategies provided a comprehensive understanding of the data and how students made sense of their data (Creswell & Clark, 2007, 2011; Curry, Nembhard, & Bradley, 2009; Johnson, Onwuegbuzie, Turner, 2007; Tobin & Fraser, 1998). Creswell (2002) further added that the use of a mixed methodology is indeed an effective tool to best understand the research questions in many cases. This study employed the convergent parallel design in which qualitative and quantitative data were collected concurrently, and therefore emphasizing both datasets (Creswell, 2002, 2013). Though qualitative and quantitative data were analyzed separately, however they are merged together to create a comprehensive evaluation of the research questions (Creswell, 2002, 2013; Creswell & Clark, 2007, 2011). The mixed methodology tools included pre- and post-test, animation, online activity or quizzes, as well as interviews and students’ drawings.

Table 3.1 Constructs of research questions and data analysis.

| Research questions | Construct/variables addressed | Type of data |
|---|---|---|
| #1 Does implementation of the Calvin cycle animation complemented with an interactive activity quiz positively influence students' comprehension of concept of the photosynthesis? | <u>Comprehension:</u><br>Students' understanding of the Calvin cycle following the intervention implementation and observing possible correlation in assessment scores. | 1. Quantitative analysis<br>2. Qualitative analysis of interview |
| #2 How does the use of interactive activity quiz in a core biology course influences students' retention of the Calvin cycle? | <u>Retention:</u><br>Student retention of the Calvin cycle process following the teaching intervention implementation and observing possible correlation in assessment scores. | 1. Quantitative |
| #3 What are students' perception about implementation of multimedia and interactive multimedia in their learning environment? | <u>Perception:</u><br>Student perception about the implementation of animation and interactive activity quiz:<br>a) Animation: Fundamental or trivial?<br>b) Animation: Influence on comprehension and retention<br>c) Animation: important in science classes<br>d) Interactive multimedia: fundamental or trivial? | 1. Qualitative analysis of perception via student interviews<br>2. Qualitative analysis of learning via student drawing during interview |

### 3.3.1 Data source

Sources for collection of quantitative data in this research included:

- Written pre-test to measure student knowledge prior to completion of the interactive activity
- On-line quizzes to quantify student's gained knowledge following the completion of the activity
- Multiple choice and written open-ended questions to assess students' short term and long term retention

- On-line demographic survey to aid with analyses of quantitative and qualitative data.

Sources for collecting qualitative data in this research included:

- Interview questions to determine information about students' perception toward implementation of activities
- Interview questionnaire to measure the cognitive aspect of students' understanding of the process of photosynthesis
- Students' drawing and audio recording to assess their level of understanding following the implementation of multimedia

Audio recording and notes taken during interviews were also among the sources utilized during qualitative data collection to better analyze the effects of the multimedia and interactive multimedia on students learning process. Figure 1 and succeeding sections provide detailed explanations of the assessments used prior and after the implementation of the intervention and approaches utilized by the researcher to assess the collected data.

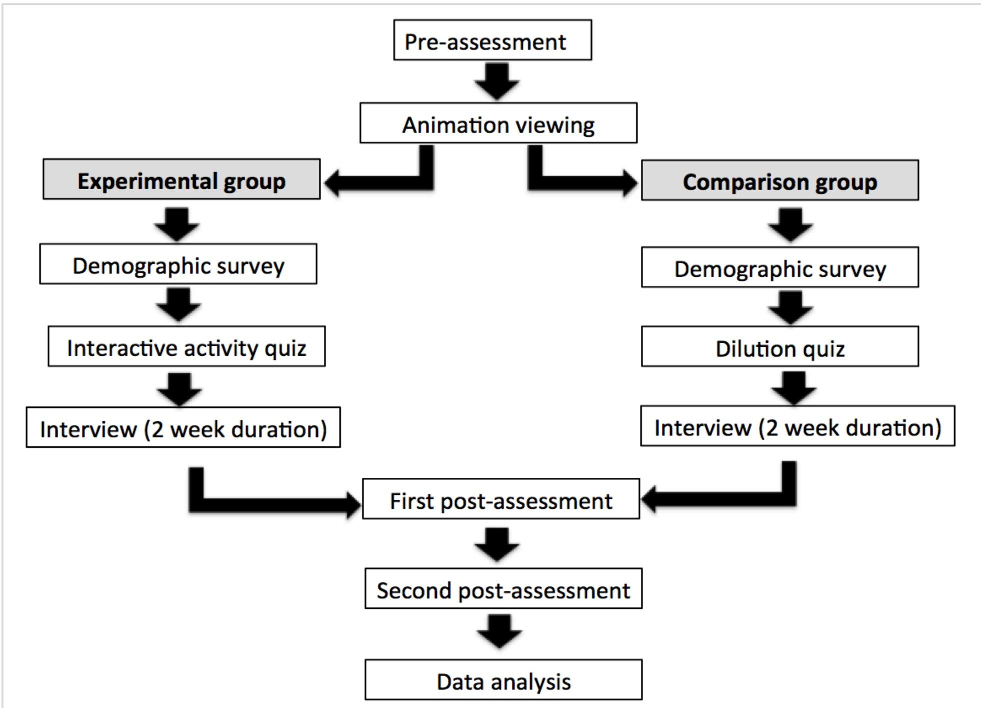



Figure 1: Flowchart representing the system utilized by the researcher to collect data during two semesters of spring 2013 and spring 2014.

### 3.4 Student Population

The public 4-year university where the research took place is designated as Hispanic-, and Asian American Native America Pacific Islander Serving institution. The university enrollment during spring semesters of 2013, 2014, and 2015, when the research took place were 34168, 35849, and 36937, respectively. Ethnic distribution statistics provided by the university stated that 36% of students were Hispanic, 25% White, 21% Asian/Pacific Islanders, 8% International students, 4% multiple race, and 2% Black ("Fact sheet," 2017; Fox, 2014; Sullivan, 2013). In academic year 2012-2013, the university employed 1,958 full-time and part-time faculties and increased the number to 2,151 in 2012-2014 academic year (Fox, 2014; Sullivan, 2013).

The university consisted of eight colleges including the college of natural sciences and mathematics (NSM), with an average of 8% of total student population enrolled in NSM-related undergraduate programs. One of the five departments under the NSM college was biological science department served by 48 faculty and staff, and encompassed the student population for this research. The academic year in the university consisted of two, 16-week semesters and summer and winter intersessions (Fox, 2014).

#### 3.4.1 Population of interest

The target population for this study consisted of students enrolled in a first year cellular biology course at the university during spring 2013 and 2014 semesters. The cellular basis of biology course, Bio172, was originally designed as the second course in a four-course curriculum to fulfill the lower division requirements for students majored in biological sciences. Bio 172 composed of three-weekly lectures (150 minutes/week) and twice-weekly laboratory sessions (6 hours/week). An average of 170 students were enrolled in Bio172 each semester (spring 2013 and spring 14). Both classes were taught by a tenured professor, while laboratory sessions were divided into ten 24-students' classes taught by graduate teaching associates or part-time faculty members. Students were expected to actively participate during lectures either through the use of i>clicker and/or contribution to group or whole class work. Additionally, each student effectively utilized, Titanium, an online platform functionally similar to Moodle and/or Blackboard, to satisfy online participation requirements (i.e. homework, activities, and surveys).

In fall 2014, a set of new course designs for biology core classes was initiated, and fully implemented at the start of fall 2015 by the biological science department. The goal for the change was to better accommodate transfer students from two-year colleges and to reduce the bottleneck effect of the Bio 172. The redesigned courses were similar to the former curriculum, where students completed the four core courses as prerequisites to enroll in upper division (third and fourth year) biology courses, or transfer to a different university. In the new curriculum, Bio 172 was renamed cellular molecular biology, Bio 151, and became the first course in the four-course series. The transition phase initiated in fall 2014 and continued through spring 2015 with full implementation in fall 2015. While the modification did not affect the lecture time and time spent of the topic of interest, laboratory session hours were reduced to a weekly meeting of three hours. Furthermore, another tenured associate professor of biological science taught the course during spring 2015.

### 3.4.2 Student sample

Prior to any data collection, the researcher obtained approval from both the Institutional Review Board (IRB) at California State University Fullerton (CSUF) and Research Integrity Team at Curtin University. Data was collected for the duration of two semesters, the spring 2013 and spring 2014. Total of 192 students were registered for Bio 172 lecture during spring 2013 semester and were divided into 10 laboratory sections. Similarly, 160 students signed up for the course during spring 2014 and were enrolled in one of the eight laboratory sections. Both student populations were taught by the same instructor, utilized the same textbook, and received similar activities, and assignments, and were assessed in similar styles throughout the semester. Such conditions ensured that variation between the populations were minimal, enabling the researcher to focus on the study research questions and collect more accurate data from both groups.

Based on the demographic survey collected as part of the study, the majority of the enrollees (125 of the 190 students, 66% of course population) in spring 2013 were female. A similar pattern was also observed for spring 2014 in which 92 of 154 (60%) participants were female.

Many students registered for both semesters were under the age of 24 (98% and 92% of spring 2013 and spring 2014 population, respectively). Furthermore, while a significant percentage (40%) of the student population did not work, 30% worked less than 15 hours, 20% work less than 25 hours, suggesting that majority of students received financial support from an external source.

### 3.4.3 Comparison group

Comparison groups for spring 2013 and 2014 were composed of students registered for specific lab sections. Each laboratory section was randomly assigned to be a part of the comparison group. Students in this group received identical instructional hours and material, course assignments, and assessments in both semesters. Furthermore, they had the same opportunity to view the animation as a supplemental resource to the given lecture. However, students did not have access to the online interactive activity quiz, rather they were asked to complete an online quiz, independent of the study content, yet related to the course information. While the content of quizzes for the comparison and treatment group were different, however the same number of points were assigned to both quizzes. Animation, demographic survey, and quiz were made available through the university's web-based Learning Management System (LMS) called Titanium. It should be noted that total of four students did not sign the consent form and did not participate in the study; therefore, a different assignment was provided by the researcher to ensure non-participants' grade was not affected.

### 3.4.4 Treatment group

Biology 172 Laboratory sections for spring 2013 and 2014 were randomly assigned to be part of the treatment group. Students in these laboratory sections were identical to the comparison group for instructional hours, course material, assignments, and assessments in both semesters. In addition, they had access to the same animation and completed the same demographic survey. The main difference between the comparison and treatment groups was the quiz questions. The treatment group completed an interactive quiz consisted of animation-related questions that reinforced knowledge of the intricacy of the Calvin cycle process, number of molecules involved, and how each molecule was utilized throughout the cycle.

## 3.5 Teaching Intervention

The focus of this study was to understand the role of multimedia and interactive activities on students' understanding of the Calvin cycle and their ability to retain the learned concept. In addition, this study attempted to better comprehend students' stance on implementation of such technology in their classrooms and its effectiveness in their comprehension of multi-step scientific process.

To best assess the role of interactive multimedia on learning processes, students enrolled in Bio 172 during spring 2013 and 2014 semesters were grouped to either the comparison or treatment group. The comparison group had open access to the Calvin cycle animation only, while the treatment group learning was supplemented with both the animation and an interactive quiz. The group designation was based on individual's enrolment in specific laboratory section. A pre-test was designed to assess students' prior knowledge of the subject of photosynthesis. The pretest (Table 3.2) was a series of questions created through the collaboration of the researcher and the course instructor. The pretest was completed at the beginning of the 7th week of lecture and evaluated students' knowledge on the Calvin cycle prior to the photosynthesis lecture and the intervention implementation. During a week-long lecture (3hours), the course instructor discussed the photosynthetic processes, including the light dependent and light independent (Calvin cycle) reactions (Figure 3.1). During weeks 8 and 9, students of both groups had access to their assigned activities, through the university's LMS, Titanium. The comparison group activity encompassed, the animation, quiz and demographic survey, while the treatment group has access to the teaching intervention that incorporated the animation, interactive activity quiz, and demographic survey. The three components of the activity would have taken an average of 15 minutes to complete (if every component was accessed once). For additional practice, both groups had the opportunity to revisit the animation during the two weeks, and could retake their assigned quiz up to three times. It should be noted that since the interactive multimedia was the focus of the study, animation component was accessible to both groups

Table 3.2 Pre-assessment questions to assess student's prior knowledge

| Topic | Questions |
|---|---|
| Carbon fixation phase of the Calvin cycle | 1. Where does carbon fixation occur in the plant cell?<br>2. What is the final molecule product at the end of the carbon fixation?<br>3. What enzyme catalyzes Calvin cycle reaction? |
| Source of high-energy molecules in the cycle | 4. Where does the ATP utilized in the Calvin cycle come from?<br>5. Where does the NADPH utilized in the Calvin cycle come from? |
| Utilization of high-energy molecules in the cycle | 6. What function does ATP play in Calvin cycle?<br>7. What function does NADPH play in Calvin cycle? |
| The Calvin cycle | 8. What molecule(s) is/are recycled in the Calvin cycle?<br>9. How many "rotations" of the Calvin cycle produce a single molecule of sugar? |

A designated folder titled "Calvin Cycle Activity" was created for all laboratory sections, where students received direction describing the assignments and deadlines (Figure 3.2). All students' concerns and questions were directed to the primary researcher through email communication. Furthermore, each laboratory section was visited by the researcher during week 7. In these visits, the researcher provided guidelines, addressed some of the common questions regarding the activity and deadlines, and announced possible dates for interviews.

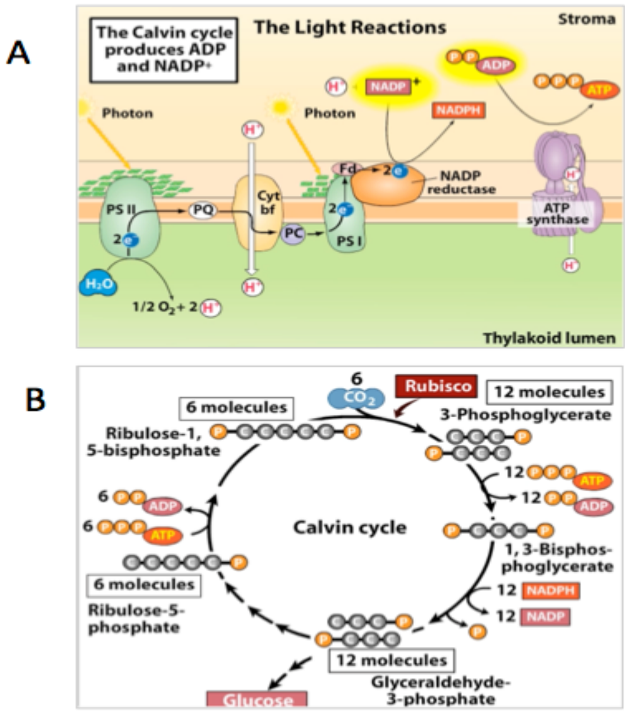



Figure 3.1 Snapshots representing the two reactions of the photosynthesis (a) light dependent reaction and (b) the Calvin Cycle. Images were taken from the animation used by students of both groups.

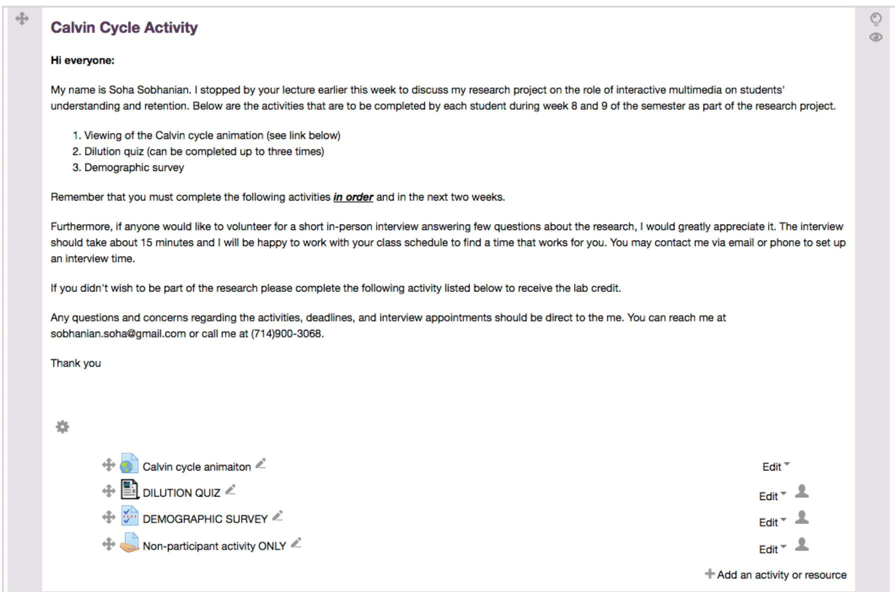



Figure 3.2 Direction and links provided to students through online platform Titanium. Note: students in the treatment group completed the Calvin cycle interactive quiz instead of the dilution quiz.

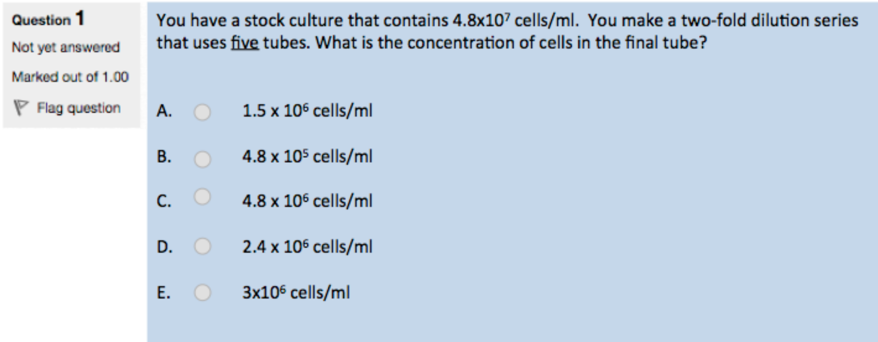
### 3.5.1 The animation

Both the comparison and treatment group were asked to watch a 1:30 minute animation titled "The Calvin Cycle". The animation was produced by Sinauer Associates Inc., and was made available through a public access link (http://sites.sinauer.com/cooper6e/animation0305.html). The link was available to each laboratory section through Titanium LMS. The animation consisted of two versions, 1) narrated and 2) step-through (see Figure 3.1). The narrated animation enabled students the control to flow of the information using the control keys (●II, ►). Additionally, subtitles (subtitles) at the bottom of the screen supplemented the narrated animation. The step-through version presented the same information as the narrated animation, however, rather than moving images, it utilized still images with no auditory supplementation. The style of the step-through presentation was similar to a PowerPoint presentation with total of six slides and was enhanced with a transcript identical to the subtitles of the narrated animation. Students were still able to move between the slides using the forward and backward buttons.

### 3.5.2 Comparison group activity

The comparison group completed a three-part activity accessible through Titanium LMS. To establish a level of consistency and reliability, a function of Titanium was utilized by the researcher. This function granted access to each component of the activity only when prior requirements were met (Figure 3.2). Therefore, activities were completed in the order set by the researcher, however no time restrains were placed on any of the activity components.

The three-part activity started with a 1:30 minute narrated version of Calvin cycle animation accessible the main laboratory page (section 3.3.3. the animation). After animation was viewed, participants gained access to a four-question quiz on dilution (Figure 3.3), and concluded the activity with an 18-question demographic survey (Table 3.3). The dilution quiz completed by the comparison group was to satisfy the participation and time requirements met for the treatment group, completing the interactive quiz.



Question 1
Not yet answered
Marked out of 1.00
Flag question

You have a stock culture that contains $4.8x10^7$ cells/ml. You make a two-fold dilution series that uses five tubes. What is the concentration of cells in the final tube?

A. $1.5 \times 10^6$ cells/ml

B. $4.8 \times 10^5$ cells/ml

C. $4.8 \times 10^6$ cells/ml

D. $2.4 \times 10^6$ cells/ml

E. $3x10^6$ cells/ml

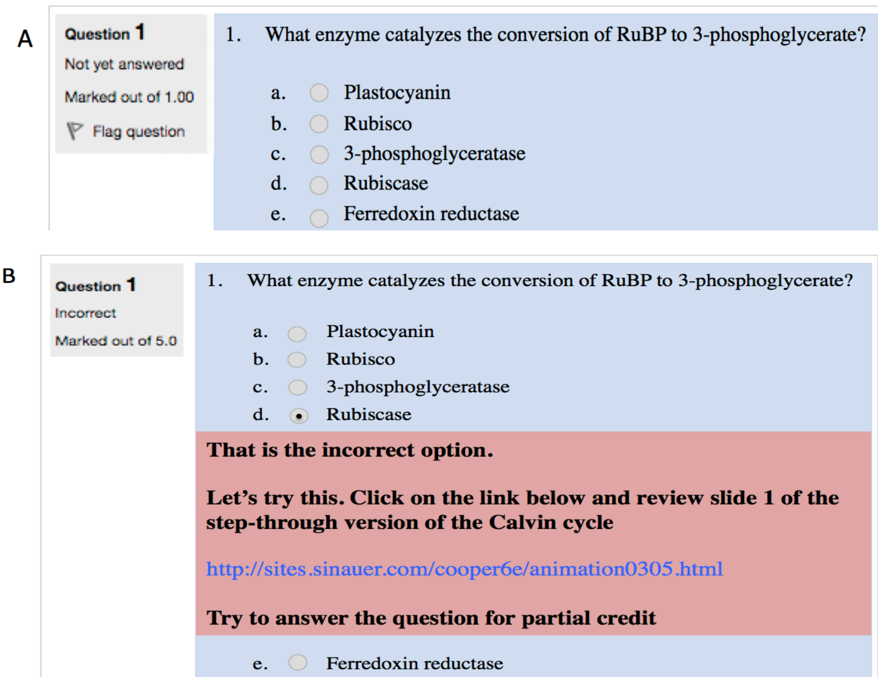
Figure 3.3 Dilution quiz question completed by the comparison group through LMS Titanium. Question pool for the dilution quiz is available as Appendix 1.

### 3.5.3 Treatment group activity

Students in the treatment group completed similar activities and in the same order as the comparison group, starting with the 1:30 minute Calvin cycle animation, an interactive activity quiz (specific to the treatment group), and the 18-question demographic survey. Titanium tools were used to design the interactive activity quiz, with for question categories. Each category highlighted a distinct concept of the animation: carbon fixation, high-energy molecules (ATP, and NADPH), utilization of high-energy molecules in the cycle, and general understanding of the Calvin cycle. The interactive feature of the quiz was the focus of the treatment group quiz. This interactive feature provided an immediate feedback for students, following their response to each multiple-choice question. The interactive nature of the feedback for either incorrect or correct responses, were designed to reiterate the concept, to enhance students' understanding, and to engage students in higher order thinking. These features were not conventionally associated with traditional multiple-choice quizzes. Listed below are the responses that students received based on the given answer. Figure 3.4 shows an example of the interactive quiz question and Appendix 2 comprised of the complete list of questions and responses.

- For the correct response, student's answer was marked as "correct", followed by a simple explanation and visual depiction to reinforce the concept (Figure 3.4c).
- For the incorrect response, student's answer was marked as "incorrect". A link to the step-through version of animation with additional instruction was provided to direct student to the appropriate section of the animation. Student was then allowed to attempt to answer the question again with 33% penalty to their score. This process was repeated until the correct answer was selected (Figure 3.4b).

Student's attempts to retake the quiz was limited to three times in the 2-weeks' time. The Titanium system automatically recorded individual's data including time spent taking the quiz, number of attempts, and the score for each attempt. However, upon completion of the activity, Titanium system recorded student's highest score as their final grade.



C

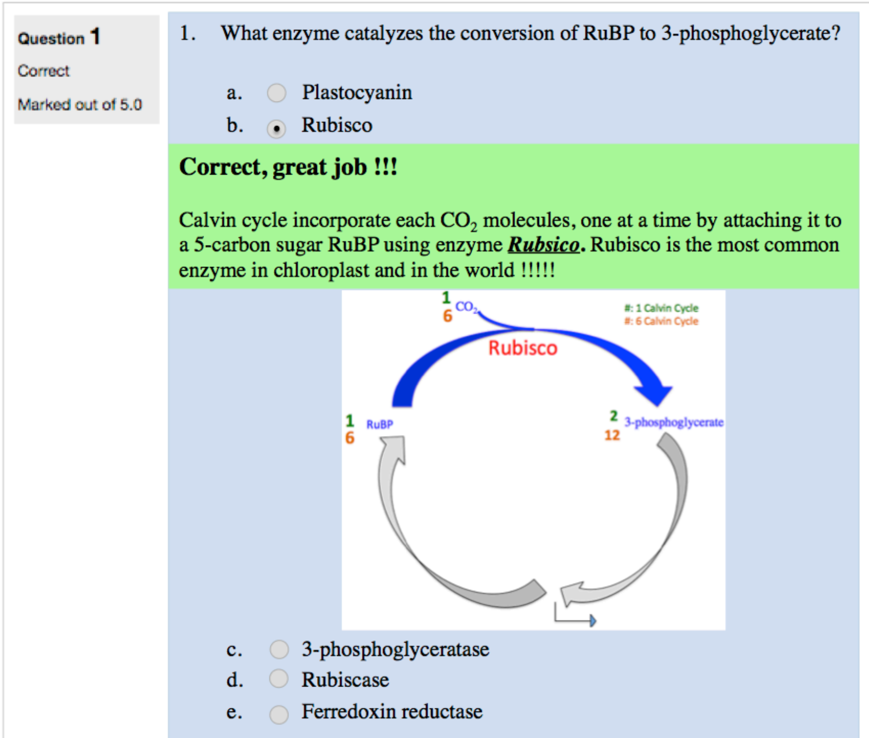



Figure 3.4 Sample question and feedbacks provided to the treatment group for the Calvin cycle activity quiz. (a) The original question (b) feedback given for an incorrect response and (c) the feedback given for the correct answer.

To ensure that recorded scores were an accurate representation of students' understanding of the Calvin cycle, an instructor-approved question pool was created for the four previously listed categories. Question pools for carbon fixation and high-energy molecules categories had six questions each, while utilization of high-energy molecules and general understanding of the Calvin cycle had five and four questions, respectively (Figure 3.5). If students attempted the quiz, they would be presented with a different set of questions since initiating a new attempt, randomly selected one question from question pools of each category to create the quiz.

To assess the influence of interactive multimedia on short- and long-term learning and retention, both the comparison and treatment group's knowledge was evaluated twice. First at the end of week 10 (midterm) and second at the end of week 16 (final examination).

A

**Carbon Fixation Category:**

In addition to RUBP, what other molecule is needed to initiate Calvin cycle?

**A. $CO_2$**

B. Ribulose-1,5-Bisphosphate

C. 3-phosphoglycerate

D. 1,3-biosphosphoglycerate

***Feedback for correct answer***

- Correct !!!
- Calvin cycle requires ribulose-1,5-bisphosphate (RuBP) and Carbon dioxide to initiate.

***Feedback for incorrect answer***

- This option is Incorrect !!!!
- Click on the link below and review slide 1 of the step-through of the Calvin Cycle animation. http://www.sinauer.com/cooper5e/animation0305.html
- Try to answer the question for partial credit.

B

**High energy molecule production category**

Where does NADPH used in Calvin cycle come from?

A. Light independent reaction of photosynthesis

**B. Light reaction of photosynthesis**

C. Photosystems I & II

D. Photosystem I

E. None of the choices

***Feedback for correct answer:***

- Correct, nice work!!!!
- During the light-capturing reaction of photosynthesis, excited electrons are donated to electron transport chain. In the last step of process, the high-energy electron is transferred to $NADP^+$ converting it to NADPH and is eventually used in Calvin cycle.

***Feedback for incorrect answer***

- This option is Incorrect !!!!
- Think about reactions of photosynthesis. You can also refer to slide 2 on the step through (http://www.sinauer.com/cooper5e/animation0305.html) or figure 10-14 of your textbook.
- Try to answer the question for partial credit.

C

**High energy molecule utilization category**

What molecule is utilized to regenerate RuBP for a new Calvin cycle?

**A. ATP**

B. $FADH_2$

C. $NADP^+$

D. NADPH

E. ADP

***Feedback for correct answer:***

- Correct, good job!!!!
- During the last phase of Calvin cycle, also known as regeneration phase, ribulose-5-bisphosphate molecule is converted to RuBP, utilizing an ATP molecule. This phase allows the Calvin cycle to be repeated.

***Feedback for incorrect answer***

- This option is Incorrect !!!!
- Review slides 4 and 5 of the step through (http://www.sinauer.com/cooper5e/animation0305.html).
- Try to answer the question again for partial credit.

D

**General understanding of the Calvin cycle category**

Calvin cycle purpose is to:

**A. Use CO2 and high-energy molecules to form sugar**
B. To create high-energy molecules
C. To utilized ATP and NADPH to produce $CO_2$
D. To create Glucose and $CO_2$ using sunlight
E. None of the above

***<u>Feedback for correct answer:</u>***

- Correct, Great Job!!!!
- Plants use CO2 (from atmosphere) and high-energy molecules of ATP and NADPH (from light-dependent reaction of photosynthesis) to form glucose molecules.

***<u>Feedback for incorrect answer</u>***

- This option is Incorrect !!!!
- Review the Step through (http://www.sinauer.com/cooper5e/animation0305.html)
- One more time, locate ATPs and NADPHs, Count them. Try to answer the question again for partial credit.
- *Hint:* both NADPH and ATP are considered high-energy molecules.

Figure 3.5 Samples for four question categories used for the Calvin cycle activity quiz. Questions were related to (A) carbon fixation phase (B) production of high-energy molecules (C) utilization of high-energy molecules, and (D) general knowledge of the Calvin cycle. The full list of questions and feedbacks are available in Appendix 2.

### 3.5.4 Demographic survey

All students who participated in the research study during spring of 2013 and 2014 semesters were expected to complete an 18-question demographic survey (Table 3.3) to fulfill the assignment requirement.

This survey, designed by the researcher, was made available as part of course assignment, accessible through Titanium webpage. These questions attempted to provide additional details on student population by focusing on students'

- General education and science background
- Preferred method of learning and study habits
- Socioeconomic background
- Gender, age, and employment as well as
- Potential suggestions to improve the intervention

Students gained access to the survey through their personal Titanium LMS that required their campus log in. To ensure students' privacy was not infringed upon as per Curtin ethical procedures, students' information (i.e. name and student ID numbers) were removed from Titanium servers, where data was stored. Data were then transferred to an Excel file and effectively used to identify patterns and associations among student population.

### 3.6 Student Assessment: Quantitative Data Collection Procedures

Quantitative data was collected from treatment group's responses to the Interactive quiz. Additional quantitative data was collected from pre- and post-test questions for both treatment and comparison population. Data were analyzed to answer the research questions discussed earlier.

Table 3.3 Question survey completed by comparison and treatment groups during spring semester of 2013 and 2014.

| | Questions |
|---|---|
| 1 | How many semesters have you been a student at this university? |
| 2 | Did you transfer from either a community college or another university? |
| 3 | What was the primary language spoken in your home during your childhood? |
| 4 | What biology course did you complete in high school? (Select all that apply) |
| 5 | What college level biology courses have you completed prior to this semester? (Include Biology 172 only if repeated) |
| 6 | What is your major? If Biology, identify your concentration if possible. |
| 7 | What is your GPA as of Fall 2012? |
| 8 | On average, how many hours do you spend per week studying for this course? |
| 9 | How often do you study using the textbook? |
| 10 | Which of the following statements applies the most to you? I learn best when I |
| 11 | What is your opinion of the following statement? "Computer animations are a very helpful tool for learning biology." |
| 12 | Did you view "Calvin cycle" animation? |
| 13 | Did you complete the activity quiz? Answer "No" if you were only assigned to view the animation. |
| 14 | Was the concept "Calvin Cycle" new to you this semester? |
| 15 | What is your age? |
| 16 | What is your Gender |
| 17 | How many hours do you work a week? |
| 18 | Do you have any comments or suggestions regarding the animation &/or activity? |

### 3.6.1 Quantitative data collection and assessment: Pre-assessment

The pre-assessment (Table 3.4) was composed of nine questions designed to provide a base for students' knowledge of light-independent reaction of photosynthesis (Calvin cycle) prior to their exposure to lecture, animation, and interactive activity quiz. During week 7 of spring 2013 and 2014 semesters, the researcher visited the lecture hall. During the visit, she talked to students of both groups and provided a brief research background, information about the consent form (Appendix 4), and answered questions about the nature of the study. Consent forms and the nine-question pre-assessment were distributed and collected shortly after. Students did not include personal information (i.e. name or student ID numbers) on the pre-assessment questionnaire except their lab section numbers, which was used to separate the data for the comparison and treatment population.

Pre-assessment data collected prior to the implementation of the intervention was intended to assess students' level of understanding of the Calvin cycle. The questions were intended to have simple but precise responses that could ascertain student's view of this multi-step process prior to their exposure to the concept. Through the collaboration of the researcher and the course instructor, a pre-assessment scale (Table 3.3) was created and utilized to analyze students' responses. Students who gave the listed answer or one of the listed answers received one point credit, while those who provided no answer or an incorrect answer did not earn the point. Collected data from each section was entered in an excel file and assessed for patterns.

Table 3.4 Pre-assessment questions and scale utilized to evaluate students' prior knowledge about the Calvin cycle process.

| Topic | Question | 1 out of 1 | 0 out of 1 |
|---|---|---|---|
| Carbon fixation phase of the Calvin cycle | 1. Where does carbon fixation occur in the plant cell? | Chloroplast or stroma | Incorrect or no answer |
| | 2. What is the final molecule product at the end of the carbon fixation? | Either production of 3-phosphoglycerate or glucose | Incorrect or no answer |
| | 3. What enzyme catalyzes Calvin cycle reaction? | Rubisco | Incorrect or no answer |
| Source of high-energy molecules in the cycle | 4. Where does the ATP utilized in the Calvin cycle come from? | Light reaction of photosynthesis | Incorrect or no answer |
| | 5. Where does the NADPH utilized in the Calvin cycle come from? | Light reaction of photosynthesis | Incorrect or no answer |
| Utilization of high-energy molecules in the cycle | 6. What function does ATP play in Calvin cycle? | Power for sugar synthesis in the Calvin cycle | Incorrect or no answer |
| | 7. What function does NADPH play in Calvin cycle? | Production of G3P, generation of glucose, or precursors of glucose | Incorrect or no answer |
| The Calvin cycle | 8. What molecule(s) is/are recycled in the Calvin cycle? | ADP and $NADP^+$ | Incorrect or no answer |
| | 9. How many "rotations" of the Calvin cycle produce a single molecule of sugar? | Total of 6 cycles | Incorrect or no answer |

### 3.6.2 Quantitative data and assessment: First post-assessment

The first post-assessment focused on identification of any alterations in students' understanding and retention upon completion of the interactive multimedia activity quiz described in the teaching intervention (Section 3.5.3). The researcher implemented four multiple-choice questions (Figure 3.6 and Appendix 5) at the end of lecture examination given at week 10 of spring 2013 and 2014 semesters. These questions, approved by the course instructor, were created while considering the four focal points (section 3.5.3) of the interactive activity quiz completed by the comparison group. The evaluation of responses enabled the researcher to assess the cognitive and retention propensity, following the implementation of the teaching intervention. Answers to the multiple-choice questions utilized in the midterm examination were marked on a ParSystem scantron, ParScore. ParSystem automatically scored the multiple-choice questions, created Excel files, gave the researcher the freedom to arrange the data based on score, course sections, etc., and transferred the data directly to an online gradebook. Scantron forms were ran through the Scantron machine equipped with Parscore software to create an Excel file that included students' identification number, section number, and their responses to all questions. Students' identification numbers column was removed from the file and data was rearranged by laboratory section number and used in later analyses.

Data from the two comparison groups collected during spring 2013 and 2014 semesters were compared for learning environment, class size, instructor's teaching style, lecture and laboratory hours, and/or examination style. This assessment did not reveal any variation between the two comparison groups. Furthermore, the demographic survey showed similar distribution for student age, hours of study, major, prior exposure to concepts, GPA, etc. Consequently, the data from the two comparison groups were merged during data analysis to form one main data pool for the comparison group. Similarly, evaluation of the demographic survey data for the two treatment groups revealed no significant differences between them, and therefore the two semesters data were also merged to form one main data pool for the treatment group.

Each of the four multiple-choice questions included in the midterm examination, had 5 options (a-e) (Appendix 5), with one correct answer. To assess the data, a point system was used, where one point was given when the correct answer was selected and no point for any other chosen options. A more involved approach determined the percentage of students that have selected each of the given options. Students' responses for comparison and treatment groups were entered in Excel files and analyzed for any discerning patterns between the groups. Furthermore, the data was used to identify possible misconceptions among student population about the Calvin cycle.

Which of the following statements is **true** about one of the ways ATP is utilized during the Calvin cycle?

A. To 'fix' carbon molecules onto RuBP, forming 3-phosphoglycerate
**B. For the regeneration of RuBP at the last phase of the Calvin cycle**
C. To convert 1,3 bisphosphoglycerate to G3P
D. To produce of NADPH from $NADP^+$
E. Both a and b

Figure 3.6 Sample of a multiple-choice question used in midterm examination to assess their knowledge of the Calvin cycle (correct response bolded). Full list of questions is available in appendix 5.

### 3.6.3 Quantitative data and assessment: Second post-assessment

Students' understanding and long-term retention for spring 2013 and 2014 semesters were assessed during the second post-test assessment at the time of the final lecture examination, on week 16, six weeks after the implementation of the intervention. The assessment consisted of two open-ended questions about the Calvin cycle. Spring 2013 students wrote their responses in the back of Parscore scantrons, which were then organized by laboratory section numbers. Photocopies of all students' responses were made and original Scantrons were returned to the course instructor. A detachable sheet stabled to the Scantron was using for spring 2014 data collection. The course instructor organized the answer sheets by laboratory section number, separated them from the original exam, and collected by the researcher. Student papers collected for both semesters had no identifiable mark such as students' ID number of name to ensure students anonymity. The data were compared between the treatment and comparison groups to better understand if the implementation of the teaching intervention had any positive influence on students' understanding and long-term retention of the concept.

In the second post-test assessment, students were asked to explain what they knew and understood about the Calvin cycle. The first question (Table 3.5) evaluated students' comprehension and retention of the concept but at a general and broad level. The second question required a deeper thought process as students recalled and recreated the cycle steps from their prior knowledge and through utilization of their mental model of the Calvin cycle. The second question allowed for a more comprehensive analysis of students' mental model, depth of understanding, and retention. The second post-test assessment enabled the researcher to explore the effects of intervention implementation on students' mental model, long-term retention, and recollection abilities.

To evaluate students' responses to the second post-test questions a grading scale was created with the help of three cellular and molecular biology professors (including the lecture instructor). Each faculty read both questions and wrote down answers that expected to receive full credit. The utilization of instructor's responses produced 5-point grading scales for both questions (Table 3.7 & 3.9).

Table 3.5 All participants (comparison and treatment group) were asked two open-ended questions about the Calvin cycle as part of the final examination.

| | Question |
|---|---|
| 1 | Explain the Calvin cycle in one sentence |
| 2 | Draw a diagram of the Calvin cycle. Label & explain in as much detail as possible |

For question 1, students were scored on the accuracy of their knowledge and written skills. The grading scale requirement included a complete sentence that showed clear conceptual understanding and included four key phrases (Table 3.6 & 3.7). The original grading scale for question 2 was rigorous and expected the response to include at least 14 of the 17-elements required for the complete answer (Appendix 6). Students' drawings, choice of vocabulary, order of information presentation, and number of molecules involved in the cycle were the required components of the grading scale. The reliability of the scale was checked by a cellular and molecular biology faculty member. The faculty graded 10 randomly selected student responses from both groups. After consultation with the faculty member, the second question grading scale was modified to remove redundant components, to create an 11-element response (Table 3.8). The improved version of the scale assessed responses on the 11 components for which students received 5 out of 5 when at least 10 of the 11 elements were included in their answers (Table 3.9). Populations' data were entered in an Excel file and reviewed for possible patterns.

Table 3.6. The key phrases that should be present in the answer to question "explain the Calvin cycle."

| | Main components of the answer |
|---|---|
| 1 | Location of the cycle/phase |
| 2 | Utilization of high energy molecules (ATP and NADPH) |
| 3 | Carbon fixation (utilization of CO2) |
| 4 | Production of organic molecule (sugar) |

Table 3.7 A 5-point scale created from the main elements identified in Table 3.6 to evaluate students' ability to explain the cycle.

| Scale | Requirements |
|---|---|
| 5 out of 5 | All 4 items are mentioned |
| | Correct terminology is used (i.e. ATP or high energy molecule) |
| | Student used one complete sentence |
| 4 out of 5 | At least 3 of the 4 items are mentioned |
| | Minor mistake in conceptual understanding |
| | Student used one complete sentence |
| 3 out of 5 | At least 3 of the 4 items are mentioned |
| | 2 or more mistakes in the terminology/conceptual understanding |
| | Either sentence is incomplete or incoherent |
| 2 out of 5 | At least 2 out the 4 items is mentioned |
| | Major mistakes in the terminology/conceptual understanding |
| | Either sentence is incomplete or incoherent |
| 1 out of 5 | At least 1 out the 4 items are mentioned |
| | Major mistakes in the terminology/conceptual understanding |
| | Sentence structure is no incomplete or incoherent |
| 0 out of 5 | No answer was given |
| | Incorrect answer/student doesn't show any conceptual understanding |

Table 3.8 The eleven key components that should be present in the students' drawings in answer to the question "Draw a diagram of the Calvin cycle. Label and describe in as much detail as possible".

| | Key components to be included in the answer |
|---|---|
| 1 | Start with RuBP (arrow) |
| 2 | Addition of carbon dioxide (arrow) |
| 3 | Name the enzyme rubisco |
| 4 | Production of 3-phosphoglycerate |
| 5 | Use of ATP and conversion to ADP (arrow) |
| 6 | Utilization of NADPH to NADP+ (arrow) |
| 7 | Production of 1, 2, (no number) G3P |
| 8 | Conversation of 2 (no number) G-3-P to glucose (or simply G-3-P leaves cycle) |
| 9 | Eventual conversation to Ribulose 1, 5-biphosphate (or mention of 5 glyceraldehyde 3-phosphate) |
| 10 | Utilization of ATP and production of ADP (arrow) |
| 11 | Number of ATP and NADPH utilized |

Table 3.9 A 5-point scale was created from the main elements identified in Table 3.8 to evaluate students' ability to draw and explain the Calvin cycle.

| Scale | Requirements |
|---|---|
| 5 out of 5 | Student has drawn/labeled at least 10 of the 11 items available |
| 4 out of 5 | Student has drawn/labeled at least 8 of the 11 items |
| 3 out of 5 | Student has drawn/labeled at least 6 of the available 11 items |
| 2 out of 5 | Student has drawn/labeled at least 4 of the 11 items |
| 1 out of 5 | Student has drawn/labeled at least 2 of the 11 items |
| 0 out of 5 | Student did not answer the question or the question or labeled 1 of the 11 items |

### 3.7 Student Assessment: Qualitative Data Collection Procedures

To provide a comprehensive evaluation of the teaching intervention, qualitative data were collected from both groups during spring 2013 and 2014 semesters. Volunteered interviewees were only identified by their original assigned groups. The researcher did not collect any information prior, during, or after interviews that might have led to identification of participants.

#### 3.7.1 Qualitative data: Interview

To identify volunteers for the interview process, the researcher visited each laboratory section and briefly explained the purpose and procedure for the interview, and answered related questions. Per given guidelines, interested students contacted the researcher via email and set up an appointment. Same information was also made available on the announcement board of the Titanium webpage for interested individuals.

Total of 17 volunteers (10 females and 7 males) were interviewed in spring 2013. Among the 17 students, 11 volunteered from treatment group while the 6 remaining volunteers were part of the comparison group. During spring 2014, total of 10 (8 females and 2 male) students volunteered for the interview with majority (six individuals) belonging to the treatment group.

Volunteers were notified that their interviews were recorded (audio only) for future transcription. All volunteers' verbal acknowledgment and consent were collected prior to recording. Each interviewee received a copy of the questionnaire (Figure 3.7 and Appendix 10) and was asked to review them prior to the start of the recording. Students reviewed the interview questions for 1 to 2 minutes. The comparison group's questions focused on the role of multiple representations (i.e. animation, narration, and subtitles) on students' learning process, classification of learning styles (i.e. visual, auditory, read-write, kinesthetic), and students' stance on implementation of multimedia in classrooms. The comparison group's interviewees answered 11 questions with an average time of 12 minutes/interview. Analysis of qualitative data was the key in ascertaining the influence of multimedia as a teaching tool and its role in explaining complex and/or multistep scientific processes in future college courses and across all majors.

Qualitative data collected from the treatment group interviewees encompassed the comparison group questionnaire and questions related to interactive active quiz (Figure 3.7 and Appendix 10). The treatment group volunteers answered 18 questions with an average time of 15 minute/interview. The interview included questions to evaluate the design of the quiz, the usefulness of the feature of the activity, and students' preference toward implementation of variations of the activity. This data could be utilized to improve and enhance features of the activity for future implementations.

***Influence of multiple representation of information on students' learning process:***

- How helpful did you find the subtitles (available at the bottom of the animation) in your learning process?

***Students' learning styles and attitude toward multimedia implementation in classrooms:***

- Do you consider yourself a visual learner (learn through image/graphic/written notes, or animation), auditory learner (learn through listening), Kinesthetic learner (learn through action) or a combination of the three? explain.

***Evaluation of the interactive activity quiz (treatment group):***

- Was interactive aspect of the activity quiz beneficial in addressing your questions about the Calvin cycle? Please explain.
- You received two different feedback depending on your answer in the activity quiz:
  - ✧ Correct answer: graphic combined with a written statement explain the answer
  - ✧ Incorrect answer: reference to specific segment of the step-through animation

  Which one of the two did you find more useful/helpful (option of receiving information as a statement combined with an diagram or option of referencing the step through and extracting your own information)

Figure 3.7 Example of questions students responded to during the interview. The questions of the first two categories aided with a better evaluate the role of animation as a multimedia for both groups, while the third category was exclusive to the treatment group and appraised the interactive quiz.

Individual interviews conducted in spring 2015 collected supplementary qualitative data to better assess the animation's role in students' comprehension of the Calvin cycle. To better assess the multimedia component of the teaching intervention, a revised version of prior semesters' interview questions was used for the 2015 interviews (Appendix 11). Procedure followed by the researcher was similar to what was described for spring 2013 and 2014 semester interviews. The researcher, with the permission of the lecture instructor, visited the class and discussed the purpose and the process for the interview and answered related questions. Over a period of 3 weeks, 33 one-on-one interviews (18 females and 15 males) were conducted. Since audio recording of the interviews were made for future transcription, students' verbal acknowledgment and consent were collected prior to the start of audio recording.

For 2015 interviews, volunteered watch a 1:30min subtitled animation about the Calvin cycle accessible through: http://www.sinauer.com/cooper5e/animation-0305.html. Students had the option of watching the animation multiple times until they felt comfortable with the presented information. Interview questions were then reviewed by the volunteers prior to the start of interviews. The Interview consisted of 10 questions (table 3.10) and was concluded by a question where students drew/wrote and talked about the Calvin cycle in as much detail as they could. To better understand student's understanding, their verbal responses as they answered the last question was recorded and reviewed in later time.

These interview questions focused on students' prior knowledge about the cycle, and identification of specific animation features that were described as beneficial and/or confusing. This data highlighted the importance of implementation of multimedia in science classes. All recorded interviews and their transcripts for all three semesters were kept at the researcher's office, on a computer that was password protected. To protect the anonymity of the participants, volunteers did not answer any personal questions

Table 3.10 Student questionnaire utilized during spring 2015 interview sessions to better assess the role of multimedia in students' comprehension and retention of the Calvin cycle process.

| | Question |
|---|---|
| 1 | What did you notice in this video? |
| 2 | Were there any distinctive features of the video that interested you? |
| 3 | Was the concept discussed in the video new to you? |
| 4 | Was there anything different about the information provided in the video and your prior knowledge about the topic? Explain |
| 5 | Did you find the animation helpful? If so, in what aspect? |
| 6 | Did you find the narration helpful? If so, in what aspect? |
| 7 | How would your understanding of the topic be different, if information was presented only as animation? |
| 8 | How would your understanding of the topic be different, if information was presented only as narration? |
| 9 | How was your interpretation of the topic affected when information was presented both as animation alongside narration? |
| 10 | How would your understanding of the topic differ, if you had access to subtitles while watching the video? |

### 3.8 Summary of the Chapter

This chapter described the methods to answer the main research questions. This research relied on mixed methodology approach by collecting both quantitative and qualitative data concurrently. Each data set was analyzed separately and eventually merged together to effectively answer the research questions. All the quantitative data and majority of the qualitative data were collected during spring 2013 and 2014 semesters.

Prior to the implementation of the intervention, students signed a consent form and answered a nine-question pre-assessment to evaluate their understanding of the Calvin cycle prior to their lecture. Students were randomly assigned to one of the two groups based on the lab section number. Those belonging to the comparison group watched the narrated animation, completed a dilution question, and answered an 18-question demographic survey. The treatment group also followed a similar procedure except the quiz was replaced by the interactive activity quiz, which was the key component of the teaching intervention.

Students' understanding was assessed during the mid-term examination using four multiple-choice questions, 3 weeks following the intervention. The second assessment with the goal of evaluating students' retention of knowledge was given in the form of two open-ended questions during the final examination, 6 weeks following the intervention. Specifically designed scales were used to grade both the pre- and the second post-assessment. Interviews conducted during spring 2013, 2014, and 2015 semesters aided the research to better understand how students perceived the teaching intervention (narrated animation and the interactive activity). Quantitative data supplemented with the qualitative data enabled the researcher to understand the role of multimedia and interactive activity quiz in the students' learning environment and their ability to understand and retain complex scientific concepts.

# CHAPTER 4

# RESEARCH FINDINGS

## 4.1 Introduction

This chapter outlines the data analysis for both quantitative and qualitative data collected over three semesters.

Section 4.1 introduces this chapter; section 4.2 evaluates the combined demographic data for spring 2013 and 2014 semesters. Sections 4.3 and 4.4 utilize the quantitative data to answer the first and second research questions regarding students' comprehension and retention after the implementation of the multimedia and interactive activities, respectively. Section 4.5 utilizes both quantitative and qualitative data to assess student perception about the interactive multimedia, and its influence on comprehension and retention, and lastly section 4.6 provides a summary of the chapter.

## 4.2 Analysis of Demographic Data

This research focused on understanding the role of the teaching intervention, including the interactive activity, on students' cognition of multi-step scientific processes such as Calvin cycle. The first stage of data analysis was to ensure that no significant differences existed between the comparison and treatment groups that might influence the result of the teaching intervention. California State University Fullerton identified Bio172 as the second course in a four-course series, completed by all students majored in biology. To enroll in the course, the prerequisite (Bio171 or Chem120A) was satisfactorily completed by all students. Bio 172 was also satisfied the requirement for biochemistry majors and science requirement for the non-majors at CSUF.

To effectively assess the student population involved in the research, all participants completed the demographic survey. The 18-question survey (Table 3.3) was a valuable tool that provided information on gender and age distribution, participants’ main language, their study and work habits, ranking, education and science background, and their preferred learning methods. The collected data presented a clear synopsis of students involved in the research.

The combined demographic data for spring 2013 and 2014 semesters indicated that majority of students were female with distribution of 59% and 68% for the comparison and treatment group, respectively (Figure 4.1 and Appendix 3L). English was the primary language of over 58% of the comparison group and 54% of the treatment group, followed distantly by Vietnamese and Spanish (Figure 4.2 and Appendix 3C). Examination of the population’s age showed a similar distribution pattern between groups as majority of students’ (72% of the comparison group and 78% of the treatment group) age ranged between 18-20 (Figure 4.3 and Appendix 3K). The age range for the remaining student population was 21-24 years (22% and 19% for comparison and treatment group, respectively). Students work habits was comparable between the two populations with close to 40-45% of the population not working at all and roughly half the population were employed part-time, working less than 25 hrs. /week (Figure 4.4 and Appendix 3N).

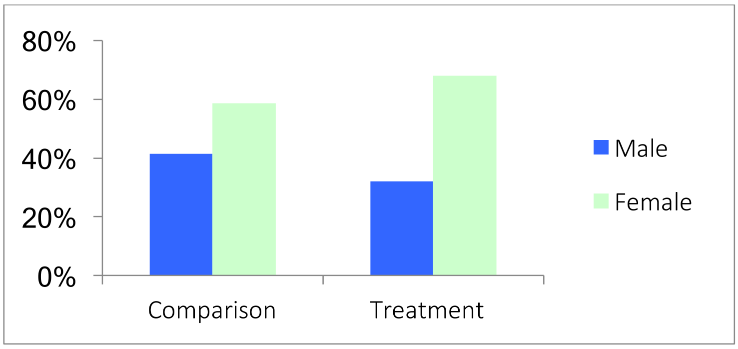



Figure 4.1 Gender distribution for comparison and treatment groups – combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

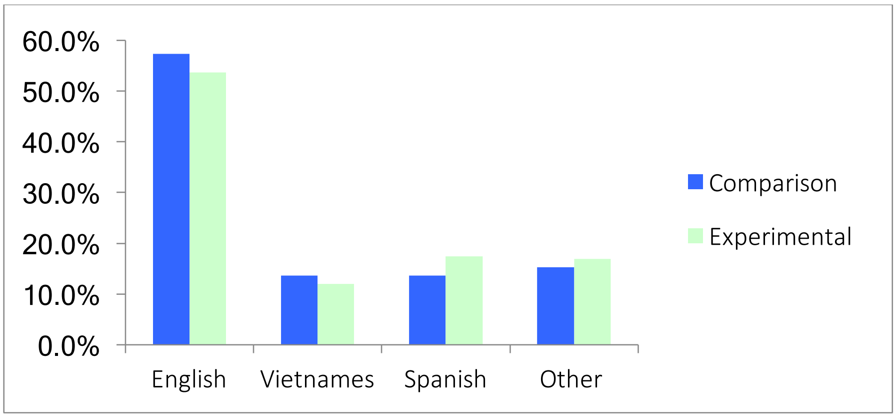



Figure 4.2 Distribution of primary language for both groups- combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

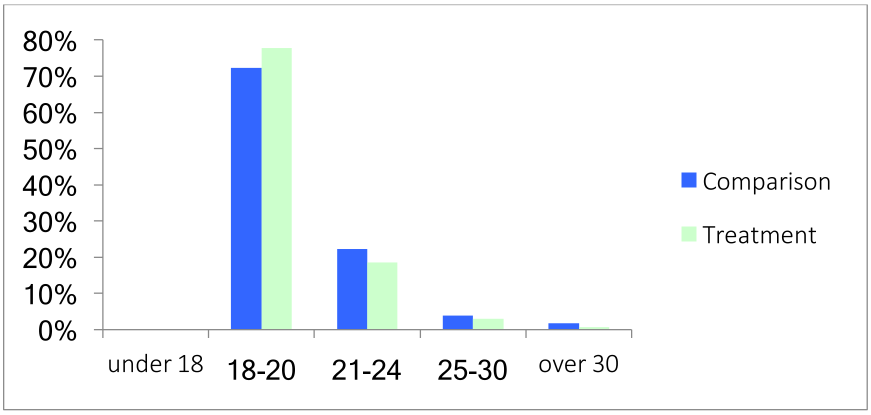



Figure 4.3 Age distribution between treatment and comparison groups- combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

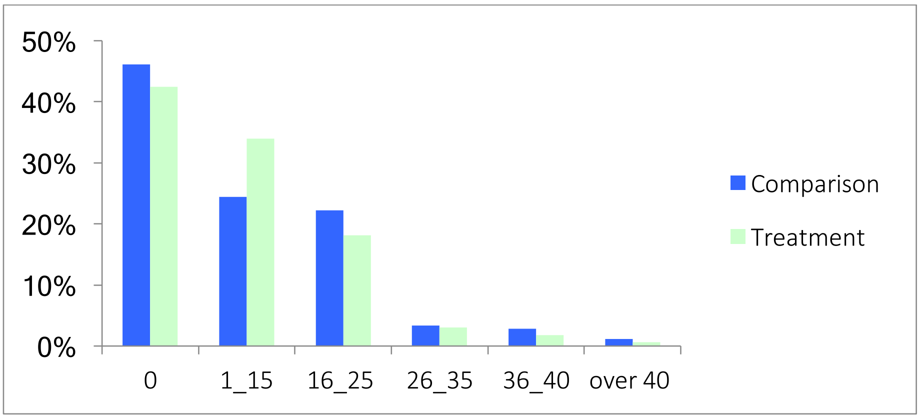



Figure 4.4 Workload distribution between treatment and comparison groups - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

On average, 13% of students transferred from a 2-year college while the remaining 87% were high school students who were directly accepted to the 4-year university program (Figure 4.5 and Appendix 3B). The age distribution and their transfer history indicated that population of interest was almost collectively made up of students who upon completion of their high school were enrolled in a higher education institution. About a third of student population were enrolled for at least 2 semesters and 85% of both groups were not enrolled for more than 4 semesters (Figure 4.6 and Appendix 3A). Considering that Bio172 fulfilled the biochemistry degree requirement, it was not surprising that a quarter of students majored in Biochemistry. Moreover, while the remaining percentage of student population majored in biology, 36% of the comparison group and slightly over half the treatment group have not yet determined their concentration in biology (i.e. cellular and molecular, ecology, marine) (Figure 4.7 and Appendix 3E). This relatively high percentage of undecided students was not unexpected as many biology students delayed their decision until they have completed their four core courses.

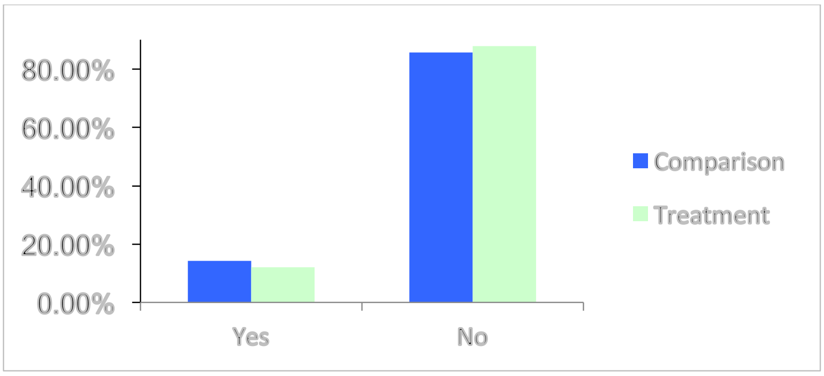



Figure 4.5 Distribution of students who were transferring form a junior college vs. those who were enrolled directly from high school- combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

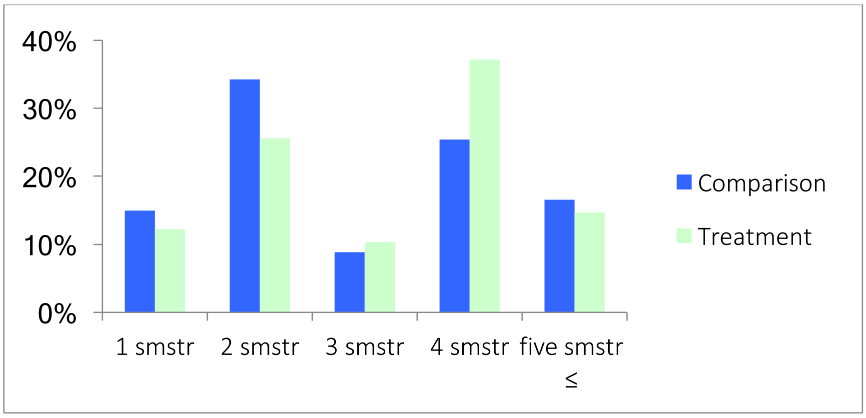



Figure 4.6 Distribution of semesters students have been enrolled at CSUF-combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

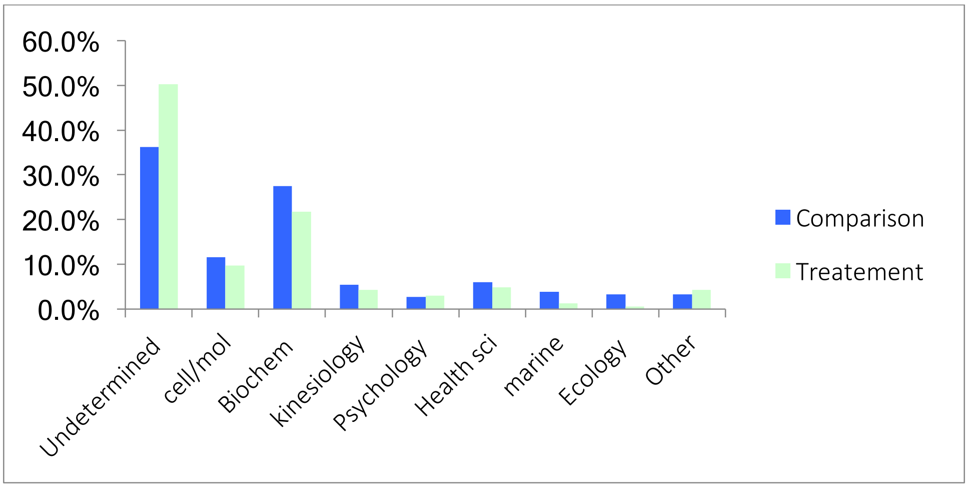



Figure 4.7 Distribution of students' major for undergraduate degree - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

Prior exposure to scientific vocabularies and concepts were evaluated through statistics related to students' course load in high school and college science, and previous lectures on Calvin cycle. While about a third of students were enrolled in a human biology (introductory anatomy and physiology) and/or Advanced Placement (AP) biology, almost 90% of student population had completed general biology course (Figure 4.8 and Appendix 3D).

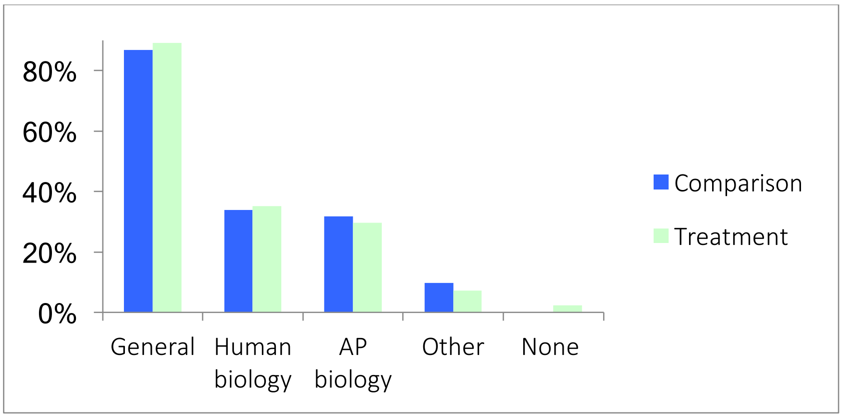



Figure 4.8 Distribution of high school science classes completed by the treatment and comparison groups - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

Further analysis of spring 2013 and 2014 semesters revealed that the treatment group had a higher enrollment rate (55% vs. 66%) for Bio171 (Figure 4.9 and Appendix 3F). This variation was the result of higher percentage of the comparison group majoring in the biochemistry (28% vs. 23%), which substituted Chem120A for Bio 171 prerequisite. A relatively low percentage of students have taken a college level general biology (16 % and 10% for comparison and treatment groups, respectively) and less that 10% were repeating the course (Figure 4.9 and Appendix 3F). Over half the student population acknowledged that they have learned about the cycle in their previous science class(es) (Figure 4.10 and Appendix 3M). This level of exposure for both groups placed them at a comparable level and provided a consistent and reliable baseline that was utilized when drawing conclusions from assessment data. During 2015 interview inquires, 60% of students conceded to prior exposure to Calvin cycle process either as part of their high school or college biology course. This pattern coincided with the demographic data collected during spring 2013 and 2014 semesters.

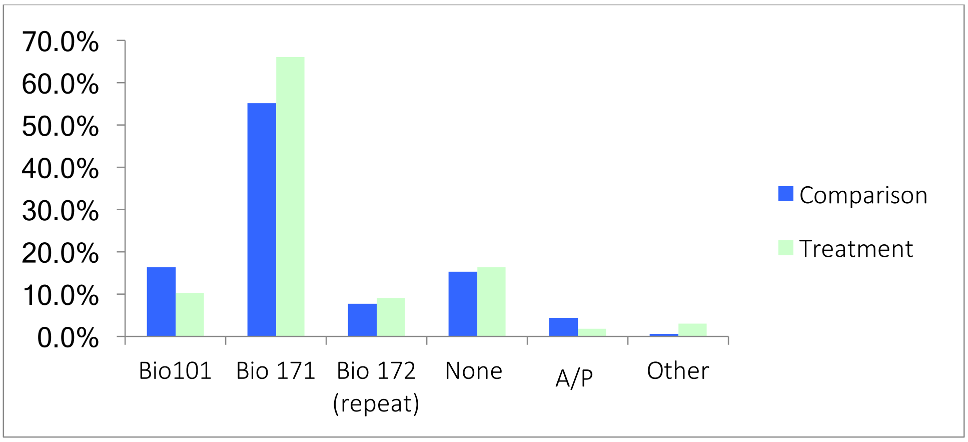



Figure 4.9 Distribution of college level science courses completed by the treatment and comparison groups - combined data for spring 2013 and 2014 semesters. Note that "other" includes genetics, molecular biology, organismal biology, and zoology. Complete statistics in appendix 3.

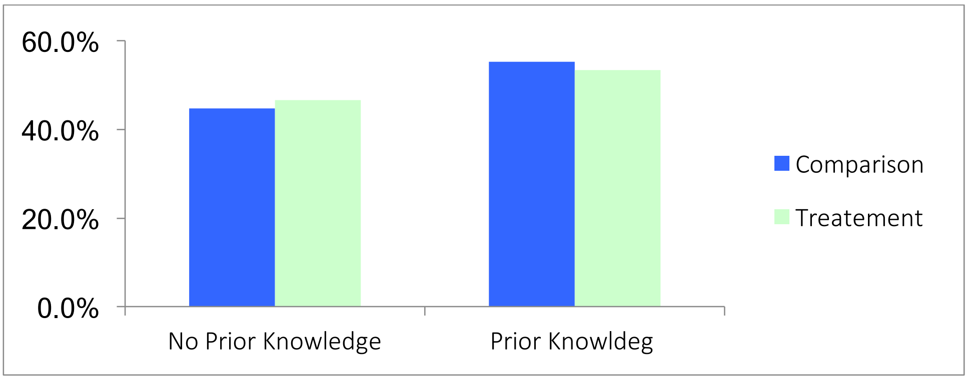



Figure 4.10 Distribution of student population who had prior exposure to the Calvin cycle process - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

Students' academic ranking was appraised through grade point average system employed by the university. Such data was used for a more accurate evaluation of students' population and formulation of appropriate conclusions. Students self - reported numbers (Figure 4.11 and Appendix 3G) indicated that approximately 20% of students' performance was outstanding (GPA 3.6-4). However, when comparing students with "good" performance, there was a somewhat noteworthy deviation between populations. About 52% of the comparison group was categorized as "B" students, while only 42% of the treatment group had the same GPA (Appendix 3G).

Though the variation in the GPA was not be dismissed, other observed similarities between the populations (i.e. prior scientific knowledge and past exposure to the Calvin cycle process) were considered before any conclusion.

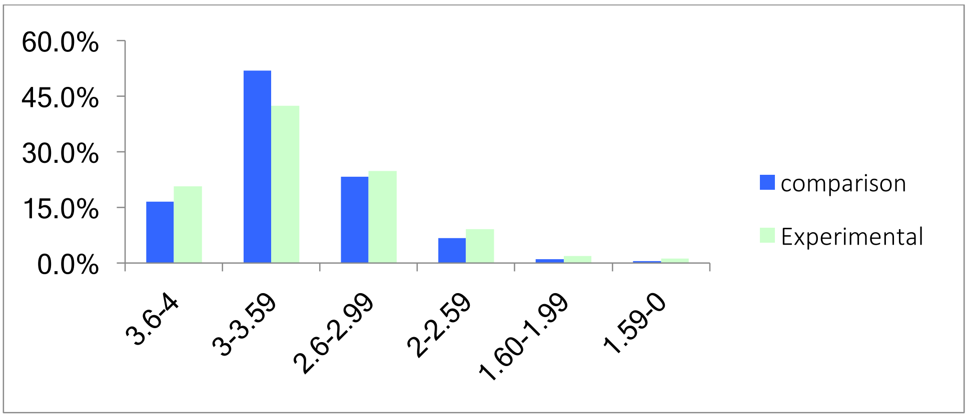



Figure 4.11 Distribution of grade point average (GPA) - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

To better understand the population, study habits (i.e. the time student spends studying and the preferred material/approach utilized for the study) of students were compared. Much of the student population spent an average of 2-4 or 5-8 hours/week studying Bio172, however there was a significant variation between the two groups (Figure 4.12 and Appendix 3H). Almost half the population in the comparison group spent only 2-4 hours/week, while approximately the same percentage (49%) of the treatment group spent 5-7 hours/week studying for the course (Appendix 3H). If the self-reported data was correct, the expectation was that the treatment groups should have performed better since they study more. It also might have created a situation to equilibrate the difference observed between the GPAs of the two groups. The percentage distribution of students who spent less than 1hour/week or more than 7 hours/week reviewing the information was small and almost identical in both groups, and therefore did not impede the proper analysis of the assessments (Appendix 3H).

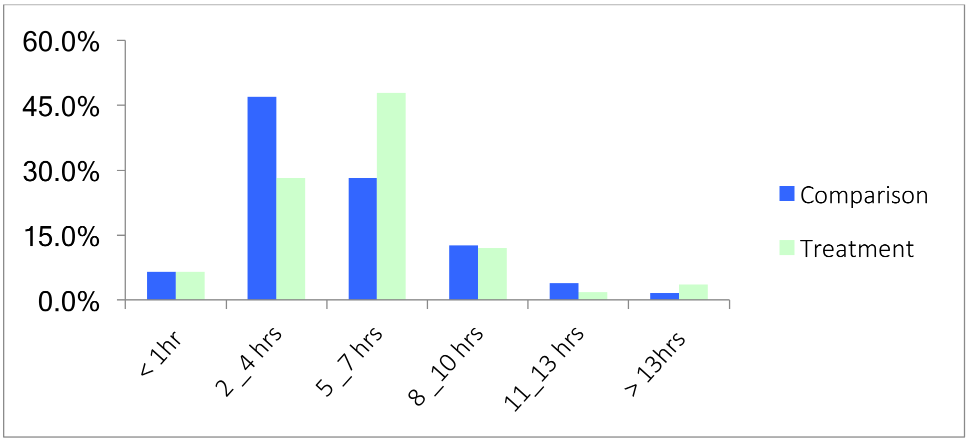



Figure 4.12 Distribution of students' study patterns between comparison and treatment group - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

To create an effective learning environment, the researcher wanted to identify techniques and approaches that enhanced and improved learners' understanding of concepts. Therefore, a demographic survey question inquired about the best method of learning for individuals. Over 40% of both groups chose "see a picture, model, and /or animation" option as their preferred method (Figure 4.13 and Appendix 3I), with a higher preference among the treatment group (42% vs. 49%). Discussion with peers was identified as the second most popular option were roughly 20% student population preferred it over other options. This option might have been preferred because of the interactive nature of the approach and instant feedback individuals received from their peers. "Lecture and review of notes" and "reading of the textbook" were the least popular options among students ranking 3rd and 4th with less than 20% popularity among students. The kinesthetic option (handling of models or acting out the concept) was the least popular with 5-8% of population selecting it as their preferred method.

Considering that narrated animation was part of multiple representations utilized in this study, students' preference for implementation of the animation was evaluated. Nearly 85% of students in both groups either strongly agree or agree that computer animation was a vital component in biology classes. These data were later supported by the review of the qualitative data collected from both comparison and treatment groups (Figure 4.14 and Appendix 3J).

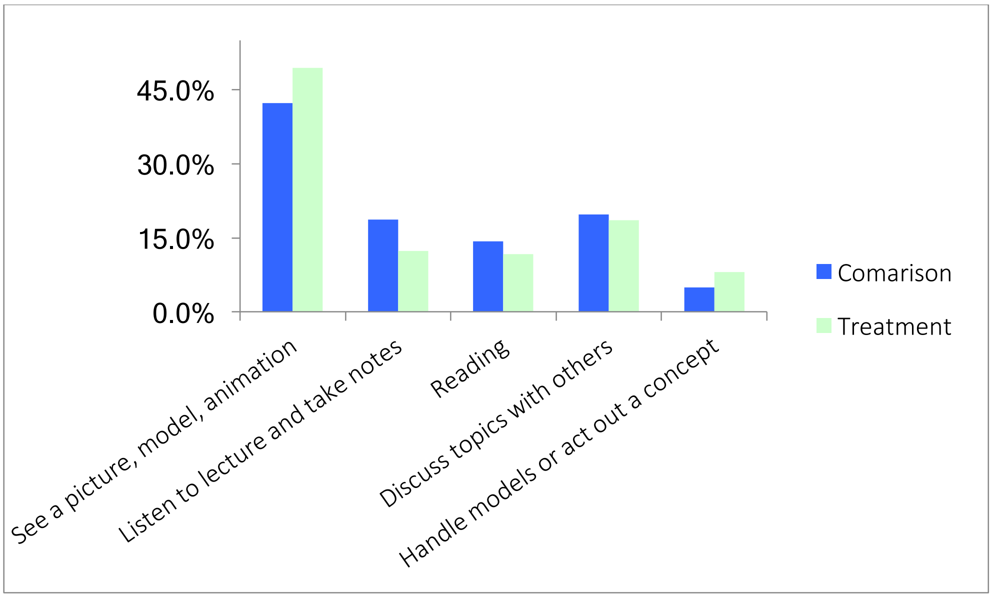



Figure 4.13 Distribution of students preferred method of study - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

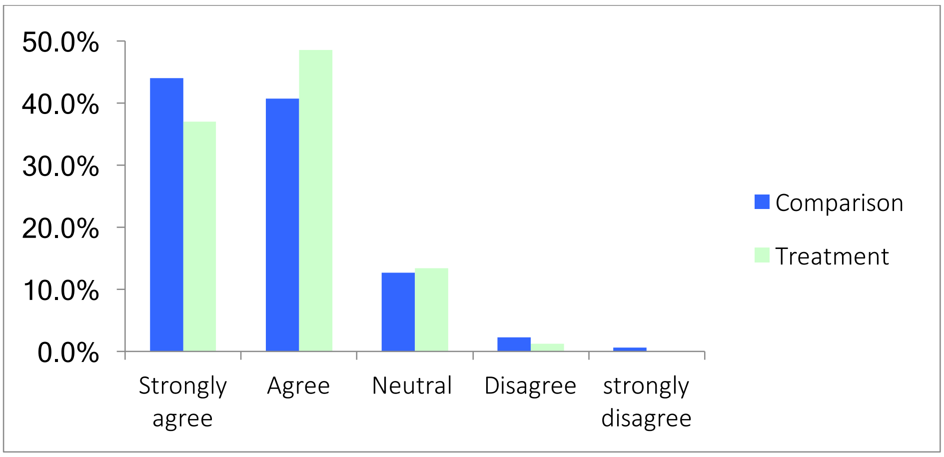



Figure 4.14 Distribution of students' opinion about the helpfulness of computer animation in learning biology - combined data for spring 2013 and 2014 semesters. Complete statistics in appendix 3.

**4.3. Analysis of the Quantitative Data - Response to First Research Question (Comprehension):** Does implementation of the Calvin cycle animation complemented with an interactive activity quiz positively influence students' comprehension of concept of photosynthesis?

Quantitative data collected from both comparison and treatment groups assessed how the implementation of the animation and interactive activity influenced students' comprehension of concept of the Calvin cycle of photosynthesis. Prior to the intervention, students' understanding of the Calvin cycle was evaluated (section 4.3.1) followed by the implementation of the activity and further analysis of students' responses through course examination using multiple-choice questionnaires (section 4.3.2).

### 4.3.1 Quantitative data analysis: Pre-assessment

To establish a baseline for students' knowledge a nine-question pre-assessment (Table 3.2) was completed by all students (comparison and treatment groups) prior to their lecture and the intervention implementation. The four focal points of the Calvin cycle were reiterated in the animation, interactive activity quiz, and post-assessment questionnaire. These principal concepts and their associated questions were as followed:

1. Carbon fixation: questions 1-3
2. Location for production of high energy molecules: questions 4 and 5
3. Utilization of high energy molecules: question 6 and 7
4. General understanding of the Calvin cycle: questions 8 and 9

Based on the assessment scale (Tables 4.1- 4.4), students' who provided a correct response received a point and those who failed to provide an answer or gave an incorrect answer received no credit. To assess the data, the comparison group data for both semesters were combined and compared to the collective responses of the treatment groups. Total of 142 of the students in the comparison group partook in the assessment while 143 treatment group participants responded to the questions. Students' populations were assessed and those with limited or no background about the Calvin cycle were identified.

The assessment first inquired about the location of the Calvin cycle. Almost a quarter of students answered the question correctly, suggesting a rudimentary familiarity with plant cell structures and function (Table 4.1 and Figure 4.15). However, a significant percentage of the students (72% and 79% the comparison and the treatment group, respectively) did not receive any credit for the question either because the question was left unanswered or an incorrect response was given. Data showed that 17% of student population identified 'mitochondria' as the location for carbon fixation, signifying a lack of understanding to distinguish between cellular respiration and photosynthesis. Other responses included endoplasmic reticulum, cytosol, and cell wall that suggested a random usage of vocabulary without any contextual elements. The detailed breakdown of students' responses for the three questions is available in Appendix 8A-question 1.

The second question of the category focused on the product of the cycle. As shown in Table 4.1 and Figure 4.15, majority of the students failed to answer the question, though the comparison group showed better scoring with 79% fail-rate compare to 92% for the treatment group. Since this deviation only existed in this question and not the other eight survey questions, it was marked as anomaly, associated with slightly better recollection of rudimentary information by the comparison group. A closer look of the group data showed that roughly half the students left the question unanswered, signifying the absence of prior knowledge or inability to recall prior knowledge. The incorrect response (i.e. oxygen, carbon, $CO_2$, NADPH, NADH, and ATP) further confirmed that students' knowledge was rudimentary or non-existence (Appendix 8A-question 2).

The third question asked student to identify the enzyme that make carbon fixation possible. Only six students among the 285 participants answered the question while the question was left unanswered by 99% and 97% of the comparison and treatment groups, respectively (Table 4.1 and Figure 4.15). Those who answered incorrectly included unrelated enzyme names (i.e. hexokinase, catalase protein, ATP synthase, and kinase). This suggested that while students understood the word “enzyme”, they did not associate specific functions for each enzyme (Appendix 8A-question 3).

Earlier analysis of the demographic data indicated that nearly half the population had been taught about the Calvin cycle in one their science classes (general biology, AP biology, Bio 171, or prior exposure in Bio 172). However, the prior exposure appeared not to translate into existing knowledge. As students’ responses to the first three questions suggested, there was a limited familiarity with the scientific vocabulary; however, it appeared that the terminology was not complemented with the correct context.

Table 4.1. Students who did not show any prior knowledge about the location of carbon fixation in the Calvin cycle - Spring 2013 and 2014.

| Questions | Comparison N (%) | Treatment N (%) |
|---|---|---|
| Location of carbon fixation | 102 (72) | 113 (79) |
| Product of carbon fixation | 112 (79) | 131 (92) |
| Essential enzyme of Calvin cycle | 138 (97) | 141 (99) |

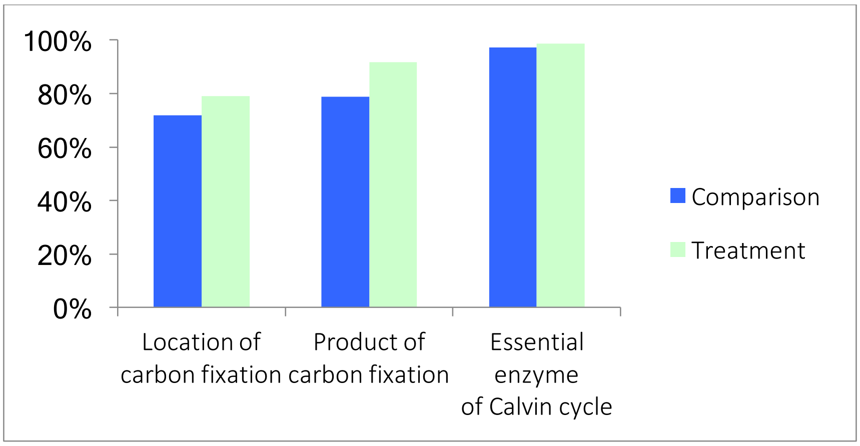



Figure 4.15 Percentage of students who failed to respond to the pre-assessment questionnaire about the location of carbon fixation– Spring 2013 and 2014 data combined.

The second principal concept examined the location for production of the two high-energy molecules (ATP and NADPH) utilized in the Calvin cycle. Students unanimously failed to answer both questions correctly (Table 4.2 and Figure 4.16). Nearly 56% of the student population left the ATP-related question blank, while 77% did not attempt to answer the NADPH related question (Appendix 8B - question 1 and 2). Such distribution emphasized the lack of background knowledge about high-energy molecules utilized in the Calvin cycle. A portion of students made an association between ATP/NADPH molecules and cellular respiration-related vocabularies (i.e. Krebs cycle, glycolysis, ETC, etc.). This was indicative of students' familiarity with the cellular processes, but their inability to distinguish between photosynthesis and cellular respiration. Moreover, 10% of students mentioned the importance of sunlight in ATP synthesis, that suggested a partial insight to the light reaction of the photosynthesis, but the process was not fully comprehended (Appendix 8B - question 1 and 2).

The qualitative data collected during spring 2015 interviews painted a similar picture. Students were asked, "Was there anything different about the information provided in the video and your prior knowledge about the topic? Explain" (Appendix 10 – question 4). Answers demonstrated that 56% of students (18 of the 32 participants) indicated that information presented in the animation was much more detailed than their prior exposure. Statements such as "I heard of it (but) not in detail, … I know about carbon fixation… but not the intermediate molecules" or "I know it was a cycle and the end product was sugar, that is it" implied very rudimentary comprehension of the Calvin cycle prior to their exposure in bio 172 lecture. Therefore, it can be concluded that while students could answer very basic inquiries about the Calvin cycle, their knowledge was superficial and without appropriate supporting context.

Table 4.2. Students who did not show any prior knowledge about the location for production of high-energy molecules in the Calvin cycle- Spring 2013 and 2014.

| Questions | Comparison N (%) | Treatment N (%) |
|---|---|---|
| Source of ATP utilized in Calvin cycle | 142 (100) | 143 (100) |
| Source of NADPH utilized in Calvin cycle | 142(100) | 143(100) |

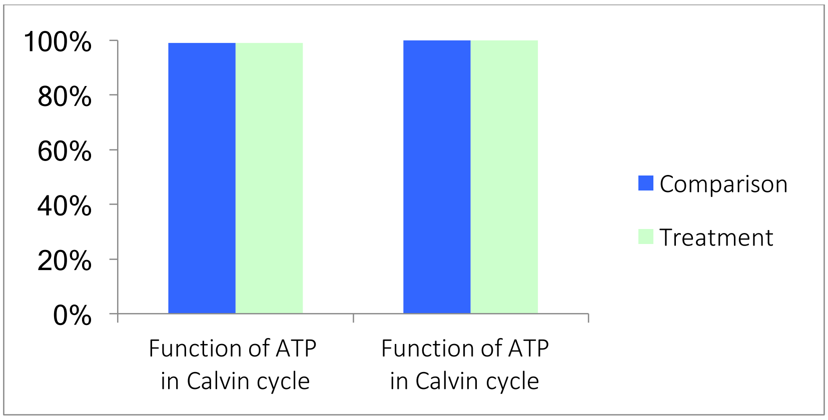



Figure 4.16 Students who were unable to provide a correct response to the pre-assessment questionnaire – source of high-energy molecules – spring 2013 and 2014 data combined.

Utilization of high-energy molecules (ATP and NADPH) in the Calvin cycle was the third focal point of the pre-assessment. Both populations were unable to provide any acceptable answer to either of the questions. On average 56% and 70% of the populations did not attempt to answer ATP- and NADPH-associated questions (Table 4.3 and Figure 4.17). Two question-specific observations were made as answers were analyzed. First, 95 of 285 participants understood that ATP was required to either initiate or continue a reaction. However, students could not describe the role of ATP in carbon fixation and regeneration phase of the Calvin cycle. Second, though 28 students explained the role of NADPH as an electron carrier, no connection was made to its role in the Calvin cycle (Appendix 8C – question 1 and 2). This data further underscored the previously drawn conclusion, describing a lack of knowledge among student population about the specifics of the Calvin cycle process.

Table 4.3 Students who did not show any prior knowledge about the utilization of high-energy molecules in the Calvin cycle- Spring 2013 and 2014

| Questions | Comparison N (%) | Treatment N (%) |
|---|---|---|
| Function of ATP in Calvin cycle | 141 (99) | 141 (99) |
| Function of NADPH in Calvin cycle | 142 (100) | 141 (99) |

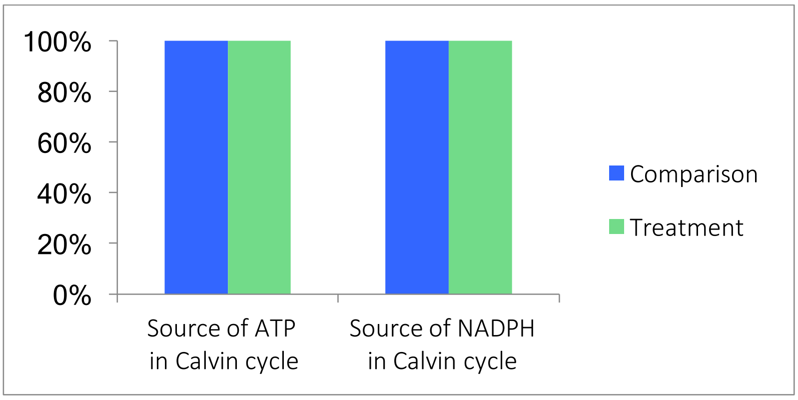



Figure 4.17 Students who were unable to provide a correct response to the pre-assessment questionnaire – utilization of the high-energy molecules – Spring 2013 and 2014 data combined.

The last two questions further assessed participants' understanding of the Calvin cycle. Students were asked to identify recycled molecules required for continuation of the process and number of cycles to create one glucose molecule. Majority of students (96% of the comparison and 98% of the treatment group) were unable to answer the first question correctly (Table 9.4 and Figure 4.18). This was similar to students' responses to previous questions, where many left the questions unanswered (86 of comparison and 87 of the treatment group's participants). Those who chose to answer the first question, provided a variety of responses, including $CO_2$, NADPH, NADH, ADP, and ATP (Appendix 8D – question 1 and 2). Analysis of responses suggested that students were conscious about high-energy molecules contribution to the cycle but an uncertainty also existed on how vocabularies and processes came together. It could also be reasoned that these given answers were not based on their understanding of the Calvin cycle, rather a rudimentary understanding of the high-energy molecules learned in the prior course lectures.

Examination of students' answers to the inquiry about the number of cycles required for production of a glucose molecule displayed a 96% and 99% deficiency among the comparison and treatment group, respectively (Table 9.4 and Figure 4.18). While over half the population left the question unanswered, others provided what seem to be random responses, ranging from one to twelve, with only six students providing the correct answer. Such a pattern suggested that students might have guessed the correct answer, without any true understanding of the molecules and processes involved in the cycle.

Table 4.4 Students who did not show any prior knowledge about the general understanding of the Calvin cycle - Spring 2013 and 2014.

| Questions | Comparison N (%) | Treatment N (%) |
|---|---|---|
| Name of recycled molecules of cycle | 137 (96) | 140 (98) |
| Number of rotations to make one glucose | 137 (96) | 142 (99) |

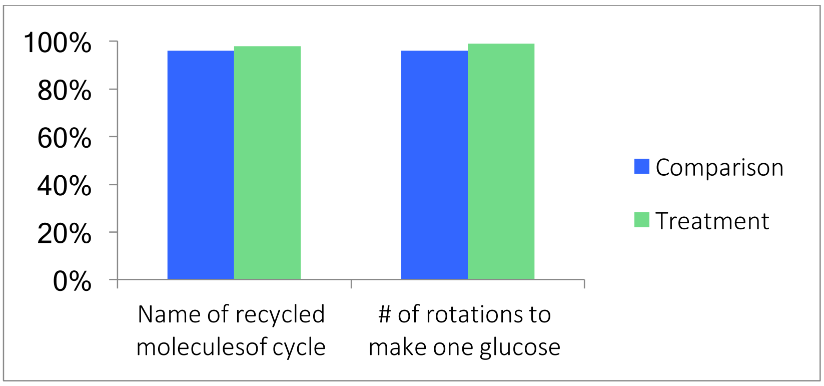



Figure 4.18 Percentage of students who were unable to provide a correct response to the pre-assessment questionnaire – general knowledge of the Calvin cycle – Spring 2013 and 2014 data combined.

Self-reported demographic survey revealed that roughly half the students had been previously exposed to the concept (Figure 4.10 and Appendix 3M). However, the demographic survey and students' responses taken together implied that prior experiences and exposures did not influence their learning. Therefore, the data indicated an insignificant contextual knowledge among majority of the students about the processes of photosynthesis and the Calvin cycle steps. Furthermore, while some students showed s rudimentary familiarity with the vocabulary (i.e. ATP, NADPH, enzyme, cycle, etc.) they were by no means proficient in their understanding of the concept. In many cases participants failed to distinguish between cellular activities such as respiration and photosynthesis, using a mixture of related language such as mitochondria, ATP synthase, ETC, glycolysis, in association with photosynthesis and the Calvin cycle. The similarities between the comparison and treatment groups, provided an appropriate starting point to assess the effectiveness of the intervention on students' learning process.

### 4.3.2 Quantitative data analysis: First post-assessment:

The first research question focused on the role of animation and interactive activity quiz on student comprehension of the Calvin cycle process (Table 3.1). Students' gained knowledge was compared between the groups using four multiple-choice questions embedded in the mid-term examination, three weeks following the intervention implementation. While questions were designed to assess students on the four principles listed in the pre-assessment but there was some context overlap within the questions.

Provided guidelines, required students to choose the best response that described the function of ATP in the Calvin cycle. The correct response (option B) was selected by 13% of the comparison group and 23% of treatment group (Table 4.5 and Figure 4.19). A chi square test was completed to determine whether the distributions of these categorical variables differed from one another in the comparison and treatment groups. A Chi-square value of 9.70 was calculated which indicated that the difference was statistically significant at $p < .05$. The observed difference is due to a higher percentage of students in the treatment group choosing the correct responses (option B). This result was encouraging in the first glance, suggestive of the positive influence of the intervention implementation, however this pattern was not repeated for the remaining three questions. Therefore, the intervention-related improvement might be isolated to specific aspects of the animation. Interestingly, over 52% of the comparison group and 49% of treatment group chose option 'E' in which two of the answers was identified as true (both A and B). One of the statements was indeed the correct answer (B) but the second option (A) was incorrect. The statement was deemed incorrect because ATP was not involved in the carbon fixation phase rather it came into play during reduction phase. Such a distinct pattern in the data indicated that while students understood that ATP was used twice in the Calvin cycle, which included the regeneration phase, they were not confident about the secondary function of the ATP in the cycle. Moreover, 19% of both groups chose answer 'C' in which described the ATP involvement in conversion of 1, 3-bisphosphglycerate to G-3-P. Selection of this answer supported the earlier deduction that students were uncertain as to the location for ATP utilization. It could be further concluded that students' mental model was either incomplete or integrated specific misconceptions.

Table 4.5 Responses to the first multiple-choice question used in first post-assessment (Figure 3.6 and Appendix 5) – Correct response is option "B"- Spring 2013 and 2014 data combined.

| Group | A<br>N (%) | B<br>N (%) | C<br>N (%) | D<br>N (%) | E<br>N (%) | Total |
|---|---|---|---|---|---|---|
| Comparison | 22 (10.9) | 27 (13.4) | 38 (18.8) | 9 (4.5) | 106 (52.5) | 202 |
| Treatment | 18 (9.0) | 45 (22.6) | 36 (18.1) | 2 (1.0) | 98 (49.2) | 199 |

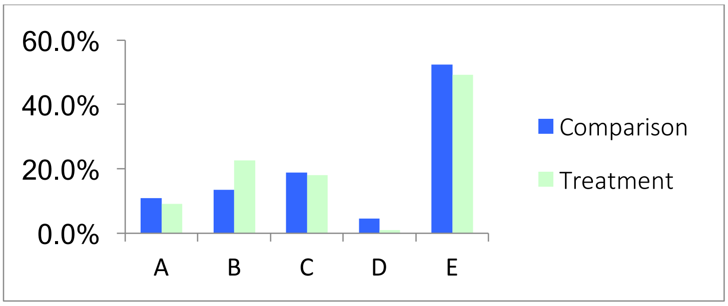



Figure 4.19 Distribution of responses to the first multiple-choice question of the first post-assessment for the spring 2013 and 2014 combined – Correct response was option "B".

The second question asked students to choose the correct response to assess their general knowledge about the cycle. Data showed that 44.1% (89 of 202) of the comparison group and 48.3% (97 of 201) treatment group chose the correct answer, with chi-square value of 3.62 which is statistically insignificant at $p < .05$. Therefore, there was no significant variation between the two groups (Table 4.6 and Figure 4.20). The result implied that a significant percentage of participants felt competent with the related vocabularies and the steps involved in the cycle regardless of their assigned groups. The relatively high success rate for the question might have been associated with the animation rather than the interactive activity. This was a rational conclusion, considering many identified themselves as visual learners, recognized the animation as the most beneficial approach (Appendix 3I), and had equal access to the animation regardless of their grouping.

Examination of the data also revealed that 31.2% of the comparison group and 28.4% of the treatment group marked option 'E'. This choice meant that students comprehended the enzyme function but were not clear about NADPH role in the cycle. Selection of this response hinted to a possible misconception in students' mental model since they were able to identify NADPH as a high-energy molecule and as an electron carrier, however, they were unclear about the location in which the high-energy molecule was utilized.

Qualitative data (section 4.4.1) further indicated a strong belief among students as to the pivotal role of animations played in creation of their mental model and addressing their possible misconceptions. However, it seemed that these misconceptions still existed for about a third of the population, and the addition of the intervention did not correct the misconception. So overall, it appeared that implementation of the intervention, might have aided the learning process but for over half the population it was not sufficient to improve their general comprehension of the cycle. This pattern was also observed during analyses of the last two questions.

Table 4.6 Responses to the second multiple-choice question used in first post-assessment (Appendix 5) – Choice "B" was the correct option- Spring 2013 and 2014 data combined.

| | A<br>N (%) | B<br>N (%) | C<br>N (%) | D<br>N (%) | E<br>N (%) | Total |
|---|---|---|---|---|---|---|
| Comparison | 17 (8.4) | 89 (44.1) | 24 (11.9) | 9 (4.5) | 63 (31.2) | 202 |
| Treatment | 23(11.4) | 97 (48.3) | 15 (7.5) | 9 (4.5) | 57 (28.4) | 201 |

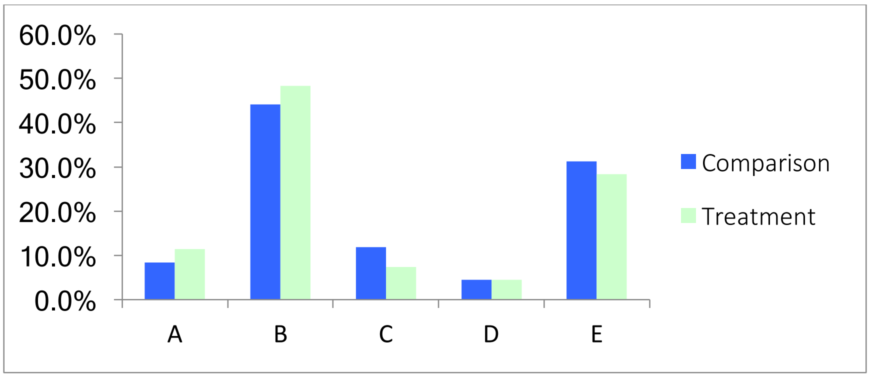



Figure 4.20 Distribution of responses to the second multiple-choice question of the first post-assessment - Combined data for the spring 2013 and 2014 combined. Choice "B" was the correct answer.

The third question evaluated students' familiarity with production of high-energy molecules utilized in the cycle. The intervention placed a significant emphasis on high-energy molecules' production and their utilization. It was hoped the interactive activity empowered students to easily identify the input and output molecules of the Calvin cycle. Therefore, one of the options included coenzyme NADH, which played an essential role in cellular respiration but not photosynthesis. Analysis of that data showed that roughly 35.1% of both groups answered the question correctly, with chi-square value of 1.10 which is statistically insignificant at $p < .05$ (Table 4.7 and Figure 4.21). Further review of the same table and figure indicated an almost identical percentage distribution between the two populations for the other options of the multiple-choice question.

The result indicated that more than half the student population chose option 'E' which recognized ATP and NADH as electron carriers in the Calvin cycle. It was interesting to note that in the previous questions over 28.4% identified NADPH as the electron carrier molecule but failed to make the same distinction in this question. It appeared that students were unable to differentiate NADH from NADPH and assumed that they were the same molecule. Cellular respiration process was discussed during a full week of lecture and prior to students' exposure to photosynthesis. Therefore, participants should have been able to discern and describe the functions associated with each molecule; however, many students were unable to do so. This combined result of this and two prior questions highlighted students' knowledge deficiencies about cellular processes; the deficiencies that even the interactive activity failed to address.

Table 4.7 Responses to the third multiple-choice question used in first post-assessment (Appendix 5) – Option "A" received full credit. Spring 2013 and 2014 data combined.

| Group | A<br>N (%) | B<br>N (%) | C<br>N (%) | D<br>N (%) | E<br>N (%) | Total |
|---|---|---|---|---|---|---|
| Comparison | 71 (35.1) | 9 (4.5) | 4 (2.0) | 12 (5.9) | 106 (52.5) | 202 |
| Treatment | 73 (36.0) | 11 (5.4) | 2 (1.0) | 14 (6.9) | 103 (50.7) | 203 |

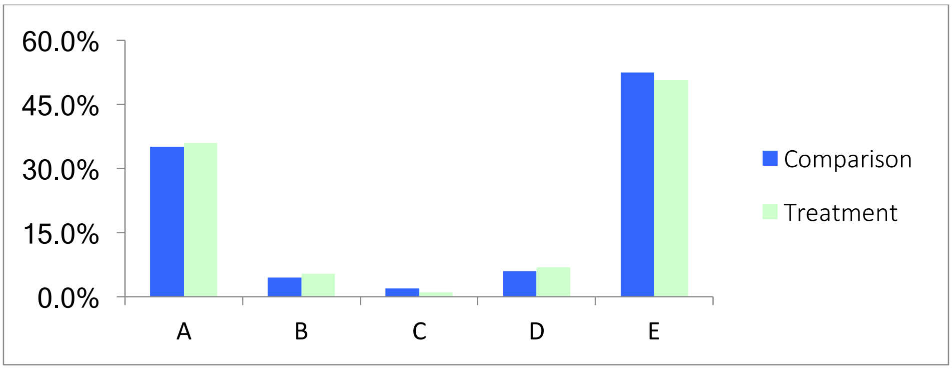



Figure 4.21 Distribution of responses to the third multiple-choice question of the first post-assessment - Combined data for the spring 2013 and 2014 combined. Correct response was option “A”.

The focus of the last post-assessment question was also on high-energy molecules. Students were asked to identify an option that best described the destiny of high-energy molecules after their utilization in the cycle. Since the activity quiz signified the importance of these molecules and their recycling through the light dependent reaction, the researcher wished to see if students’ choices reflected an enhanced cognition of the concept. Inspection of the data revealed that slightly less than half the comparison group and little over half of the treatment group were well informed about the recycling procedure for the high-energy molecules (Table 4.8 and Figure 4.22). Chi-square value of 2.97, was statistically insignificant at $p < .05$, that indicated no variation between the comparison and the treatment groups. Similarity in the percentage distribution between groups indicated that regardless of the interactive activity quiz, at least 50% of student population had sufficient knowledge of the steps involved in the movement of the electrons in the photosynthesis reactions. This success was associated with the lecture presentations, review of animation, and laboratory experiment, each of which signified the importance of light-dependent reaction in recharging ADP and $NADP^+$ molecules.

Table 4.8 Responses to the fourth multiple-choice question used in first post-assessment (Appendix 5)- Option "A" was the correct answer - Spring 2013 and 2014 data combined.

| | A N (%) | B N (%) | C N (%) | D N (%) | E N (%) | Total |
|---|---|---|---|---|---|---|
| Comparison | 99 (49.7) | 25 (12.6) | 40 (20.1) | 2 (1.0) | 33 (16.6) | 199 |
| Treatment | 103 (52.0) | 24 (12.1) | 40 (20.1) | 5 (2.5) | 26 (13.1) | 198 |

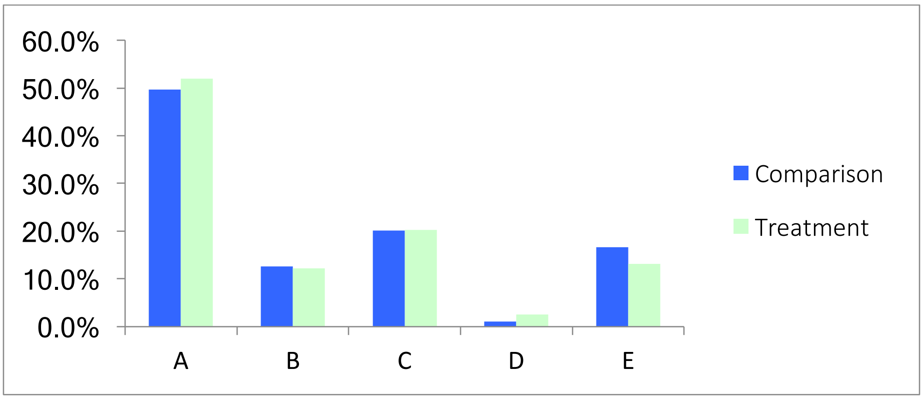



Figure 4.22 Percentage distributions of responses to the fourth multiple-choice question of the first post-assessment - Combined data for the spring 2013 and 2014 combined. Correct option was "A".

Further examination of the data identified an almost identical percent distribution for all other choices available. It was believed that this pattern accentuated the previously drawn conclusion, that while the interactive quiz might have played a role in students' understanding, the driving force for students' cognition was related to the animation, lecture presentation, class activities, and treatment observations which satisfied all students' preferred learning method, including auditory and kinesthetic learners.

The pattern that was observed for the first question where the treatment group performed better than of those in the comparison group (Figure 4.19) was not repeated for the other three questions. This observation suggested that intervention might have targeted particular aspect of students' comprehension of the cycle but was not as effective in enhancing students' understanding of the other steps involved. Review of the demographic data displayed an almost identical pattern for prior exposure (Figure 4.10 and Appendix 3M) in which around 45% had prior exposure to the information through at least one biology course (General and/or AP Biology). Moreover, review of the GPA identified that upward of 60% of both populations had an outstanding or good standing in their courses, which created a population with fewer strugglers. Therefore, the expectation was that a higher percentage of students should have answered the questions correctly. The deviation of data should have been even more pronounced for the treatment group, first because of their exposure to the teaching intervention and the variation in the study time. Roughly 50% students of the treatment group self-reported an average of 5-7 study hours verses the 28% of the comparison group with similar study habits. However, collective analysis of the question displayed an identical percentage distribution between the two groups that suggested the extra study time and completion of the interactive activity quiz did not significantly influence the treatment group understanding of the Calvin cycle.

While the collected data did not specifically support the intervention as an effective teaching tool, it definitely reconfirmed the importance of animation in students' learning. Students' preference for narrated animation supplemented with subtitles (section 4.4.1) and the fact that majority categorized themselves as visual learners lent support to the pivotal role of multimedia in students learning. Students' interviews reflected their positive attitude toward implementation of multimedia in all courses especially biology and chemistry, further fortifying the essentiality of multiple representations in learning biology.

## 4.4 Quantitative Data Analysis- Response to the Second Research Question (Retention): How does the use of interactive activity quiz in a core biology course influence students' retention of the Calvin cycle?

The second research question focused on the importance of the teaching intervention in enhancing students' ability to retain the Calvin cycle-related. To assess student's long-term retention and recollection abilities, two open-ended questions were included in the final examination during both spring 2013 and 2014 semesters. The first question focused on students' ability to recall the basic process of the Calvin cycle and explain the concept using a written statement. The second question provided a more detail analysis of students' understanding through visual representation of information. The following sections evaluated students' responses to these questions

### 4.4.1 Quantitative data analysis: Post-assessment to evaluate students' general recollection of the Calvin cycle

The initial question required students to explain the Calvin cycle in a coherent and articulated sentence. This query enabled the researcher to evaluate students' ability to recall the Calvin cycle process six weeks following the intervention, and therefore addressed the second research question, regarding the influence of intervention on student retention (Table 3.1).

A total of 201 students from each group participated in the examination. A 5-point scale, produced through collaboration of three instructors, was utilized to evaluate responses. A noticeable difference was associated with the number of students that received full credit for this question. Analysis of students' responses (Table 4.9 and Figure 4.23) showed that only one student in the comparison group received 5 out of 5, while total of six students earned the same point in the treatment group (Figure 4.24). Though both groups performance was nominal, the variation was significant between the two groups, hinting to a possible positive influence of the intervention on students' cognitive and retention capabilities.

Table 4.9 Scaled responses to the first open-ended question in the final examination – Spring 2013 and 2014

| Scale | 5<br>N (%) | 4<br>N (%) | 3<br>N (%) | 2<br>N (%) | 1<br>N (%) | 0<br>N (%) | Total |
|---|---|---|---|---|---|---|---|
| Comparison | 1 (0.5) | 14 (7.0) | 11 (5.5) | 42 (20.9) | 60 (29.9) | 73 (36.3) | 201 |
| Treatment | 6 (3.0) | 16 (8.0) | 10 (5.0) | 50 (24.9) | 52 (25.9) | 67 (33.3) | 201 |

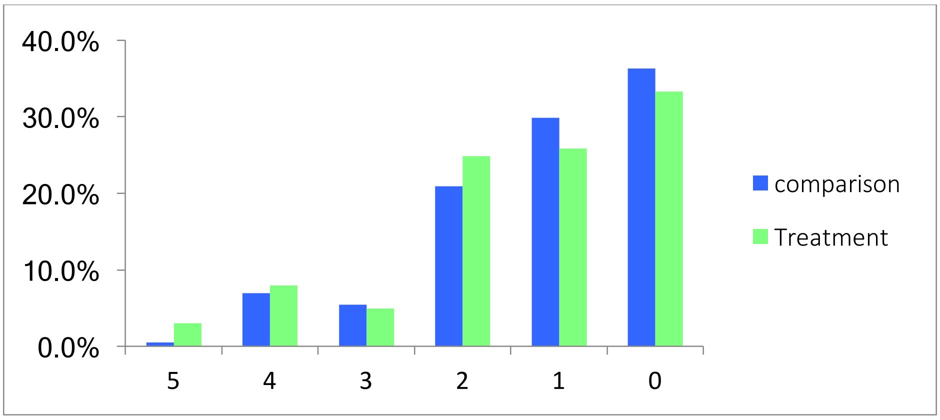
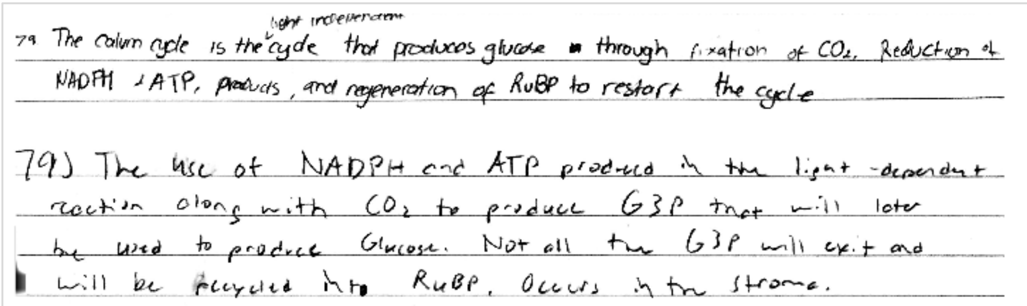



Figure 4.23 Distribution of responses to the first open-ended question based on a 5-point scale - Final examination combined data for spring 2013 and 2014.


79 The Calvin cycle is the light independent cycle that produces glucose through fixation of $CO_2$, Reduction of NADPH + ATP, Products, and regeneration of RuBP to restart the cycle

79) The use of NADPH and ATP produced in the light-dependent reaction along with $CO_2$ to produce G3P that will later be used to produce Glucose. Not all the G3P will exit and will be recycled into RuBP. Occurs in the stroma.

Figure 4.24 Examples for students' responses to the first question of the final exam that earned them a score of 5 out of 5.

A more detailed analysis of the responses was done by utilizing individual components of the scale as exclusive items to be assessed. For the response to be considered complete, students must have provided a cohesive sentence that included four key components: 1) location of the process, 2) important reactants, 3) involvement of high-energy molecules, and 4) final product of cycle. Evaluation of data indicated that 23% of the comparison group provided an acceptable answer for the location of the cycle, while 34% of the treatment group successfully responded (Table 4.10 and Figure 4.5). Also, there was a noteworthy difference between the students' population that identified the product of the cycle. Only 38% of the comparison group earned credit for this section while nearly 53% of the treatment group was correct (Table 4.10 and Figure 4.25; complete breakdown of data in Appendix 9). Data implied that while students might have not remembered all the details of the cycle, and had a low overall performance, however, the intervention might have solidified certain aspects that were not necessarily reinforced through lecture presentation and narrated animation. Interestingly, a similar percentage of both groups were able to identify the reactants and the high-energy molecules (roughly 30% and 14%, respectively) involved in the process (Table 4.10 and Figure 4.25). Demographic data (Figure 4.12 and Appendix 3H) showed that a significantly higher percentage of the treatment group spent 5-7 hours/week studying (49% vs. 28%). Therefore, it was possible that the implementation of intervention combined with higher study time helped with reiterating some aspects of the concept while it had limited to no effect on other aspects of the theory.

Another notable observation was the high percentage of students in both groups that displayed limited or no comprehension of the Calvin cycle, scoring 0 or 1 out of 5 in their written statements (Figures 4.26 and 4.27). The researcher hoped that the implementation of the interactive activity, positivity affected students scoring 0 or 1 for the treatment group, lowering their percentage when compared to the comparison group. However, a larger portion of the treatment group (66%) received scores of 0 or 1 verses 59% of the comparison group (Table 4.9 and Figure 4.23). Though, no significant positive correlation was observed between the intervention and students' retention for the first question, a somewhat encouraging pattern was observed for the second open-ended question, described in later paragraphs.

Table 4.10 Comparison of the two groups for the four essential components that defines the Calvin cycle- Spring 2013 and 2014 combined.

| Group | Location N (%) | Reactants N (%) | Product N (%) | High energy molecules N (%) |
|---|---|---|---|---|
| Comparison | 46 (22.9) | 64 (31.8) | 76 (37.8) | 28 (13.9) |
| Treatment | 68 (33.8) | 58 (28.9) | 106 (52.7) | 28 (13.9) |

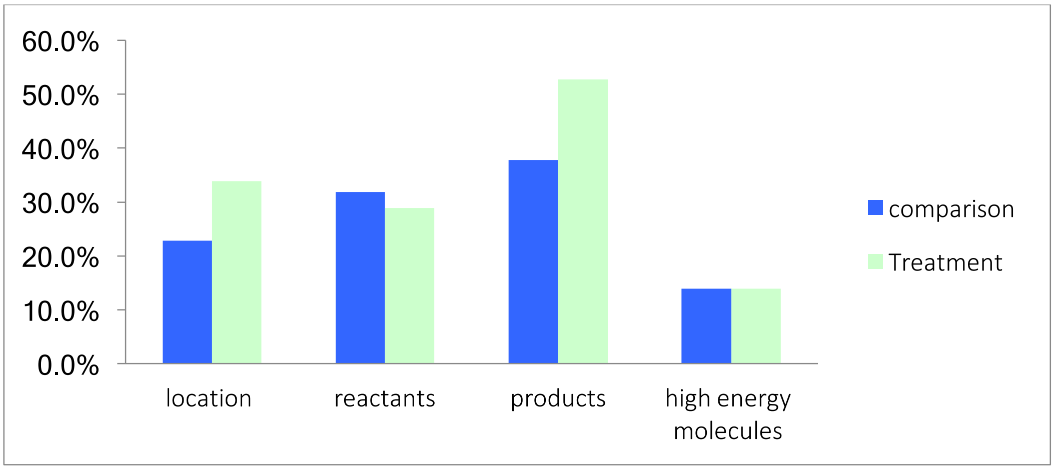
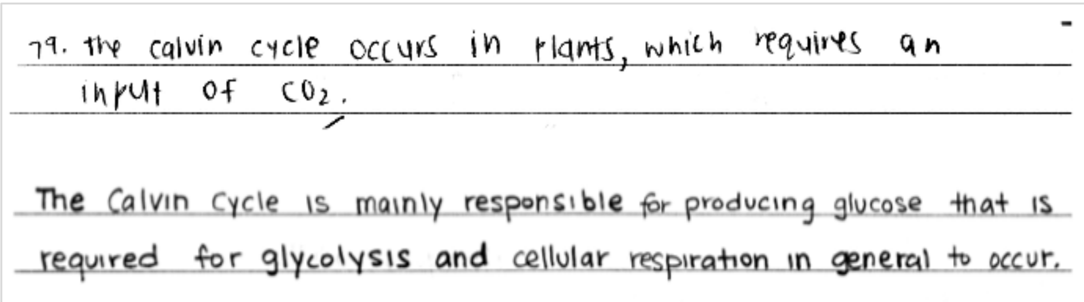
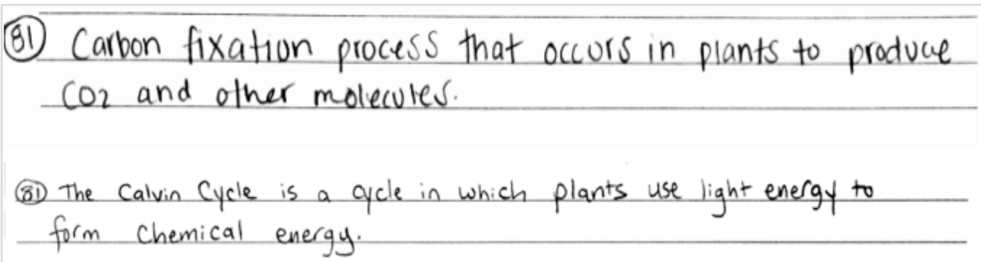



Figure 4.25 Percentage of students who identified the four key components of the Calvin cycle definition – Spring 2013 and 2014 combined. Appendix 9 includes the detail breakdown of the groups.


79. the calvin cycle occurs in plants, which requires an input of $CO_2$.

The Calvin Cycle is mainly responsible for producing glucose that is required for glycolysis and cellular respiration in general to occur.

Figure 4.26 Sample of comparison group's responses, who earned 1 out of 5 for the first question of the final examination.


81) Carbon fixation process that occurs in plants to produce $CO_2$ and other molecules.

81) The Calvin Cycle is a cycle in which plants use light energy to form Chemical energy.

Figure 4.27 Examples of students' responses in the treatment group who earned a score of 1 out of 5 for the first question of the final examination.

### 4.4.2 Quantitative data analysis: Second post-assessment to evaluate specific retention patterns

Students' ability to recall details of the Calvin cycle process was assessed in the second question of the post-assessment. The purpose of this question was to evaluate if the implementation of the intervention had improved students' ability to retain and recall information after some time had passed.

Six weeks after the implementation of the intervention, total of 201 students took the final assessment as part of the treatment group, while 201 students were assessed as part of the comparison group. A 5-point scale (5 being the highest), created with the aid of three instructors, was utilized to evaluate participants' understanding of the Calvin cycle (Table 3.8 and 3.9). Only students who included at least 10 of the 11 key elements of the Calvin cycle received a score of 5 out of 5 (Figure 4.29). Only 8 students (3.8%) in the comparison group earned the maximum point while 12 students (6%) scored similarly (Table 4.11 and Figure 4.28).

Only 0.5% of the comparison group and 3% of the treatment group earned full credit for the first open-ended question (Table 4.9). This difference might be due to variation in students' population since students with a grade point average (GPA) of 3.6-4 are 4% higher in the treatment group (Figure 4.11 and Appendix 3G). It should be noted that the data was collected as part of the demographic survey and was not independently verified. The pattern described so far, suggested that students who are the top five percentile of the treatment group benefited from the implementation of the teaching intervention and improved their retention and recollection. Though the number of students who provided a suitable answer in both groups is small, the difference was more noticeable for the treatment group.

Table 4.11 Combined Responses to the second open-ended question about the Calvin cycle included in the final examination and collected during spring 2013 and 2014 semesters.

| Group | 5 N (%) | 4 N (%) | 3 N (%) | 2 N (%) | 1 N (%) | 0 N (%) |
|---|---|---|---|---|---|---|
| Comparison | 8 (3.8) | 20 (10.0) | 34(16.9) | 39 (19.4) | 23 (11.4) | 77(38.3) |
| Treatment | 12 (6.0) | 22(10.9) | 26(12.9) | 40(19.9) | 31 (15.4) | 70 (34.8) |

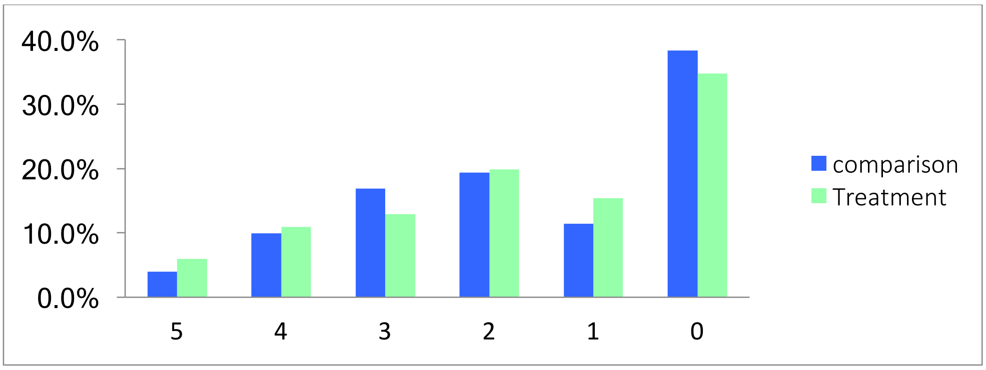



Figure 4.28 A 5-point scale was utilized to depict the distribution of responses to the second question about the Calvin cycle for the cohorts of spring 2013 and 2014.

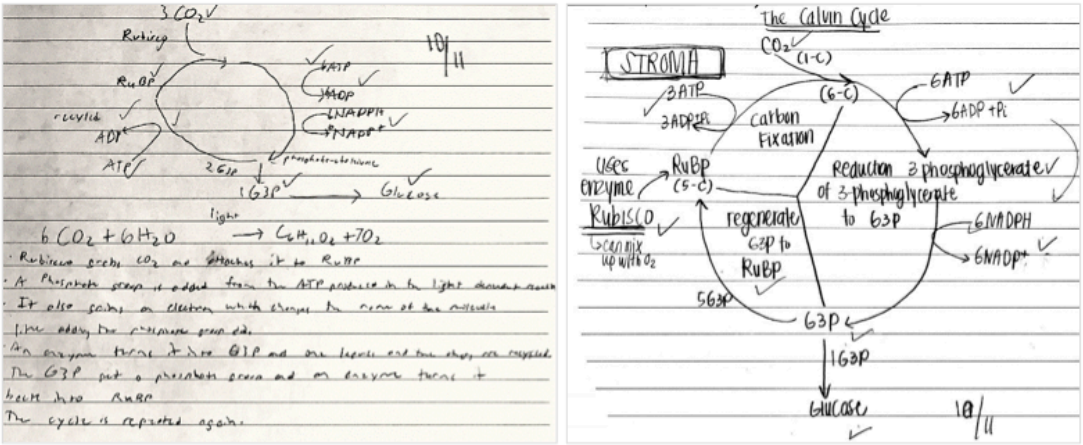



Figure 4.29 Examples of students' responses to the second open-ended question that earned them 5 out of 5.

No specific pattern was detected for students of both groups scoring 2, 3, or 4 out of 5 (Figure 4.28). The treatment group scored almost identically or slightly lower than the comparison group. Therefore, it appeared that the intervention had no influence on students' capacity to internalize the information and enhance their capability to at the level that was expected. Slightly less than half the student population in both groups earned 4 (Figure 4.30), 3 (Figures 4.31), or 2 points out of 5 points available for their responses. Similarities between groups was previously observed for both the first post-assessment (Section 4.3) and the first question of the final examination (Figure 4.23). Considering student partiality for the narrated animation with subtitles and their self-identification as visual learners suggested that similarities between groups might be associated with implementation of the multimedia for majority of the students and not the interactive activity quiz.

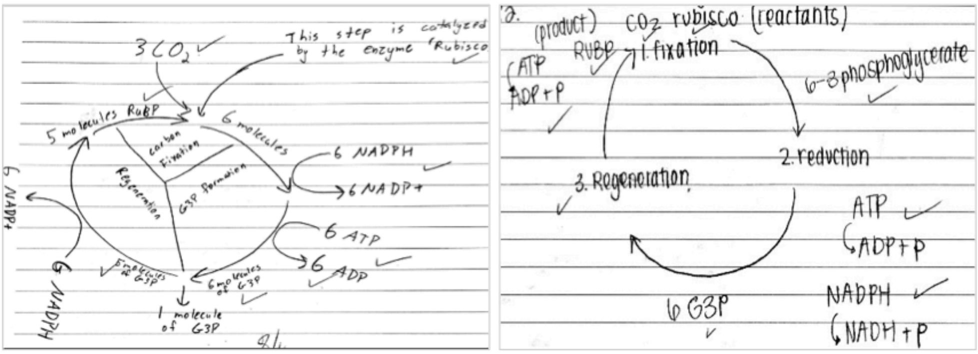



Figure 4.30 Examples of students' responses to the second open-ended question, earning them a score of 4 out of 5.

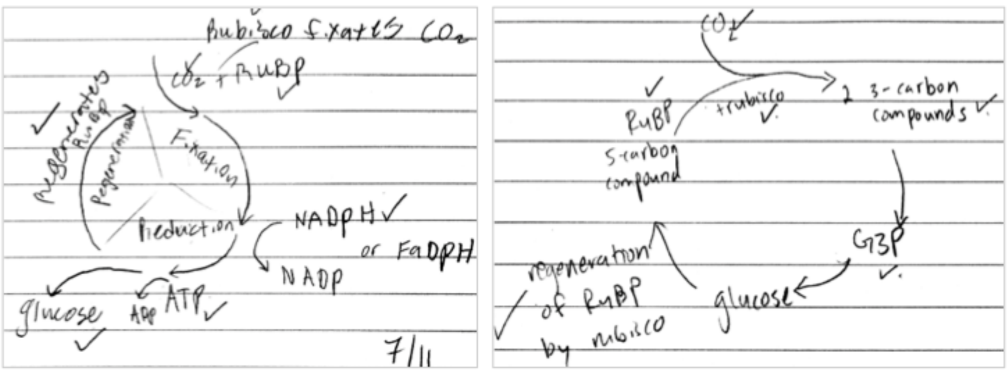



Figure 4.31 Examples of students' responses to the second open-ended question, earning them a score of 3 out of 5.

Further evaluation of the point distribution showed that an additional 4% of students in the treatment group earned 1 out of 5 (15% vs. 11%). Interestingly, lower percentage of treatment group (34%) scored 0 when compared to 38% of the comparison group (Table 4.11 and Figure 4.28). While these differences were not substantial, but it is possible that the intervention aided those with partial cognitive conceptualization. The interactive activity might have improved information retention, though it was incomplete and lacked essential components.

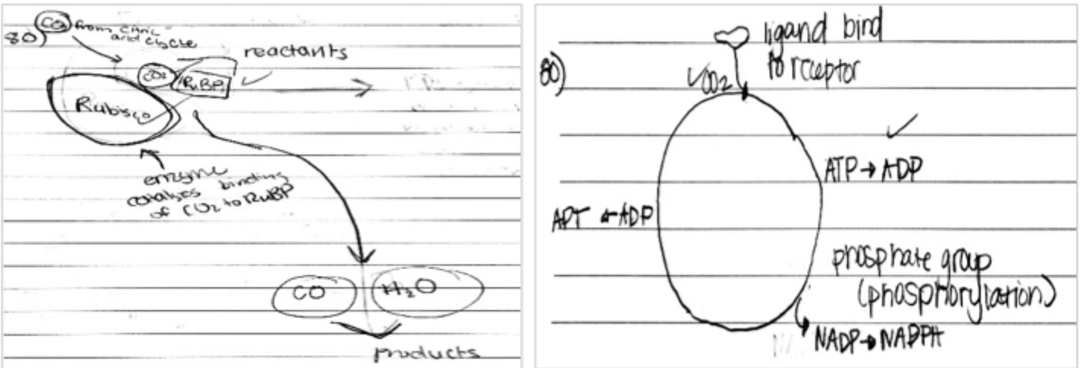



Figure 4.32 Examples of students' responses to the second open-ended question, earning them a score of 1 out of 5.

While both open-ended questions were written assessments, the way students demonstrated their gained knowledge was different. First question evaluated students by their choice of phrase/sentence compared to second question evolution that relied on students' drawings. Therefore, it was appropriate to evaluate how the implementation of the interactive activity with a visual emphasis (animation) influenced students' ability to express their understanding. A score of 0 or 1 out of 5 for either questions implied a non-existing or very limited comprehension of the cycle and steps involved.

It was observed that 66% of comparison group earned maximum of 1 out 5 for the first question while almost 50% of the same population received one point the second question (Table 4.9 and 4.11). Evaluation of the treatment group data showed that 59% and 50% earned similar scores for questions 1 and 2, respectively.

There were two points to take away from the observation. First, though percentage of students with inadequate performance for the first question was high for both groups, it was more pronounced in the comparison group (66.2% vs. 59.2%). This difference suggested that articulation/verbalization of the Calvin cycle might have been improved for the low performance students of the treatment group following the implementation of the intervention. Second, both groups' performance was improved when answering the second question, even though both questions essentially asked the same information. This suggested that students felt more comfortable presenting their knowledge in drawings rather than the describing it in a sentence. Since both groups exhibited the same progress, it reasoned that other common factors between groups' learning environment inspired the improvement, including lecture, PowerPoint, textbook, and most importantly the narrated animation. A collective analysis of students' responses to learning preferences (demographic data) and interview questions, proposed that while a percentage of students might have benefited from the intervention, the driving force behind the enhancement was related to other factors, especially the narrated animation.

The researcher created a list of common errors and misconceptions from students' drawing and further assessed the data to identify possible advantages of the teaching intervention. Each student's response was evaluated to create a complete account of the usual misconceptions and to specify the deviations between the groups. The researcher observed a common pattern of confusion from students' answers. For instance, students were unable to discern between Krebs cycle of the cellular respiration and the Calvin cycle of the photosynthesis. A total of 40 students in the comparison group included remarks or vocabularies that were specific to the Krebs cycle. A similar misconception was only present among 23 students of the treatment group (Appendix 7). This implied that while students' overall grade might have not been improved by the intervention implementation; however, some broad misconceptions were addressed that improved students' understanding of the cycle.

A common misconception that might have been addressed by the intervention was the involvement of the high-energy molecules in the Calvin cycle. Both animation and intervention paid specific attention to how these molecules energize the cycle without being consumed themselves and therefore should not be presented as a component of the cycle. Analysis of students' drawings identified 6 students in the treatment group with that misconception and total of 13 students in the comparison group with the same mistaken belief (Figure 4.33 and Appendix 7). Another misconception was related to the type of high-energy molecules utilized in the cycle. While 9 students in the treatment group mentioned molecules such as NADH or $FADH_2$, 36 students of the comparison group made comparable oversights in their responses (Figures 33A and B). The data underlined the role of interactive animation in addressing subtle and not so subtle misconceptions that existed in students' mental model.

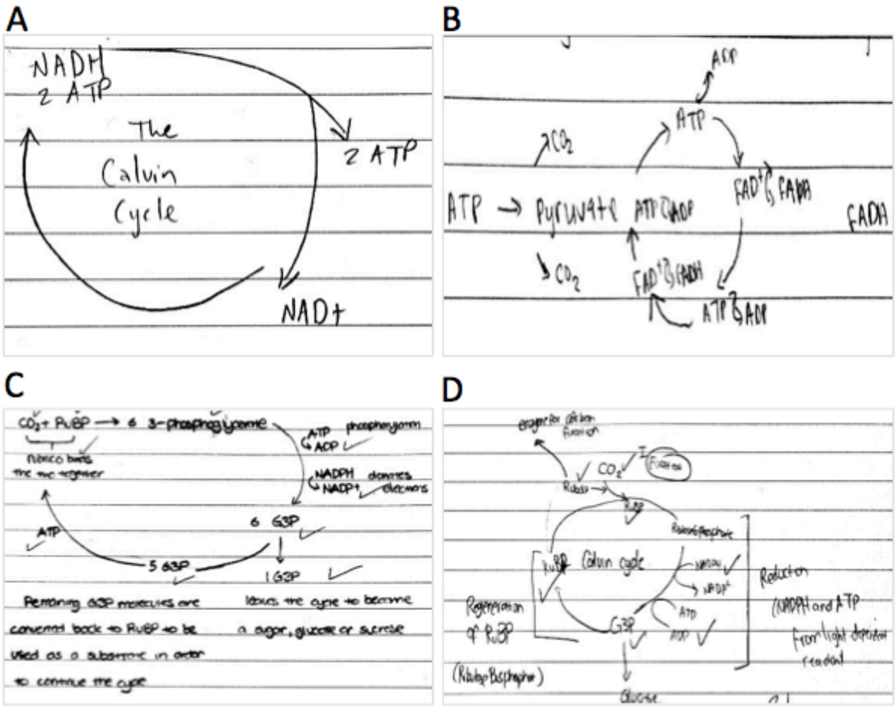



Figure 4.33 Samples of students' drawings with no understanding of high-energy molecule utilization (A & B) vs. those with good understanding (C & D).

The animation and step through version of the Calvin cycle (specific to the treatment group) utilized colored circles and lines to represent atoms and the chemical bonds and appropriate labeling to identify each molecule and intermediaries in the cycle. While the circle/line representation was suitable when learning the concept, students were expected to use proper scientific terminology when answering questions in the examination. However, when reviewing students' responses, it was noted that 11 students in the treatment group used visual representation of the molecules (circles/lines) rather that the scientific name that was expected while no student in the comparison group made such an attempt (Figure 4.34). Though such a response did not earn students any credit, but it showed a level of understanding that was not present in the comparison group. Therefore, it was plausible that students who had taken the interactive activity quiz in addition to the animation, internalized the process marginally better than those with no secondary exposure.

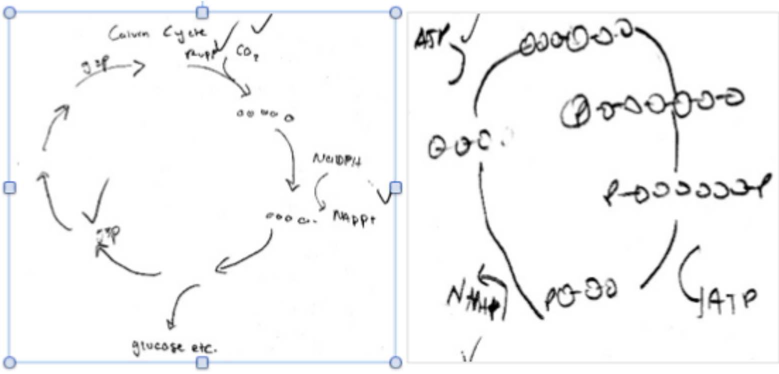



Figure 4.34 Visual representation of the molecules involved in the Calvin cycle using similar depictions in the animation/step through representation.

Another distinct pattern in the data was related to the overall understanding of the concepts through specific analysis of data, inspection of chosen vocabulary, drawing, and written statements that accompanied the answer. Among the 201 participants in the treatment group, 32 presented responses, indicating a very rudimentary impression of the context. These individuals provided terminology such as ATP, G-3-P, glucose, Rubisco, etc., or even attempted to explain the steps involved, but failed to create a cohesive image of the process and therefore received scores of 1 or 2 out of 5 points. Interestingly, analysis of the comparison group identified 57 students who fitted in this category (Figure 4.35 and Appendix 7). Therefore, it was plausible that combination of animation and interactive quiz aided certain students in the lower percentile of the class to form a mental model.

Though their mental models were incomplete and deficient in many aspects, yet this partial visualization of the process generated a minor improvement in these students' responses when compared to those with no access to the interactive activity quiz.

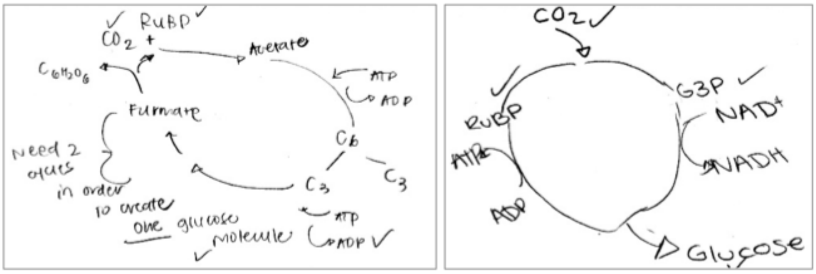



Figure 4.35 Examples of students' responses that display familiarity with the Calvin cycle vocabularies but not a complete grasp on the Calvin cycle (score of 2 out of 5).

Since one of the focal points of the research was on the influence of the intervention on students' long-term retention, an analysis was done comparing the responses of both groups for the first and second assessment. Because of the structure of question (multiple choice) in the first post-assessment, it was easy to calculate the percentage of student who responded correctly. However, drawing a line for what was considered a passing grade was more difficult for the final examination as the questions were open-ended. After discussion with other faculty members, it was decided that students who earned 3 out of 5 in either question had earned a passing grade for both questions.

A review of comparison group's responses to the four multiple choice questions showed that with an exception of one question (first question), at least a third of students and up to half the students were able to provide a correct answer (Tables 4.6-4.8). However, when final examination responses were reviewed, 13% and 31% provided satisfactory answers for the first and second question, respectively (Figure 4.36). This suggested that the comparison group was unable to retain the information from the first to the second assessment (duration of 6 weeks).

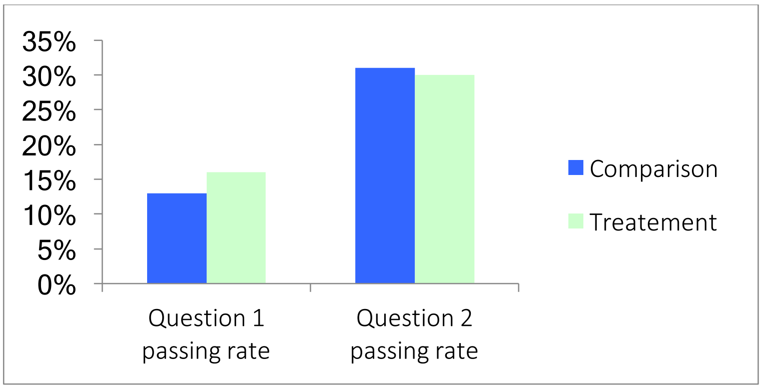



Figure 4.36 Distributions of passing rate for the two post-assessment questions between comparison and treatment groups- combined spring 2013 and 2014 semesters.

When comparing the results of the two assessments for the treatment group, a similar pattern was observed where students' retention did not improve through the implementation of the intervention. The percentage of students who correctly responded to the multiple-choice questions ranged from 23% to 52%. For two of the multiple-choice questions roughly half the student population chose the correct option (Table 4.5-4.8). However, when assessing the final examination questions for the treatment group, 16% and 30% provided an acceptable response to questions one and two, respectively (Figure 4.36). Though the scales for this comparison were different, it still provided the researcher with a rough estimation of the level of understanding. The overall pattern indicated that the interactive activity quiz did not help with students' retention abilities; however, it seemed that the benefits were at a more individual level.

It was noted that while implementation of interactive activity quiz clarified some common misconceptions, there were cases where no difference was observed between the groups' data. For instance, 14 students in each group had the same misconception that G-3-P, an essential molecule generated for production of glucose, was indeed the final product of the cycle (Figure 4.37 and Appendix 7). The observed pattern could be explained by the variation in presentation of information in the animation/step through and lecture. Animation described glucose as the final product compared to G-3-P as final product during the lecture presentation.

Taken all together, the result highlighted the positive influence of intervention on students with incomplete understanding. Furthermore, the intervention aided with cognitive dissonance and addressing common misconceptions among students. However, the intervention influence was not significant enough to create a pronounced dissonance in the long term.

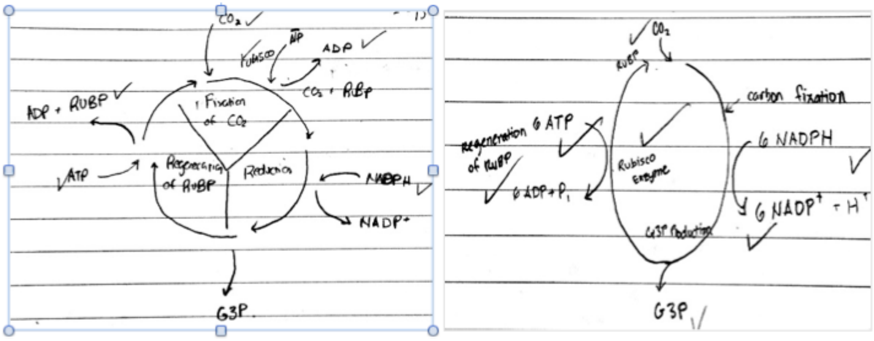



Figure 4.37 Students' responses identifying G-3-P as the final product of the Calvin cycle.

**4.5 Analysis of Qualitative Data – Response to the Third Research Question (Perception):** What are students' perceptions toward implementation of multimedia and interactive multimedia in their learning environment?

One of the main research questions focused on determining students' perceptions about multimedia and interactive multimedia on their learning (Table 3.1). Therefore, during 2013 and 2014 semesters, qualitative data in the form of individual interviews were collected from volunteers of both groups. These interviews supplemented the quantitative and demographic survey data and assessed the role of animation and interactive activity as an appropriate tool to learn about elaborate biological concepts such as the Calvin cycle and how such an addition impacted science classes.

The next sections examined each aspect of the third research question using four focal points. The four listed questions were particularly designed to address each focal point.

a. What features and attributes of the animation were deemed constitutive and fundamental verses unimportant and trivial?
b. How did such implementation influence participants' comprehension and retention of the concept?
c. What were students' perception toward implementation of the multimedia in their science classes and
d. How did students perceive the interactive multimedia and its unique features?

Additional qualitative data was collected from Bio 172 students during spring 2015 in form of individual interviews (Table 3.10). These students were not part of the original teaching intervention study group; however, they were interviewed using the refined questionnaire from spring 2013 and 2014 semesters. Students' responses assessed the multimedia and identified beneficial component that enhanced students' comprehension and retention.

**4.5.1 Multimedia and its influence as an effective teaching tool - Response to research question 3a:** What features and attributes of the animation were deemed constitutive and fundamental verses unimportant and trivial?

The first series of questions (Appendix 10) were directed at both treatment and comparison group and evaluated the influence of multiple representations of information (narrated animation with subtitles) on student learning process. Moreover, the inquires analyzed participants' learning styles and perception toward multimedia and its implementation in classrooms, therefore addressing the first two aspects of the third research question.

**Narrated animation and its features:**

Students in all three semesters recognized subtitles as an effective supplement to the narrated animation. Subtitles acted as a supplement, which reinforced the previously discussed ideas and concepts. Students' statements such as "I like reading the subtitles” or “I don’t like listening to someone, I’d rather be reading on my own” suggest that viewers’ who were considered verbal learners found the subtitles very beneficial, because subtitles provided a unique and effective method of delivering information. It also complemented the narration by providing written text that could be easily followed by individuals, maximizing the knowledge gained through multiple representations. Students comments such as “I could read along instead of trying to listen and visualize” and “… Because it explains and shows the word I couldn’t hear.., I could look at the word and understand what they were saying” emphasized the role of subtitles for students. Furthermore, such textual representation was especially beneficial to non-native students. A student stated “…because English is my second language, it helps to see the word myself,... I like to read the process to retain the information.” Review of demographic survey indicated that English was not the primary language for nearly half the student population; therefore, the textual representation including subtitles was a vital component in their learning process, as it provided a new avenue to process the information and therefore improved their retention.

In other situations, students utilized the subtitles as a method of review prior to their examination since the key concepts/ vocabulary were presented in a condensed written version. Consequently, students reviewed the information and used their notes and textbook to view a more detail representation of the context as needed. Students’ responses such as “I don’t do well with reading. I focus too much on subtitles and do not pay attention to the video” suggested that while some students have a positive viewpoint on subtitles, a percentage found the subtitles “distracting” as it drew attention away from the animation, and made it difficult to follow the process. Moreover, a minority indicated that subtitles were neither helpful nor confusing, and they were simply disregarded by the viewer. It was noted that the last two responses were mostly associated with native speakers or those who spend majority of their time speaking English.

An exciting point was discerned from spring 2015 interviews, as students were asked to identify feature(s) of animation that interested them. One of the common statements focused on the cyclic movement of molecules in the Calvin cycle. 11 of the 33 students made comments such as "I like how they did it in a cycle …" or "mainly the motion of the cycle…". Another student explained:

> "The Calvin cycle was detail and hard to explain, so going through it using the animation made it easier to understand, the representation in the cycle was very good" (student 17, spring 2015).

The researcher was unaware of students' enthusiasm about the cyclic pattern of information representation until the interview question was refined for spring 2015.

Other features that engaged the students were the narration and subtitles. Students commented that "Really liked the animation and how they were talking about it" or "the narration was very clear and easy to follow." Other responses included "…. It (subtitles) were good since as I was watching and listening I was also reading, that would help me" or "narration was great because I could pause and take notes about the wording instead of going back and try to listen". Though many students' perception of subtitles was positive, there were also 2 students who used the word "distracting" to describe the subtitles. This pattern was also observed for spring 2013/2014 data sets. Therefore, when designing future activities, students should have the freedom to either add or remove subtitles from the original animation.

The second interview question was interested in the students' opinions about the labeling utilized in the animation. The majority of interviewees' responses indicated a positive attitude toward the implementation of vocabulary and labels in the animation. 80% of interviewees (19 of 24 individuals) agreed that labels were well-suited to the animation and helpful in their learning process. Responses such as "It was beneficial without being confusing…", "… there is a lot going on in the cycle, but the labels did help" and "very helpful, I know exactly what molecules goes where" provided insights to students' opinions on animation and labeling. However, the small percentage (2 out of 24) of students had an inauspicious opinion about this aspect of the animation. Students described the simulation as “bit crowded” and went to say that it mentioned names that were not required for the course (the animation was more in-depth).

This result underlined how students effectively utilized multiple channels of learning (visual, auditory) to complement their learning process. Therefore, the researcher reflected that a balance in animation graphics complexity was required to enhance the learning process without deviating students’ attention from the main concept.

#### 4.5.2 Preferred method of learning - Response to research question 3b:

How does such implementation influence participants’ comprehension and retention of the concept?

The researcher was interested in identifying the preferred method of learning for students and compared the information to the demographic data to look for reoccurring patterns. Participants were asked to identify themselves as visual learners, auditory learners, kinesthetic learners, or combination of the two methods. Interestingly, majority of participants identified themselves as visual learners, providing responses such as “images are better for my learning process”, “visual learner! All my notes are highlighted in different colors” and “graphics and subtitles”. Moreover, it seemed that many of the students identified graphics and animation as the main modality for their visual learning. Students’ supported their answers by responses such as:

> “I am more of a visual(izer); It helps to see things, side by side of audio.” (Student 5, treatment group, spring 2013)
>
> “Narration and graphics, (I like to) hear it and see it.” (Student 3, treatment group, spring 2014)
>
> “… I need to hear what they are talking about and also see, how things are connected, how molecules are interacting.” (Student 3, control group, spring 2013)

The learning preference was also recognizable in demographic survey data, in which 60% of both groups favored visual stimulation in the form of animation, graphic, picture, or reading (42%-49% favoring animation/ graphic/ picture and 12%-14% preferring reading the text). Students' remarks suggested that 40% of visual learners did require audio supplementation to maximize their understanding, which was a component readily available as part of the animation. One participant identified himself primarily as a kinesthetic learner but also felt comfortable with visual learning tools.

During spring 2015 interviews, students were asked to explain what aspect of the animation and narration did they find most helpful. Majority of students (22 out of 33 participants) started their responses with phrases identical or similar to "I'm a visual learner." This was in line with data collected in prior two semesters, where images were the primary mode for information presentation. They mentioned that observing how molecules moved through the cycle helped them comprehend the concept easier. On student stated:

> "Definitely helpful. I'm a visual learner. So it is great knowing where ATP and NADPH go, how $CO_2$ binds to the molecule, and how G3P is used at the end, making glucose" (student 2, spring 2015).
>
> "It was cool to see ATP and NADPH coming and binding and reshuffling, so the animation definitely helped" (student 15, spring 2015).

These statements highlighted the crucial point that visual representation of content was essential in creating students' mental models.

Furthermore, spring 2015 students stated that narration was also very beneficial as it "explains what is happening in each stage" and it had a good pace and allowed the audience to absorb what was being presented. Moreover, "the repetitive nature, seeing and listening to the terminology helped me understand it more". Review of students' responses to the questions indicated that students were pleased with information presentation in the form of narrated animation with subtitles. Narrated animation enabled student to comprehend how molecules were moved and utilized in the cycle. The researcher also inquired about how students would feel if animation was presented without any narration. A few of students (6 out of 33) mentioned that the change was acceptable as long as subtitles were accessible, they had prior concept exposure, or animation was available for multiple viewing. However, even the 6 students agreed that the narrated animation was considerably more beneficial than just the animation. A few of students (4 participants) further commented that in the absence of narration, their own interpretations of information might be inaccurate or wrong. Other students used phrases such as "it would be very confusing", "I wouldn't understand it (the Calvin cycle)", or "I would be able to figure out what was happening but not retain it (information)." All these answers emphasized the importance of auditory supplementation of the animation. Therefore, if either component was omitted, it created confusion and perhaps detrimental to the learning process.

Spring 2015 interview responses (presented in the next section "most effective practice"), corroborated the previously collected data that emphasized the importance of complementary use of animation and narration in enhancing students' mental model. A conclusion was therefore drawn that the new student generation was most complacent with visual presentation of information if it was complemented with audio representation.

### Most effective practice

The researcher inspired to identify the most effective practice to teach the Calvin cycle. Many students believed that textbook was not an effective instrument in learning about the cycle, which was in accordance with the demographic survey data, where only 14% of the comparison group and 12% of treatment group found the textbook a useful resource (Figure 4.13). Furthermore, those who chose the textbook as their method of learning signified the importance of auditory supplementation (i.e. lecture presentation). Moreover, 80% of interviewees selected viewing the narrated animation with subtitles as a the most useful approach to learn about the cycle with answers such as "viewing of narration and animation really prepared me" or "I prefer option C as the best method both for general concepts and (the) Calvin cycle." This preference was further supported by prior responses where 70% of students identified themselves as visual learners and prominently relied on pictorial/graphic stimulation. Selection of this response also signified the importance of auditory stimulation as part of the learning process, reiterating the role of multiple representations to enhance students' cognition. Some of the students did mention the review of lecture, text, PowerPoint, diagrams, or step-through version as great resources that supplemented the narrated animation. However, they were no discerning pattern on preferences. Some of the responses listed below:

> "The one that shows (the) animation with step-through, but I like to first view the animation as it is narrated and then go with the step-through version to help me understand the concept by reading the text" (student 7, treatment group, spring 2013).
>
> "Both the narrated version of the animation and bulletin format presented in lecture" (student 1, control group, spring 2014).
>
> "Narration with animation; but I also looked at the PowerPoint and text. So then looking at the narration would be most effective" (student 6, treatment group, spring 2014).

Lastly, a small percentage of students chose step through with subtitles as their preferred style of learning. These were students who found the narration confusing or distracting. All responses taken together signified the importance of employing multiple modalities when presenting context so to enhance the learning environment for a larger population.

It was important to question the role that an instrument played in building, enhancing, or changing an individual's mental model. In this research, one of the focal points was how the narrated animation benefited students with their mental model of the Calvin cycle. All participants except for two found the narrated animation a helpful tool in shaping or improving their mental model. Several interviewees (8 students) decidedly identified the narrated animation as an essential component in the formation of their mental model or improving the already existing model. Students' responses included:

> "It helps when I take the test. I can see the picture as a whole visual image that pops into my head and I can locate which part (of the image) I need to answer the question, instead of remembering what teacher said during the lecture" (student 5, treatment group, spring 2013)
>
> "The animation was very helpful; it just made sense, and helped me create an image (mental model)" (student 2, control group, spring 2013)
>
> "The picture (animation) is now stuck in my mind. I would not forget the carbon going in and the glucose coming out" (student 2, treatment group, spring 2014). This student went further to describe the Calvin cycle indicating that her mental model was directly built from the animation.

Two of the students agreed that the presentation of information in the textbook was neglected because it was too detailed, and therefore was not very helpful in creating a complete mental model. Other responses suggested that while animation was not the primarily instrument, it aided with "connecting of the dots for what was already known" and that the given information in the narrated animation "supplemented" the previously discussed information. These answers suggested that a percentage of students did rely on lecture as a useful resource. This observation was also in accordance with the demographic data where 19% of the comparison group and 13% of the treatment group find lectures as the most effective tool for learning the content and concepts (Figure 4.13). However, the fact that only 20% of interviewees mentioned the importance of lecture in creation of their mental model might be due to their relatively low participation in lecture. The course instructor reported that in average 35% of students did not attend the lecture regularly. Therefore, to build an effective mental model, students reliance shifted to other available (i.e. narrated animation).

Overall, the collective data from the three semesters accentuated the importance of visual and auditory representation in enhancing students' mental model.

#### 4.5.3 Perception toward multimedia - Response to research question 3c:

What are students' perceptions about implementation of the multimedia in their science classes?

This section evaluated students' perception on the implementation of multimedia as a learning tool in classrooms and specifically in science classes. Generally speaking, students identified multimedia as a great addition in classrooms, however, it was noted that the some of the supporting statements was specific to science classes, specially biology, chemistry, and mathematics. Therefore, there were interrelating remarks when comparing students' feedback on the questions. Preliminary assessment indicated that combination of traditional teaching supplemented with multimedia could create an ideal learning environment for students. A summarized remark stated that lecture and bulletin points alone led to a mundane learning environment, which could be enhanced through utilization of the multimedia.

Other students agreed with that statement. Their agreement is reflected in statements such as "combination of both old-school teaching using books and lecture with multimedia supplement would be very valuable." These opinions lend support to this collective approach. However, as one student pointed out "it (dual method) is a helpful addition if the professor doesn't depend on it." Another participant mentioned that "instructors should notice how students interact with the multimedia; how are their attention…." Comments like these served as a warning to faculty members who rely heavily on the multimedia as a teaching tool, because while students were technologically aware, they still appreciated the traditional learning environment setting. A few students commented that while implementation of multimedia was beneficial in some classrooms (i.e. mathematics), it was still more effective in biology classes. Considering these comments, the general attitude toward the multimedia implementation in classrooms was positive when complemented with instructional hours. It was curious that while students were strong supporters of multimedia and its influence on their learning and creation of mental models, they willingly or unknowingly still depended on or were drawn to the traditional classroom, and considered it an essential component of their schools and learning environment.

### Classroom role

Review of students' remarks about multimedia's role in classrooms coincided with the role of multimedia in science classes. This pattern signified the fundamentality role of multimedia in creating an optimal learning environment. Key phrases such as "a great tool for visual learners", "this is how our (the new) generation best understands the information" and "it leaves a lasting impact" substantiated the role of multimedia in students' learning. Statements similar to

> "It is almost mandatory, because science is cycles and processes and the 2D diagrams of the text is just not enough to help with comprehension" (student 9, treatment group, spring 2013).
>
> "Helpful, at times I get confused by the instructor, so multimedia helps me get a better understanding of the information" (student 5, comparison group, spring 2013).

were further endorsement for utilization of multiple media in science classes. A comparable pattern was observed When demographic survey was reviewed. Roughly 85% of both groups demonstrated major support for the importance of computer animation in learning biological concepts. Other than biology, students identified chemistry as a science that benefited from such implementations by "breaking down the multistep processes", "providing visual representation of molecules, bonds, and reactions", and 3D images of molecules that are easier to visualize compare to "stick figures."

### Time constraints

The interviewees also described the strain placed on instructors as they attempted to discuss a vast body of knowledge during time-constrained lectures. Consequently, students must effectively utilize other resources such as YouTube and narrated animation for their studies. Continuing in the same line of thought, multiple students mentioned "Mastering Biology (an online resource attached to the textbook that provided visual representation) as an effective supplement to their biology lectures. While students did view multimedia as a great learning instrument, which gave them control and visual support, they also pointed out its limitation such as lack of interaction with an actual person to answer related questions. So, while multimedia was a great and an appropriate addition to science classes, (i.e. biology and chemistry), nevertheless, students required and desired instructor interaction to establish a sustainable learning environment.

**Importance of animation**

The last question in this series evaluated the importance of animation alone on retention ability. Students almost unanimously agreed that their retention was enhanced because of their access to animation. Number of students mentioned that it was more helpful to see the process rather than just hear about it. Such a response coincided with visual stimulation being the preferred learning style. Phrases such as "you can visualize it in your head rather than memorizing the step" and "it helped me create a complete mental model that I can use to answer exam questions." Highlighted the importance of animation. Further support was found in the student's response:

> "Science course, it is important. (For example) when we were learning about mitosis and meiosis in bio and she had videos of cell going through stages and becoming two separate cells, I think seeing that was really important. You can take snap shots and put them in text books with lot of information, but seeing it is a very different experience, it makes you want to go and research it more to understand it better. It makes science classes cool" (student 2, comparison group, spring 2013).

Students opinion about the relevance of animation was recognized in their responses, but was that optimism reflected in their assessments scores? A simple evaluation of the comparison group responses to the first and second post-assessment, discussed previously in the quantitative data, indicated that students' retention was not enhanced following the implementation of the narrated animation. So, while students felt an improvement in their retention and recollection after animation viewing, it was not the reality. Variations in the style of the questions and the scale utilized might explain some of the disparities between the data; however, the deviation was significant to be considered genuine and true.

When the researcher inquired about the animation influence on building memory, a treatment group participant stated "Animation by itself was not enough … without the activity quiz, the animation was not very helpful in retention." This response suggested that animation usefulness in students' retention was acceptable but only if it was supplemented with other activities. This was in accordance with quantitative data collected of the comparison group, where animation by itself did not improve students' retention. This section was a great transition point to the next set of questions directed at the treatment group to assess the contribution of the intervention on students' learning.

**4.5.4 Students' perspective on the teaching intervention - Response to research question 3d:** How did students perceive the interactive multimedia and its unique features?

During the interactive activity quiz, students in the treatment group completed a 4-question quiz with each question accentuated an aspect of the Calvin cycle. Depending on students' answers, they received specific feedback that provided further guidance for individuals. When the chosen response was correct, the feedback reiterated the concept. However, if an incorrect choice was selected, students were redirected to the specific segment of the animation, searched for the required information, and had a second chance to respond. Interview volunteers were asked the following questions (in addition to inquires discussed in section 4.4.1) regarding:

1) Benefits of the interactive style quiz in general
2) Available feedback options
3) Personal preference on quiz styles (traditional vs. interactive)

4) Inclination on information representation (narrated+ subtitles vs. step-through+ subtitles), and

5) The most beneficial aspect of the teaching intervention

Students' remarks provided a basic outline to design an effective future intervention and enhance the learning environment for prospective students.

**Benefits in teaching style**

The first question identified specific aspects of the interactive activity quiz that students found most beneficial. Students' remarked that the feedback for an incorrect choice was very helpful. Participants' answers included key phrases such as "It told me where to go back to so I was not lost", "sent me back to specific section so I could search for the answer" and "referred you (student) to a specific section." The feedback feature further aided students' understanding as it identified their errors/misconceptions and gave them the opportunity to learn and understand the concept and reassessed their knowledge. The same students described the review of animation after their failed attempt as a "hint" that helped them understand their mistakes. Consequently, if there were asked the same question, the hint acted as a trigger, helping individuals remember the context.

While students believed that their understanding was enhanced using the interactive quiz, the data suggested differently as both groups underperformed in their post-assessments (Section 4.3 and 4.4). The analysis of the first post assessment did not show any significant improvement for the treatment group (Figures 4.19 - 4.22). The percentage of students who correctly responded to the four multiple-choice questions was similar with negligible deviation. Furthermore, when comparing the first and second assessment scores for the two groups, no sharp and clear patterns of improvement were observed (Figures 4.25 and 4.28). This further substantiated the general deficiency of knowledge and retention among students, including those of the treatment group. Therefore, while students perceived the interactive activity quiz as a great tool that helped them with comprehension and retention of information, the data suggested that the perception did not translate to an actual improvement for the treatment group.

Analysis of the treatment group remarks showed an appreciation for the positive content reinforcement given when questions were answered correctly, because "it solidified the concept." However, a few students mentioned that they ignored the correct answer explanations since their understanding was sufficient. The researcher's reasoning for the implementation of the positive feedback was to enhance students' comprehension, solidify the already learned concept, and build students' confidence. However, based on students' responses not everyone utilized the available resources to its fullest extent. Therefore, special attention should be given to the correct answer feedback when redesigning or improving the teaching intervention to captivate students' attention and give them the opportunity to reiterate the content.

**Feedback options available**

Next, students' opinion toward the two feedbacks was evaluated. The first option was available only for correct responses and included a basic diagram, statement, and/or picture (Appendix 2), while an incorrect response made references (website link) to the step-through version of the animation so students could find the information prior to their second attempt on the same question. All interviewees, except for two, selected the option in which they searched for the answer using the animation. Their remarks indicated that referring to a specific segment of the animation for information retrieval was very beneficial and aided with their learning process. These selected quotes reflect the general view of students:

> "When answering a question wrong, it (the intervention) gives me a specific segment to go through instead of going through the whole animation or going to the book to find the correct answer" (student 11, treatment group, spring 2013)

> "When I got it, I didn't look at the explanation, (but) when I got it wrong, then I needed to find out what I got wrong and the set up that gave us a link made it easy" (student 1, treatment group, spring 2014).

The second statement was by one of the two participants who commented on their oversight on the correct answer feedback. However, other students paid attention to the feedback. One student even suggested the incorporation of graphic/statement at the end of the quiz so questions could be reviewed and concepts reiterated. Although such implementation was not part of the original activity, however, should be considered if teaching intervention was to be modified.

**Quiz style**

The next interview question focused on the identification of the most appropriate quiz style. Students chose the style of quiz that work best for them. The options were the interactive activity quiz with immediate feedback to each question verses traditional quiz with feedback at the conclusion of the quiz. Students unanimously chose the interactive activity quiz as their preferred method of quiz taking. They preferred this style because the immediate feedback reinforced the concept and addressed their misconceptions. A willingness to search for the correct response was also stronger among the participants. The interactive quiz also enabled participants to focus on one question at a time and limited the chance of information overload. Interestingly, few students' preference was driven by test anxiety. They explained that their uncertainty about their choices hindered their ability to focus on other questions and made them apprehensive during the quiz. However, the instant feedback built their self-confidence as it provided positive feedback for correct response or identified and addressed their misconceptions. This quote from a participant encapsulated students' opinion about the benefits of the interactive activity quiz:

> "I prefer the new method (immediate feedback), because it seems to work very well for me. For the traditional (quiz), I always look at the answer at the

end, but I never memorize because I never find the answer by myself. But once you find the answer for yourself, you have a deeper understanding about it. So by going back to the slide to look and find the answer, I learned myself and can remember it for a longer time" (student 3, treatment group, spring 2013).

**Information representation**

Information about the Calvin cycle was either presented through narrated animation with subtitles or step-through version. Therefore, students were asked to identify their preferred method of information delivery. Moreover, 80% of participants identified the narrated animation as a more useful representation of information, which in majority of students' opinion was further enhanced by the addition of subtitles. Responses indicated that collaboration between visual and auditory (animation and narration) representations were essential for their learning process. The data was in accordance with responses to the earlier question, in which the student displayed partiality for the narrated animation with subtitles (narrated animation and its features). Similarly, subtitles were considered "distracting" by a small percentage (2 students) of participants even though they showed a bias for the narrated animation.

Interestingly, 20% of participants favored the step-through representation, which emphasized the variation in students' preferences. Students' reasoning for the partiality was as simple as dislike of the voice. Other's statements included "I don't like someone narrating unless they are telling something different from the information presented" and "I don't like to be lectured, I want to read on my own pace." So when constructing a multimedia intervention, educators must be conscious of the diverse learning styles within the population and create a flexible and adaptable activity to encompass the larger population with visual, auditory, and kinesthetic preferences.

### Beneficial aspects

The researched wished to isolate strengths and weaknesses of the teaching intervention for future adaptation and implementation. Therefore, students identified the most and least helpful aspects of the teaching intervention. Features encompassed narrated animation, the interactive quiz, subtitles, or the step-through animation. Narrated animation was recognized as the most valuable segment of this intervention. The key reason for such a preference was that students governed their own learning. The ability to pause and rewind enabled students to take charge and learn on their own pace which was in line with the previously published work (Hasler, Kersten, & Sweller, 2007). Moreover, it provided visual representation of the information and was used as a review prior to their midterm examination. Student population almost collectively favored presentation of information in the form of subtitles. Those who found subtitles a distracting element earlier persisted in their assumptions and identified subtitles as the least helpful aspect of the animation. This results supported prior study that suggested that textual information that presented the same information as auditory presentation could hinder learning (Leahy et al., 2003). A couple of participants suggested improvement to the animation through incorporation of an overview at the beginning and partnership with lecture. Future animation design could benefit from students' input to create a learning environment that encompass both the traditional and current teaching ideals.

The interactive activity quiz was designed so that when an incorrect answer was selected, a link to the step-through animation was provided to students with a guideline to a section (i.e. slide 3) of animation where they could retrieve the answer. Students highly favored the interactive activity quiz, ranking it second, closely following the animation. Several students (4 participants) emphasized the role of interactive quiz in improving their retention and recollection. Moreover, they described the quiz as an effective way to assess their gained knowledge and as a powerful tool, capable of identifying and correcting their misconceptions. Although students praised the design of the activity quiz, the instant feedback, and easy access to the animation, it was noted that the given direction was not always easy to follow. A student described her predicament, "I was not sure what part of the animation I needed to go to." Moreover, it was noted that some students utilized narrated animation (available on the same link) instead of the step-through animation. This oversight made it difficult for student to identify the precise section of the animation required for the extrapolation of the information.

None of the interviewees described the step-through as the most beneficial aspect of the intervention and one student described it as ineffective because "I didn't see things get connected, rather it was just the concept as a whole." This answer suggested that some students might have used the step-through version outside its designated functional framework, which was when quiz questions were answered incorrectly. If step-through animation was used outside its designated frame, it would not have been a compelling representation of information. Furthermore, a review of students' remarks indicated that most participants, 60%, classified the step-through depiction as part of the interactive activity quiz, describing its potential to address and correct misconceptions and improve retention and recollection. It was concluded that students appreciated attempts to employ a diverse technique to enhance their learning environment. Therefore, a future challenge is to improve the activity quiz design by implementing precise instructions to minimize confusion and misunderstanding among students.

Both the interview responses and demographic survey data displayed similar patterns with most the students' greatly favoring animation/graphics as their choice of instruments. Roughly 20% of both groups chose discussion among peers as the second most beneficial approach in their learning. Discussion in general relies heavily on the interaction among peers and the immediate feedback they receive from each other. An analogues environment was created for students when they completed the interactive activity quiz online, in which they received instant feedback but from the different source. This is indicative of students' persistence in choosing specific approaches to enhance their learning environment.

### Improvements of the intervention

After the interview, the researcher asked for students' suggestions to further strengthen the teaching interventions. One suggestion was to remove the grading aspect of the interactive quiz, to minimize the associated stress. Students believed that the anxiety related to assessments and scoring deviated their attention from the concept being taught. College students were already under tremendous pressure to do well in their courses, therefore added pressure from additional assignments might have not been favorable. While, some of this anxiety should have been relieved considering everyone had the three opportunities to take the quiz and improve their, it was still a concern that could be addressed in the future activities. Another comment was to include both immediate feedback for each question and an end-of-quiz review. Two limitations prevented such an implementation, 1) limited number of available questions for each category and 2) opportunity of retaking the quiz up to three times. However, for more complex processes, such an enhancement could improve students' comprehension of the concept.

Students' positive impression of the intervention was noticeable based on these comments asking for an activity that combined light-and dark reactions of photosynthesis. Another comment stated that if there were a multistep process, it would be ideal to compartmentalize the animation with its corresponding interactive questions to assess the knowledge gained, prior to moving to the next section. This was a great suggestion since it combined the animation and the interactive quiz together, adding more depth to the intervention and therefore should be considered for future interventions.

While students' attitude toward the implementation of the interactive quiz and animation was positive, the results of the assessments were not encouraging. Quantitative data did not display a discernible improvement in the treatment group assessments' scores (Tables 4.5-4.10). So, further analysis and research is required to understand how the teaching intervention could be improved to enhance students' comprehension and retention.

### 4.6 Summary of the Chapter

This chapter endeavored to answer the three main research questions about how multimedia and interactive activity quiz influence students' comprehension, retention and perception of the complex process of the Calvin cycle.

The demographic data collected from the comparison and treatment group over the two semesters showed minor differences between the populations, when comparing age, prior knowledge, transfer history, study and work habits, etc. This enabled the researcher to effectively assess the importance of multimedia and interactive activity quiz on students' comprehension and retention.

Analysis of the first post assessment (4 multiple-choice questions) showed an almost identical pattern of distribution between the comparison and treatment groups. Considering that many students were self-identified as visual learners, it was possible that the observed similarities in students' responses were related to the implementation of the narrated animation, which in turn enhanced students' comprehension of complex scientific processes. The data also suggested that the interactive activity quiz role in enhancing students' comprehension was limited.

The second post-assessment evaluated the role multimedia and interactive activity quiz play in retention of the information. Student defined the Calvin cycle process in the first question and drew out the process in as much detail for the second question. Analysis of students' responses to the first question did not show any significant improvement in students' retention ability following the intervention implementation, though minor improvement was identified and described. There was a more discerning pattern for the second question where a higher percentage earned a perfect score in the treatment group vs. the comparison group. Furthermore, data suggested that students with low performance or partial cognitive conceptualization could benefit from the intervention and retain information better that the comparison group. A more detailed analysis of the data revealed that interactive activity quiz might have addressed some of the students' misconceptions and therefore improving the understanding even though no significant improvement was observed in their scores.

Review of the qualitative data proposed that in general, students did perceive narrated animation (with subtitles) and the interactive activity quiz as positive components of their learning environment, especially their science classes. Student explained that such addition could aid them with comprehension, creation of mental model, and retention and recollection of information. However, as evident in the quantitative data, that positive perception did not translate to improved cognition and retention in student population. Therefore, further research is required to find a suitable median for the intervention where the usefulness extends beyond students' perception and present itself as an effective learning tool that works elegantly to improve students' comprehension and retention.

## Chapter 5

## Conclusion, Limitations and Implications

### 5.1 Introduction

This chapter summarizes this study. Section 5.2 provides an overview of the thesis and includes brief summaries of the reviewed literature, research methods, and results. Section 5.3 incorporates the limitations of the research, implications and future studies that may stem from the current studies. Lastly, section 5.4 provides a summary of this chapter.

Technology has become an integral part of the society and has been embedded into our educational system as well. Multimedia is an essential component of the new age technology that is effectively utilized in classrooms to teach a variety of content to diverse student populations. The purpose of this study was to better evaluate the influence of multimedia (i.e. narrated animation) and interactive activities on students' understanding and retention of a complex scientific concept. Furthermore, this study attempted to explore students' perception of multimedia and interactive activities.

**The main purpose of this research involved**

1. A quantitative assessment of the role of multimedia and interactive multimedia intervention on enhancing students' understanding and retention of the Calvin cycle process among university introductory biology students.
2. A qualitative evaluation of students' perceptions about the use of multimedia and interactive activities in their learning environment.

This educator's goal was to use the resources at her disposal to create an engaging learning environment whereby students can improve their understanding of the Calvin cycle.

## 5.2 Summary of the Thesis

### 5.2.1 Summary of the first chapter

Recent research and statistics showed that while all USA high school students complete a two-year science requirement, only about a third of students graduating were considered competent in the sciences. These students were likely to find the college experience challenging as they were exposed to the same scientific concepts with added details. Therefore, college instructors persistently worked and used all available resources to enhance students' cognition, preparing them for the challenges of advance science courses in later years. Because the new age generation is so dependent on their gadgets and technology, it is only logical to use those tools to enhance the learning environment. Other studies described and supported a learning environment built on the concept of dual coding theory where students received their information through multiple channels (visual and auditory) to enhance their understanding and retention capabilities. Such an environment could be achieved through the effective adaptation of multimedia and could be further improved through addition of interactive components where students were actively engaged in their learning process. This research utilized both quantitative and qualitative data to evaluate the role of interactive multimedia in the learning environment. It further analyzed students' perceptions on the features, implementation, and adaptation of these tools in their learning environment.

### 5.2.2 Summary of literature review chapter

This chapter was dedicated to the review of literature that provide contextual framework for this study. The literature review was design to 1) inform readers of the educational hierarchy in the United States and included information related to students' learning from K-12 as well as higher education institutions; 2) to better understand the role of multimedia and interactive multimedia in students' understanding, and retentions; and 3) to evaluate how prior research viewed the interactive multimedia in teaching complex scientific concept of photosynthesis.

It became clear that while many students advanced in K-12 education, their understanding of science lagged. The gap between their level of education and scientific understanding stemmed from disconnect between scientific concepts and real world examples, teachers' limited background in their subject matter, lax academic setting of high schools, and over-emphasization of the standardized tests. Therefore, post-secondary institutions were challenged by student populations that were unprepared for the rigor and intensity of college level science courses. Such conditions led to high turn around for students enrolled in the STEM education. In recent years, numerous higher education institutions have attempted to create technology-friendly curriculums to better suit the need of their student populations. The goal of educators in such institutions was to effectively use technology to enrich the learning environment.

Numerous studies have successfully demonstrated the positive impact of multimedia in students' comprehension of chemistry-, biology-, and mathematics-related concepts. Moreover, adaptation of multimedia in the form of narrated animation to teach scientific content satisfied the requirements for dual coding theory and has been proven to benefit students' understanding and retention. Interestingly, students and teachers agreed on the positive impact of the implementation on the learning environment. Some studies also supported a supplemental role for subtitles in a narrated animation specially for minorities with English as their second language.

More recently, multimedia has adapted an interactive competent, with encouraging result in support of such addition. Studies showed positive effects of interactive activities on nursing, pharmacy and medical students as well as students enrolled in science and mathematics courses. The influence of multimedia was even visible in teaching one of the most difficult concepts in biological science, the photosynthesis process. Several research studies highlighted the role of multimedia and interactive activities, in helping students understand the concept and possibly address misconceptions associated with the content. This research took a closer look at the utilization of interactive multimedia to teach an aspect of photosynthesis known as the Calvin cycle, help students understand the complexity of this microscopic process, and then effectively retain the knowledge for future use.

### 5.2.3 Summary of methodology chapter

The focus population for the study was enrolled in an introductory biology course, Bio 172. Majority of quantitative and qualitative data were collected during two semesters with additional qualitative data gathered in the third semester. Total of 192 and 160 students were enrolled during spring 2013 and 2014 semesters, respectively, and were randomly assigned to either the comparison or treatment group based on their laboratory section number. The researcher discussed the study with students and collected consent forms from all participants. Pre-assessment data was collected during both 2013 and 2014 semesters in a form of a 9 open-ended questionnaire and a specific scaled was designed to assess students' prior knowledge on Calvin cycle.

Individuals in the comparison group watched a 1:30 minute narrated animation with subtitles on the Calvin cycle process, completed a demographic survey, and dilution quiz (unrelated to the Calvin cycle concept). The treatment group also viewed the animation and completed the demographic survey. However, the interactive activity related to the cycle replaced the dilution quiz. In average students spent 15 minutes completing the activity.

The first post assessment collected quantitative data from both groups three weeks after the intervention implementation. The Post assessment consisted of four multiple-choice questions embedded in midterm examination. Treatment and comparison group responses were analyzed to evaluate the influence of intervention implementation on the treatment group's understanding of the Calvin cycle process. The second set of quantitative data was collected during the final examination, six weeks after the teaching intervention implementation. This post assessment comprised of two Calvin cycle-related open-ended questions with specifically designed 5-point grading scales. These questions evaluated how the multimedia and interactive activity influenced students' retention was. Lastly, qualitative data in the form of individual interviews was collected from 60 students over the span of three semesters. The interviews consisted of questions related to the animation, narration, subtitles, and/or interactive activity, and supplemented the quantitative data to better understand how students perceived multimedia and interactive activity.

### 5.2.4 Summary of the results chapter

#### Demographic data

Evaluation of demographic data showed a relatively similar distribution between the comparison and treatment group population. Majority of students were female between the ages of 18-20 who chose English as their primary language (55%), with further distribution of 15% for Vietnamese, Spanish, or other languages combined. Over 40% of the students did not work and the remaining percentage worked less than 25 hours/week. Demographic data further indicated that close to 90% of students were high school graduates who were accepted to the four-year institution following their graduation and have been enrolled for at least two semesters. Interestingly, nearly half the student population had prior exposure to the Calvin cycle concept in earlier science courses (i.e. general biology, ecology, or high school science).

A question related to students' choice of major showed that many students have yet to choose a major or have chosen biochemistry, and small percentage had selected an allied health-related major or a biology concentration. Students of various majors were enrolled in the course because Bio 172 fulfilled the course requirement for multiple majors. The distribution for students' GPA was similar with minor to moderate deviation for the outstanding and good status students. The study pattern responses indicated that a large percentage of the comparison group studied an average of 2-4 hours/week vs. 5-7 hours/week for the treatment group and the remaining population studied less than 1 hour or more than 7 hours/week. These differences were of interest and were considered when quantitative data was analyzed. However, evaluation of the quantitative data suggested that the variation in study patterns did not influence students' understanding of the Calvin cycle.

Other collected data suggested that student population preferred the use of pictures, models, and animation during their studies compared to listening to lectures, reading, handling models, or through discussion of topic with others. Correspondingly, over 80% of population felt strongly about the helpfulness of computer animation in learning biological concepts.

**Quantitative data analysis – Response to the first research question (Comprehension): Influence of the teaching intervention on students' understanding of the Calvin cycle**

The first research question was interested in the role of Calvin cycle animation and interactive activity quiz on students' comprehension of photosynthesis. Prior to the lecture and intervention implementation, students' knowledge of the Calvin cycle process was analyzed through a 9 question pre-assessment. Data were collected during spring 2013 and 2014 semesters from 142 and 143 students of the comparison and treatment group, respectively. Students' were assessed on four main components of the cycle (1) carbon fixation, (2) production of high-energy molecules, (3) utilization of high-energy molecules, and (4) general understanding of the cycle.

Only a small percentage of student population answered two of the questions related to carbon fixation. Questions for the remaining categories were either left unanswered or were answered incorrectly by both groups. This signified the limited or lack of prior knowledge among students even if they were previously exposed to the information. Students' interview remarks further supported students' limited understanding of the cycle regardless of their prior exposure. This result was in line previous studies that indicated students' difficulty with understanding of the concept (Barker & Carr 1989; Bell, 1984, 1985; Haslam & Treagust, 1987; Hazel & Prosser, 1994; Tepla & Klimova, 2011; Wandersee, 1983). Further analysis of data indicated students' familiarity with concept-related vocabulary; however, there were also evidences of misconceptions among student population. For instance, students were unable to distinguish Calvin cycle of photosynthesis from Krebs cycle of cellular respiration, thinking they were one of the same.

The researcher hypothesized that the implementation of the intervention would improve assessment scores for the treatment group. The pattern of improvement was visible in the responses to the first multiple-choice question, where the treatment group performed better (13% vs. 23%). However, the identical distribution in which almost 50% of both groups chose an incorrect response was also observed, indicating that animation and interactive activity did not necessarily aid students in understanding the role of ATP in the Calvin cycle. Analysis of responses to the second, third, and fourth question showed an almost identical distribution for both groups and for every option available, including the correct response. A relatively large percentage of students chose an answer that was indicative of confusion about the high-energy molecule utilization. Similarity in percent distribution between the comparison and treatment groups highlighted the importance of multimedia (the shared component of the intervention between group), rather than the interactive activity as an effective tool to aid students' understanding. However, regardless of the tool, some misconceptions and confusion related to high-energy molecules persist, again signifying the challenges associated with teaching and learning of photosynthesis (Koba & Tweed, 2009; Russell, Netherwood, & Robinson, 2004; Tasker & Dalton, 2006).

**Quantitative data analysis – Response to the second research question (Retention): Influence of the teaching intervention on students' retention of the Calvin cycle process**

The second research question was interested in evaluating students' retention after the implementation of the Calvin cycle animation and interactive activity quiz. To do so, the second post-assessment composed of two-open ended questions evaluated students for retention of knowledge. First, students were asked to define the process of the Calvin cycle. One student in the comparison group and six students in the treatment group received full credit. This might be the result of slightly higher percentage of high performing students and possibility that these the intervention did indeed enhance their retention. A more detailed analysis of participants' responses showed that a higher percentage of treatment group included certain key ideas while their response was similar in other aspects. Therefore, it was possible that the implementation of intervention helped with reiterating some aspects of the concept while it had limited to no effect on other aspects of the theory. The observed differences could be contributed to the deviation in the study habits since 47% of treatment group verses 28% of the comparison group spent an average of 5-7 hours/week on their studies. Students' whose performance was minimal in the course, performed slightly better with 59% of the students who earned 0 or 1 in the 5-point scale vs. 66.2%. However, the difference was insignificant since still 6 out of 10 student failed to understand the Calvin cycle regardless of the multimedia or interactive activity.

The second question asked students to draw and provide as much information they could about the Calvin cycle process and were then evaluated using a 5-point scale. Interestingly, students in both groups performed better with eight and twelve students in the comparison and treatment group, respectively, who earned full credit. This slightly better performance in the treatment group for both questions was contributed to slightly higher percentage of students with outstanding GPA. Moreover, it appeared that students' felt more comfortable presenting the information in drawing rather than articulating the concept. This could be related to cyclic depiction of the process in lecture diagrams or in narrated animation and the interactive activity. Lack of differences in percentage of students of both groups who earned 4, 3, or 2 in the 5-point scale indicated that the interactive component did not influence students' retention and recollection abilities. A more detailed comparison of students' drawings indicated that a smaller percentage of the treatment group included common misconceptions related to the Calvin cycle in their responses. Considering that students' learning environment was identical except the addition of interactive activity, it could be concluded that the interactive nature of the activity was helpful in addressing some of students' misconceptions. Furthermore, data showed a minor enhancement in students' mental models with the interactive activity quiz.

Data comparison between the first and second post- assessment was not encouraging. The correct answer was selected by at least 23% of students and as high as 52% of the treatment group, while only 16% and 30% of students provided an acceptable answer for the second post-assessment. These data suggested that intervention was not successful in helping students retain the information.

#### Qualitative analysis: Student interviews

Students' remarks demonstrated their strong belief in support of narrated animation on creating their mental models and addressing their misconceptions. Interestingly, one of the appealing aspects of the animation was the cyclic depiction of the Calvin cycle that enabled students to visualize the movement of molecules in the process. Furthermore, non-native English language students showed interest for the addition of subtitles to the narrated animation, while in some cases native speakers found the addition distracting. These responses supported prior studies that addition of subtitles to a narrated animation might hinder student learning by creating split-attention effect. However, it might enhance non-native students' comprehension and performance (Chandler & Sweller, 1992; Krugar & Steyn, 2014; Mayer & Moreno, 2002; Plass, Chun, Mayer & Detlev, 1998). Most participants identified themselves as visualizers whose learning was further enhanced through the addition of auditory supplementation. This result lent further support to previously observed patterns in the demographic survey. Students were avid supporters of multimedia use in their classrooms specially science classes such as biology and chemistry. They indicated the importance of multimedia for visual representation of processes that happen at a molecular level and were invisible to them (Beakes (2003); Fadaei, Daraei, & Lay, 2013; Tasker and Dalton, 2006). Furthermore, students believed that time constraints issues could be resolved through the addition of multimedia as far as the role was supplemental and did not replace lectures and instructor interaction.

A set of questionnaires inquired about students' perceptions of the interactive activity quiz. Generally speaking, students perceived the interactive activity quiz as a great tool to improve their understanding of the Calvin cycle. Students perceived the incorrect response feedback was positive, as it redirected them back to the animation where they searched for the appropriate response, and therefore reiterating the content. Moreover, students' view of the correct answer feedback was also encouraging; however, some students failed to utilize the resource as they skipped the information. Students explained that the design of the interactive activity quiz prevented information overload, enabled them to activity search, learn, and retain the information. It also helped to build their self-confidence through positive reinforcement. It was noted that some students felt anxious since the quiz was graded and had a role in their overall grade for the course.

The most helpful aspect of teaching intervention was the narrated animation viewed prior to the interactive activity quiz with an overwhelming number of students favoring subtitles. Students identified the interactive activity quiz as the second most helpful aspect of intervention, enabling them to assess content, and address misconceptions. However, students did add that the quiz could be further improved through compartmentalization of multi-step content, and by providing more precise directions during the feedback and referral to the Calvin cycle animation.

## 5.3 Limitations, Implications and Significance of the Study

This chapter focused on identifying the limitations of the study and offered implications for future studies. Moreover, the researcher highlighted the significance of the study for future research related to teaching complex scientific concepts using multimedia and interactive multimedia.

### 5.3.1 Limitations

#### Animation design

The opportunity to create a balance and harmonious teaching intervention was not fully within the reach of the researcher. The Calvin cycle animation created by a textbook publication was selected because it was an accessible animation that was similar in content and level of information presented in the lecture. However, there was no option for additional modification of this animation. It was suggested that improvement could be made to future animation so it included a more detailed overview of the concept and a better representation of information with clear and direct connection to the lecture content. The consistency between lecture diagrams and graphics utilized in the narrated animation could limit confusion and misconceptions associated with representations enabling the researcher to collect more reliable data.

While reviewing the qualitative data, an important point of view lent support to the modality principle. Within the student population, some students identified narrated animation accompanied with subtitles as “distracting” while others identified it as “helpful”.  Consequently, narrated animation should be designed with optional subtitles especially where large number of learners are non-native English speakers. Such a design could create a balance in the animation to support the knowledge without hindering the learning process.

### Interactive activity quiz

There were number of limitations associated with the design and completion of the interactive activity quiz. For instance, a main limitation was the number of questions available for the activity quiz. To ensure that students' score was a representation of their understanding, question pools were created for the four main concepts of the Calvin cycle. However, because of the limited number of questions, students only had access to the question and the correct answer while working on the questions. There was no further reiteration of the content at the end of the activity quiz. This might also have limited the affectivity of the interactive activity quiz as a learning tool, especially while teaching complex biological processes. It would be appropriate to create a larger pool of questions and to include both immediate feedback for each question and an end-of-quiz review to recap the concept, therefore enhancing the learning tool.

Because of time limitation and the nature of the interactive activity, this activity was completed online without any proctoring. This is a limitation since the researcher is unaware of time and resources students are utilizing during this activity (In such set ups, students tend to group together to view the questions and discuss among themselves the possible correct option). Therefore, the quiz score might not have been an accurate representation of the students' conceptual knowledge. Online resources utilized in this study were the same resources that were employed by the instructors to assess students, providing reliability of the intervention. However, in future activity design, an attempt should be made to allocate specific time during the lab meeting for the completion of the assignment to keep the layout consistent, and provide a level of control over the learning environment. It was also a possibility to remove the grading option as mentioned in the next section, therefore shifting students' focus away from points/grades to the content being presented.

Students' remarks during the interview indicated that some individuals felt confused about the direction provided for the interactive activity quiz feedback.

This logistical challenge might have hindered the learning process by deviating students' attention from the content. Such a condition, limited the proper assessment since students were not fully engaged in the process. The future challenge is to improve the activity quiz design by implementing precise instructions to minimize the confusion and misunderstanding among students.

It was understood that students were under tremendous pressure to perform well in their courses. Therefore, it became clear through the interviews that while students perceived the interactive activity quiz as positive, in some cases they were overly anxious by the fact that activity was being graded. This added anxiety might have interfered with the purpose of the interactive activity quiz as a learning tool to help students grasp the process of the Calvin cycle. While, some of this anxiety should have been relieved considering everyone had the opportunity to improve their grade by retaking the quiz up to three times with only the best grade recorded, it was still a concern that could be addressed in the future activities.

**Laboratory setting:**

While information presented in the lecture was identical for both comparison and treatment groups, the same could not be said for their laboratory meeting. During spring 2013 and 2014 semesters, there were total of 18 sections that were randomly assigned to either treatment or comparison groups. These 18 sections were divided between five to seven teaching associates each semester. Since each teaching associate had her/his own style of teaching, variation between information presentation was expected. Furthermore, researcher was concerned about possible questions related to study that might be directed to teaching associates. The concern regarding information presentation was partially addressed in teaching associates' weekly meeting. Specific guidelines ensured a consistent presentation of photosynthesis-related information, even though the mode of presentation could not be controlled. Furthermore, the researcher visited each laboratory to address any questions regarding the activities and requested that any related questions be directed to her and not the teaching associates. While such steps did not eliminate the variation in the class setting, it did limit them to some degree, ensuring a level of consistency in the learning environment.

### Student population

A main limitation of the study was lack of control on the student population assigned to the comparison and treatment groups. Review of the demographic data showed slight to moderate differences between students' grade point average, study habits, work habits, etc. when comparing the groups. This limitation could be addressed by making additional connections for individuals of the group. For instance, finding correlations between GPA, study habits, their preferred method of learning, time spend on each quiz, number of time animation was viewed, and how such conditions influenced their understanding and retention of concept. Furthermore, qualitative data could also provide addition resources for a more detailed analysis of relationships.

### Student resources

Major obstacles with this study stemmed from the lack of control over various variables that may have affected the outcome of the research. A successful evaluation of the teaching intervention depended on a consistent learning environment, which only varied by one component, the intervention (interactive activity quiz). A significant limitation was inability to control the resources students utilized to independently study the concept of photosynthesis. Students open access to textbooks, notes, lecture PowerPoint, university tutors, supplemental instructions (SI), online resources such as YouTube videos and animation enabled them to use any of such resources to supplement their own studies. Therefore, it would be difficult to conclude that the changes observed between comparison and treatment group was a direct result of only the implementation of the interactive tool. Therefore, future studies should be aware of this drawback and attempt to collect additional data on what resources are utilized and to what degree.

Another limitation was related to the amount of time students spent with the given resources. The online platform utilized in the study and the animation website, limited researcher capability to count how many time the animation was viewed by individual users. This was a drawback for the treatment group because students' success or lack thereof could not be directly correlated with the animation or the interactive activity quiz. However, the researcher did provide a level of consistency by controlling the order which students gained access to the component of the teaching intervention, starting with narrated animation, interactive activity quiz, and ending with demographic survey. Future research should implement technology that enables the researcher to have additional control and insight to the frequency of the viewing.

#### Variation in assessment

Another major limitation of this study was variation in the styles of assessments used for the first and second post-assessment. The midterm examination, evaluated students' understanding of the Calvin cycle comprised four multiple-choice questions. However, the final exam included two open-ended questions to assess students' retention. This variation in question styles existed because of specific guidelines provided by the lecture instructor. While specific scales were developed for the two-open ended questions to provide an appropriate unit of comparison, there were still concerns about the compatibilities of the scales for the assessments. Future studies could be improved through the utilization of an identical set of questions and scales for both assessments, limiting other factors that may influence the result of the study.

#### Intervention duration

One of the critical limitations that might have influenced the outcome was the duration of the intervention. Individuals spent an average of 15 minutes completing the intervention (time included the viewing of the animation, completion of the activity quiz, and demographic survey). This was not much time considering many students spent an average of 2-7 hours/week preparing for the course. Moreover, students had access to the intervention for two weeks, which was a short time considering a 16-week semester. So, future studies should focus on creating an intervention that engages students for a longer period (i.e. multiple interactive activities that is completed over multiple sessions and reiterating the same concept). The animation and interactive activity accessibility could be extended so students could revisit the content, review the animation, and assess their knowledge using the interactive quiz. It is hoped that such implementation, would provide positive reinforcement of concepts and therefore enhance students' understanding and retention capabilities.

### 5.3.2 Implications for future study

Future studies should expand on the effects of multimedia and interactive activities on teaching complex scientific concepts. The more comprehensive study would take place over a longer period, and include larger population of students. The comprehensive study could follow the cohort of students as they advance through their course work, and look for patterns related to knowledge retention or the influence of intervention on addressing students' misconceptions.

Furthermore, an attempt should be made to collect detailed data regarding students' prior knowledge, enabling the researcher to make appropriate connections between students' background and how the implementation of the intervention influenced their learning process. The teaching intervention could be implemented in other courses that review the photosynthesis process (i.e. biochemistry) and assess how students in other classes benefit from the teaching intervention.

In this study, qualitative data was utilized to better understand students' perception of the teaching intervention. However, future research could utilize students' interviews prior and after the teaching intervention. This offers a unique insight to students' level of understanding and their existing misconceptions prior to the intervention implementation, and aid with evaluating how the intervention influences each aspect.

Future studies should keep in mind the limitations set by this study. Improving the design of the animation and the interactive activity, as well as more appropriate means of students' assessment may prove to be useful in creating an effective learning environment. A particular attention should be given to amending the interactive activity, including clear guidelines, an improved feedback procedure, and higher emphasis on content rather than evaluation. Such implementations may enhance the intervention, and encourage a more active engagement from the participants.

Considering our ever-advancing society, the propagation of technology in classroom is inevitable. Therefore, careful and meticulous research should be conducted to identify the role of each teaching instrument in improving the classrooms. It is hoped that interactive activity and narrated animation become essential components of the learning environment, and effectively utilized to enhance students' understanding of complex concepts including but not limited to photosynthesis.

### 5.4 Summary of the Chapter

The role of interactive activity quiz was not as significant as was envisioned. There was a slight improvement in the treatment group's understanding and retention of the Calvin cycle process. Furthermore, misconceptions related to the Calvin cycle was not as pronounced in the treatment group, suggesting that the interactive activity quiz might have corrected some of the common misconceptions.

While there were no noteworthy differences between the comparison and treatment group following the adaptation of interactive activity, but this research does add support to the significance of narrated animation as an ideal multimedia to teach students the complex scientific processes. Considering students' responses, it was clear that not only students' perception of the narrated animation was positive, they also viewed it as an essential component of their learning environment and their science courses, which could be further enhanced through subtitles supplementation. They also perceived the interactive component of the intervention as a positive addition to the course. The positive perception of students toward the intervention was an optimistic sign that should be considered when thinking of the learning environment enhancement, though further modifications are required to make it an ideal teaching tool to supplement the course curriculum.

Photosynthesis is one of the most essential concepts taught in biology courses, from K-12 as well as post-secondary institutions. However, prior research and this study painted a foreboding picture, where majority of student population showed a rudimentary understanding of the process. The inadequate understanding was the result of incomplete mental models and misconceptions that persisted throughout their education. Moreover, it appeared that the complexity of the process might be the major contributor to the existing challenge. Therefore, it was the educators' responsibilities to use their knowledge and resources to create a learning environment that would enhance student's understanding, correct their misconceptions, and help them retain the knowledge for future use. Recently, multimedia and interactive activities have received special attention in creating the optimal learning environment. However, as this study proved, there is still a way to go until we can properly incorporate the technology in classrooms. It is hoped that future research could improve such technology and therefore create a desired learning environment for all students

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## APPENDICES

### Appendix 1

Question pool for dilution quiz used for the comparison group to fulfill the assignment requirement for the Calvin cycle activity

1. You have a stock culture that contains $4.8 \times 10^7$ cells/ml. You make a two-fold dilution series that uses five tubes. What is the concentration of cells in the final tube?
   A. $1.5 \times 10^6$ cells/ml
   B. $4.8 \times 10^5$ cells/ml
   C. $4.8 \times 10^6$ cells/ml
   D. $2.4 \times 10^6$ cells/ml
   E. $3 \times 10^6$ cells/ml
2. What is the dilution factor if you add 2.5ml of solution A to 7.5ml of solution B?
   A. 0.25
   B. 0.33
   C. 0.38
   D. 0.75
   E. none of the above
3. What is the dilution if you add 20mls of a stock to 80mls of water? Use the format X:Y in your answer.
   A. 1:4
   B. 1:2
   C. 1:5
   D. 2:6
   E. 1:10
4. You have a stock culture that contains $3.8 \times 10^8$ cells/ml. You make a four-fold dilution series using three tubes. What is the concentration of cells in the final tube?
   A. $3.2 \times 10^7$ cells/ml
   B. $9.5 \times 10^6$ cells/ml
   C. $5.9 \times 10^6$ cells/ml
   D. $3.8 \times 10^2$ cells/ml
   E. $1.3 \times 10^8$ cells/ml
5. What is the dilution factor if you add 47mls of solution A to 98mls of solution B?
   A. 1.45
   B. 0.48
   C. 0.32
   D. 0.68
   E. None of the above
6. To make 20mls of a 0.5% NaCl solution, you will need _____ of a 10% stock and _______ of water.
   A. 1ml, 9ml
   B. 2ml, 8ml
   C. 1ml, 10 ml

D. 5ml, 5ml
E. None of the above

7. How many mls of a 2.5x10e8 culture would you need to make 100mls of a 1.25x10e4 culture?
    A. 0.03ml
    B. 0.3ml
    C. 0.003ml
    D. 0.285ml
    E. None of the above
8. How many mls of a 1.5x10e5 cells/ml culture would you need to make 3mls of a 6x10e4 cells/ml culture?
    A. 1.5ml
    B. 2.4ml
    C. 1.2ml
    D. 2.5 ml
    E. 1.8ml

**Appendix 2**

Treatment group activity questions categorized to four main sections

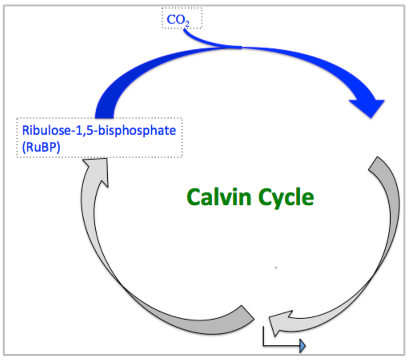
**Appendix 2a**

Question bank for "carbon fixation" category.

Question 1. What molecule(s) initiate Calvin cycle? (Students need both answers for full credit)
Answer: Ribulose-1,5-bisphosphate and $CO_2$

Feedback for correct answer:

- Correct!!! Calvin cycle requires ribulose-1,5-bisphosphate (RuBP) and Carbon dioxide to initiate. See below image




Feedback for partial answer: (student only chose one of the two correct answers)

- You are half right!!! Cells need $CO_2$ and ribulose-1,5-bisphosphate (RUBP) to initiate the Calvin cycle.
- Review slide 1 of the step-Through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit

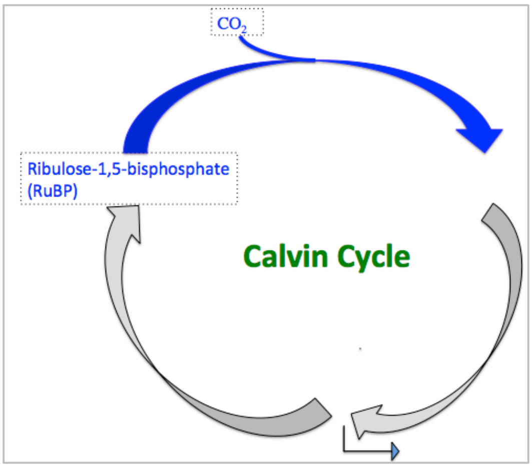
Feedback for incorrect answer:

- This option is Incorrect!!!!
- Review slide 1 of the step through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit

Question 2: In addition to RUBP, what other molecule is needed to initiate Calvin cycle? (Multiple-choice)
Answer: $CO_2$
Incorrect response: Ribulose-1,5-Bisphosphate, 3-phosphoglycerate, 1,3-biosphosphoglycerate

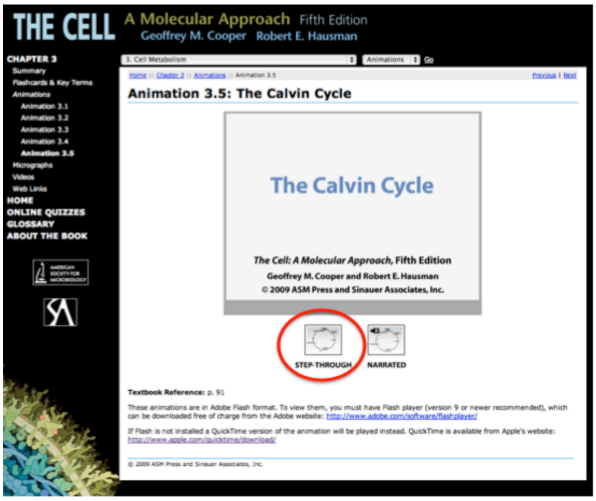
Feedback for correct answer:

- Correct!!! Calvin cycle requires ribulose-1,5-bisphosphate (RuBP) and Carbon dioxide to initiate. See below image




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Click on the link below and review slide 1 of the step-through of the Calvin Cycle animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question for partial credit.



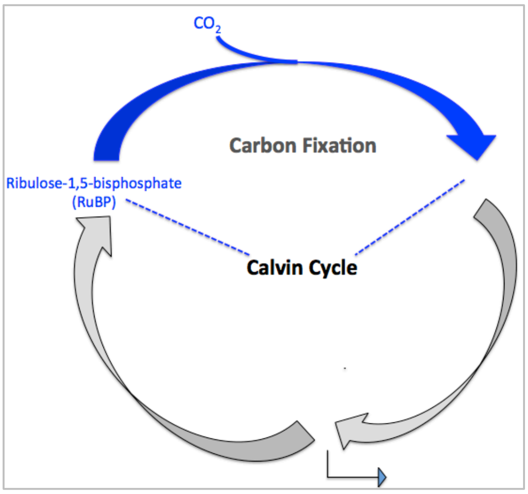

Question 3: What molecule is produced when carbon of CO2 is added to ribulose-1,5-bisphosphate (RuBP)? (Multiple-choice question)

Answer: 3-Phosphoglycerate

Incorrect options: Ribulose-1,5-bisphosphate; Glyceraldehyde 3-phosphate; G3P

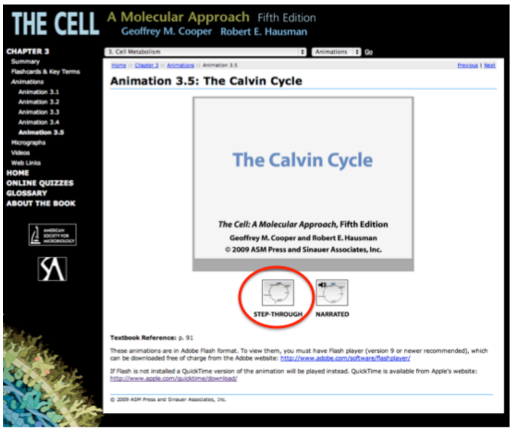
Feedback for correct answer:

- You are correct!!! One RuBP molecule is combined with $CO_2$ to create two 3-phosphoglycerate; This phase of Calvin cycle is known as carbon fixation phase ($CO_2$+ RuBP → 3-phosphoglycerate). See image below




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Click on the link (http://www.sinauer.com/cooper5e/animation0305.html) and review slide 1 of the step-through of Calvin Cycle animation.
- Try to answer the question for partial credit.



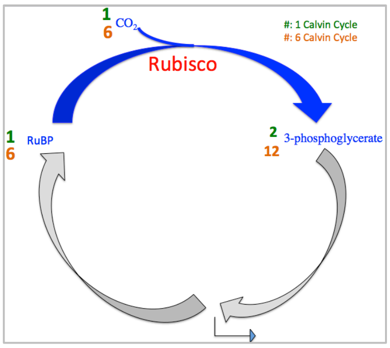

Question 4: What enzyme catalyzes the conversion of RuBP to 3-phosphoglycerate?

Answer: Rubisco

Incorrect responses: Ferredoxin reductase; 3-phosphoglyceratase; Rubiscase; plastocyanin

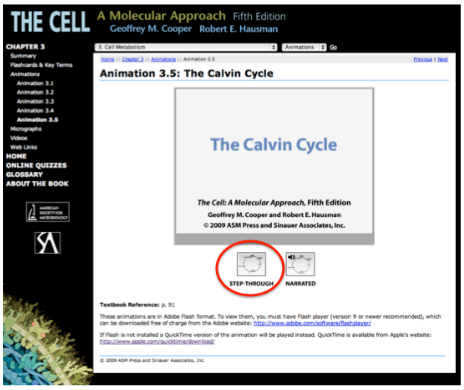
Feedback for correct answer:

- Correct, Good job!!
- Calvin cycle incorporates each $CO_2$ molecule, one at a time, by attaching it to 5-carbon sugar RuBP using enzyme Rubisco. Rubisco is the most common enzyme in chloroplast and in the world!!! See image below




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Click on the link below and review slide 1 of the step-through of Calvin Cycle animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question for partial credit.

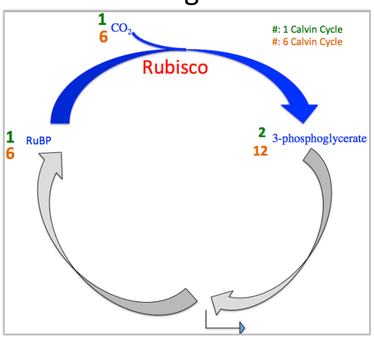



Question 5: Rubisco is an enzyme that catalyzes which of the following reactions?
Answer: Rubisco

Incorrect options: RuBP formation, Oxygen fixation, Glucose formation

Feedback for correct answer:

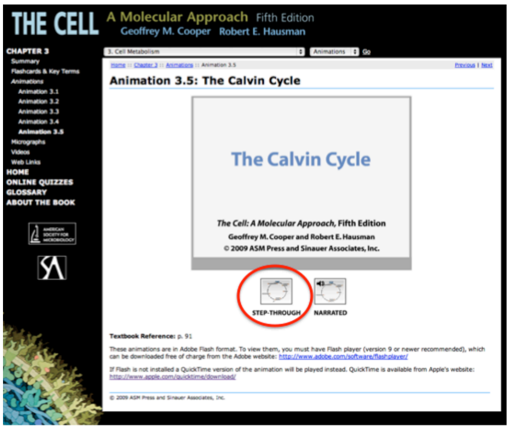
- Correct, Good job!!!!!!
- Calvin cycle incorporates each $CO_2$ molecule, one at a time, by attaching them to a 5-carbon sugar RuBP using enzyme Rubisco.
- Rubisco is the most common enzyme in chloroplast and in the world!!! See below image




Feedback for incorrect answer:

- This option is Incorrect!!!!

- Click on the link below and review slide 1 of the step-through of Calvin Cycle animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question for partial credit.




Question 6: Where does $CO_2$ molecules used in fixation phase of Calvin cycle come from?

Answer: Atmosphere

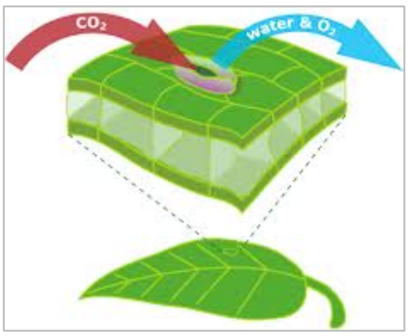
Incorrect option: Breakdown of sugar molecules, 3-phosphoglycerate; from plant itself

Feedback for correct answer:

- Correct, Good Job!!!!
- Plants use the $CO_2$ from the atmosphere and ATP and NADPH produced during the light cycle to create sugar molecules

Feedback for incorrect answer:

- This option is Incorrect!!!!
- Hint: Leaves and stems of plants contain many epidermal pores known as stomata that allow for the movement of $CO_2$ and $O_2$ into or out of the plant cell.



## Appendix 2b

Question back for "ATP and NADPH production" category

Question 1. Where does ATP used in Calvin cycle come from?

Answer: Light reaction of photosynthesis

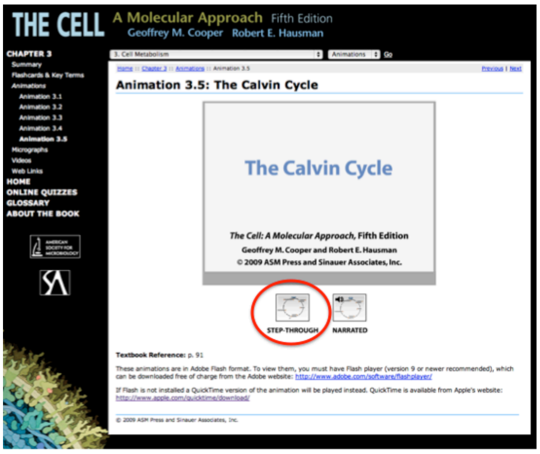
Incorrect options: photosystem I; photosystem I & II; light independent reaction of photosynthesis, none of the choices

<u>Feedback for correct answer:</u>

- Correct, nice work!!!!
- During the light-capturing reaction of photosynthesis, excited electrons are donated to electron transport chain, which in turn create an electrochemical gradient for protons. Flow of protons don their electrochemical gradient through ATP synthesis drives the phosphorylation of ADP (chemosmosis)

<u>Feedback for incorrect answer:</u>

- ➢ This option is Incorrect!!!!
- Hint: Think about reactions of photosynthesis. You can also refer to slide 2 on the step through (http://www.sinauer.com/cooper5e/animation0305.html) or figure 4.2-14 of your textbook.
- Try to answer the question for partial credit.




Question 2: Where does NADPH used in Calvin cycle come from? (Multiple-choice)

Answer: Light reaction of photosynthesis

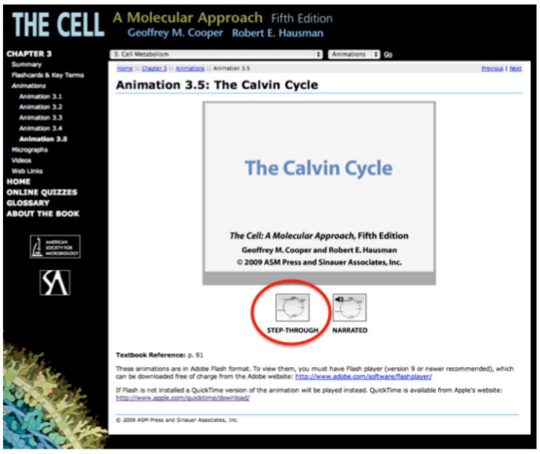
Incorrect responses: Light independent reaction of photosynthesis; Photosystems I & II; Photosystem I; None of the choices

<u>Feedback for correct answer:</u>

- Correct, nice work!!!!
- During the light-capturing reaction of photosynthesis, excited electrons are donated to electron transport chain. In the last step of process, the high-energy electron is transferred to $NADP^+$ converting it to NADPH and is eventually used in Calvin cycle.

Feedback for incorrect answer:

- This option is Incorrect!!!!
- Hint: Think about reactions of photosynthesis. You can also refer to slide 2 on the step through (http://www.sinauer.com/cooper5e/animation0305.html) or figure 10-14 of your textbook.
- Try to answer the question for partial credit.



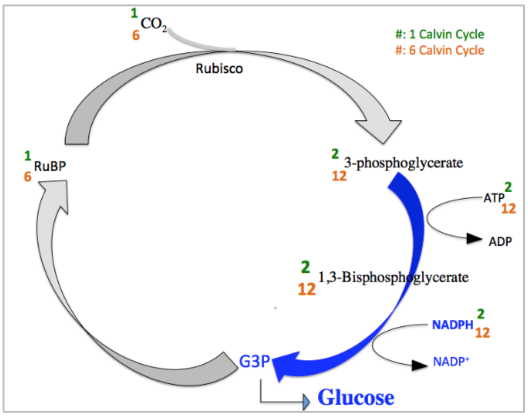

Question 3: What molecule is formed when NADPH donates electron to three-carbon molecule of 1,3-Bisphosphoglycerate?

Answer: Glyceraldehyde-3-phosphate (G3P)

Incorrect options: 3-phosphoglycerate, Ribulose-1,5-bisphosphate, Glucose

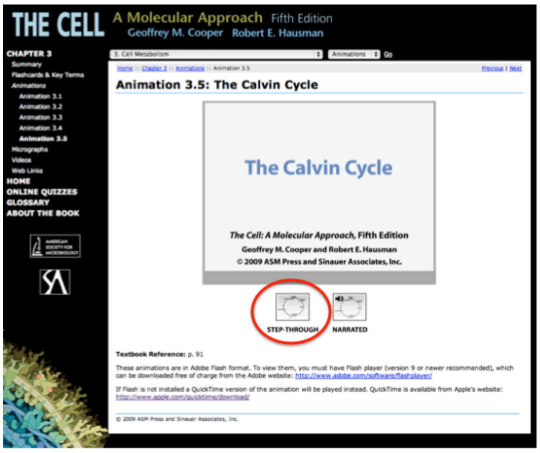
Feedback for correct answer:

- Correct, Good job!!!!!
- NADPH donates electrons to 3-carbon molecule (1,3-bisphosphoglycerate), resulting in glyceraldehyde-3-phosphate (G3P). See image below.




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Click on the link below and review slide 3 of the step-through of Calvin Cycle animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit.



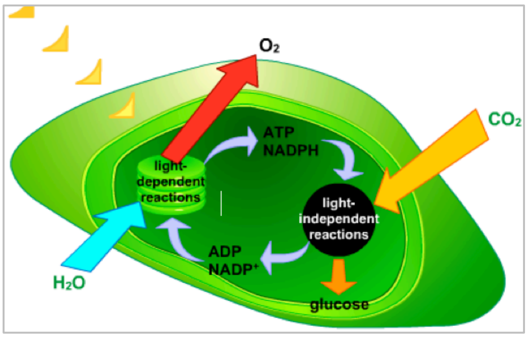

Question 4: What happens to ADP and NADP$^+$ produced during Calvin cycle?

Answer: Return to light-dependent reaction of photosynthesis

Incorrect options: Return to light-independent reaction of photosynthesis; Removed from the cell via stomata; none of the choices; Utilized to form new glucose molecules

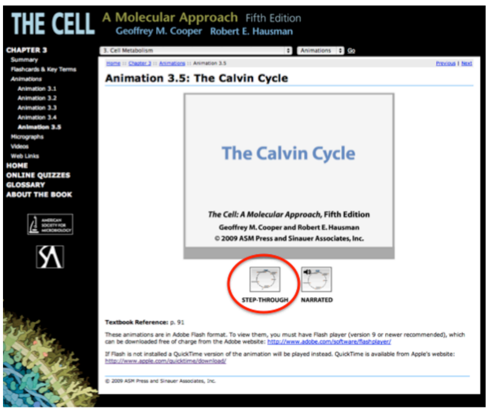
Feedback for correct answer:

- Correct, Good job!!!!
- ADP and NADP$^+$ are needed by the light reaction of the photosynthesis, where they are reduced to ATP and NADPH. See image below.




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Incorrect, Review slide 6 of the step through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit.



## Appendix 2c

Question bank for "ATP and NADPH utilized" category

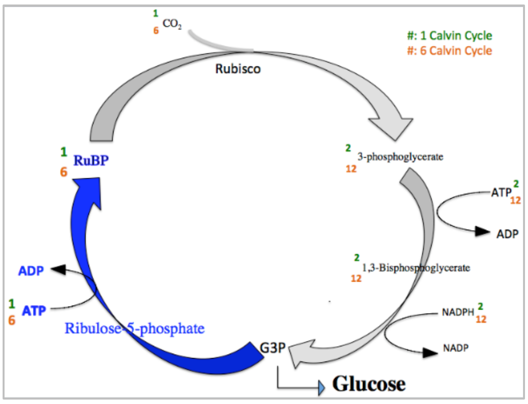
Question 1: What is one of the Functions of ATP in Calvin cycle? (Multiple-choice)

Answer: Regeneration of RuBP molecules for a new Calvin cycle

Incorrect options: Regeneration of G-3-P, production of glucose, regeneration of 3-phosphoglycerate, regeneration of $CO_2$

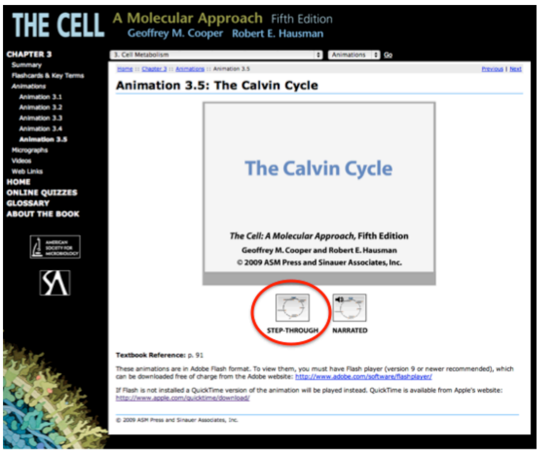
Feedback for correct answer:

- Correct, good job!!!! Ribulose-1, 5- bisphosphate (RuBP) is regenerated from Ribulose-5-phosphate in the last phase of Calvin cycle using an ATP molecule. See below figure




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Review slide 4 and 5 of the step through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit.



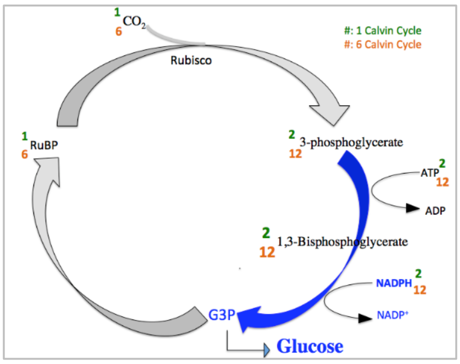

Question 2: What molecule is utilized to regenerate RuBP for a new Calvin cycle?

Answer: ATP

Incorrect options: FADH, $NADP^+$, NADPH, ADP

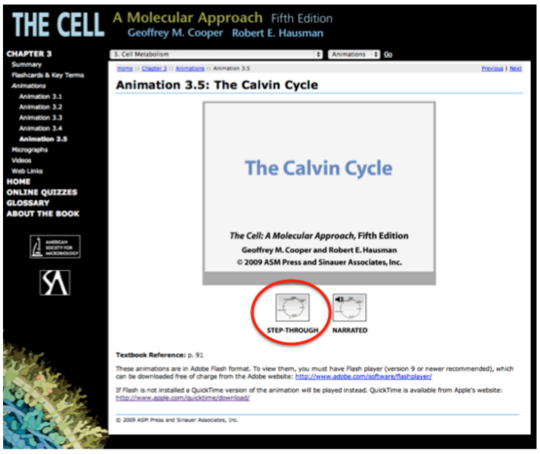
Feedback for correct answer:

- Correct, good job!!!! During the last phase of Calvin cycle, also known as regeneration phase, ribulose-5-bisphosphate molecule is converted to RuBP, utilizing an ATP molecule. This phase allows the Calvin cycle to be repeated.




<u>Feedback for incorrect answer:</u>

- This option is Incorrect!!!!
- Review slides 4 and 5 of the step through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit.



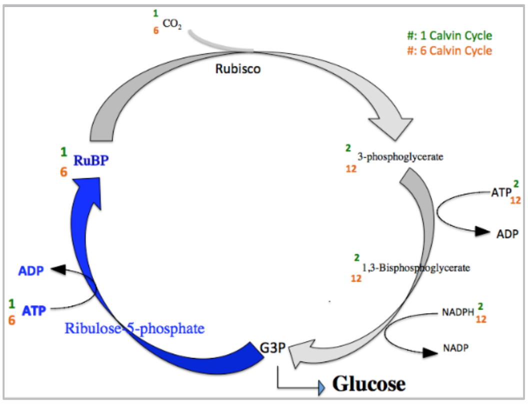

Question 3: During the last phase of Calvin cycle, ribulose-5-bisphosphate molecule is converted to ________, using a high-energy molecule of ___________.

Answer: RuBP, ATP

Incorrect options: 3-phosphoglycerate, NADPH; RuBP, ADP; glucose, ATP; Rubisco, ATP

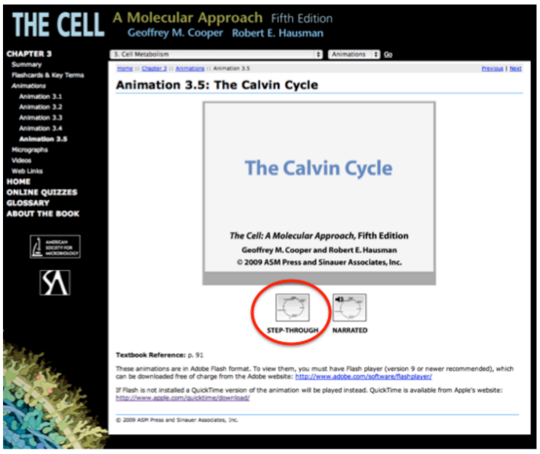
<u>Feedback for correct answer:</u>

- Correct, good job!!!! During the last phase of Calvin cycle, also known as regeneration phase, ribulose-5-bisphosphate molecule is converted to RuBP, utilizing an ATP molecule. This phase allows the Calvin cycle to be repeated. See image below.




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Review slide 4 and 5 of the step through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit.



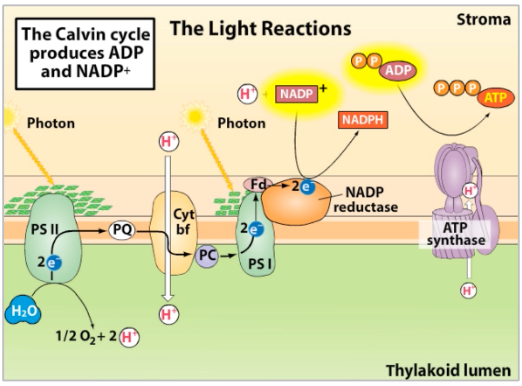

Question 4: ATP is utilized in the last phase of Calvin cycle to convert ribulose-5-bisphosphate to RUBP. Where does such ATP, a high-energy molecule, come from?

Answer: Light-dependent reaction of photosynthesis

Incorrect options: light-independent reaction, photosystem I, Photosystem I and II, stroma

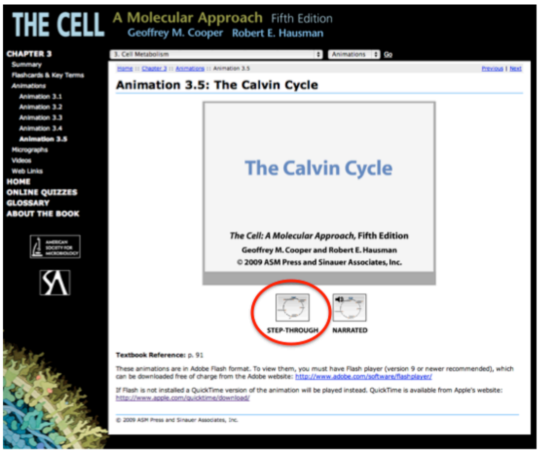
Feedback for correct answer:

- You are correct!!!!
- During the light-capturing reaction of photosynthesis, excited electrons are donated to electron transport chain, which in turn create an electrochemical gradient for protons. Flow of protons don their electrochemical gradient through ATP synthesis drives the phosphorylation of ADP (chemosmosis). See image below.




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Incorrect. Hint: Think about reactions of photosynthesis. Refer to slide 2 on the step through animation (http://www.sinauer.com/cooper5e/animation0305.html) or figure 10-14 of your textbook.
- Try to answer the question again for partial credit.



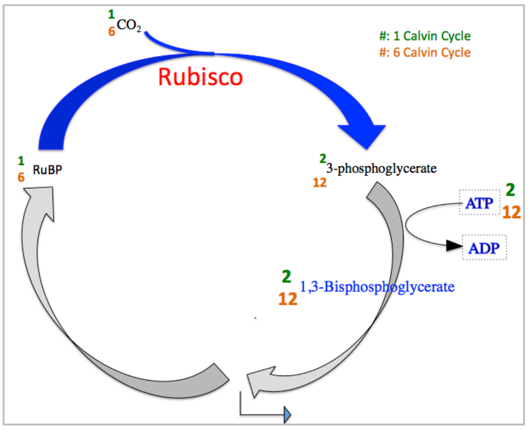

Question 5: What is one of the functions of ATP in Calvin cycle? (Multiple-choice)

Answer: Phosphorylation of 3-phosphoglycerate to form 1,3-Bisphosphoglycerate

Incorrect option: Phosphorylation of 1,3-Bisphosphoglycerate to form 3-phosphoglycerate; Fixation of Carbon to RuBP to form 3-Phosphoglycerate; Phosphorylation of 1,3-Bisphosphoglycerate to Glyceraldehyde-3-phosphate; none of the above

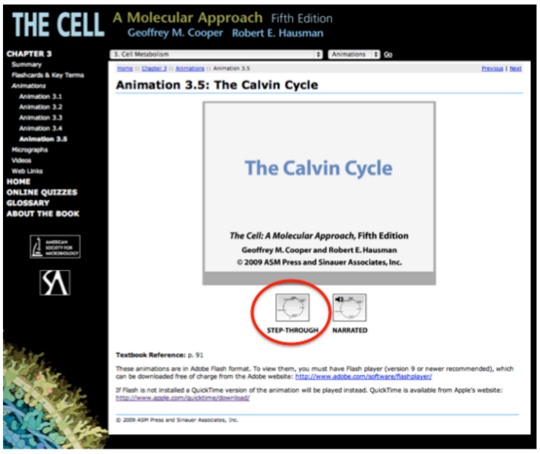
Feedback for correct answer:

- Correct, Good job!!!!
- ATP molecules are used to convert 3-phosphoglycerate to 1,3-Bisphosphoglycerate; Total of twelve ATP is consumed to produce 1 glucose molecule. See image below.




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Click on the link below and review slide 1 & 2 of the step-through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit.



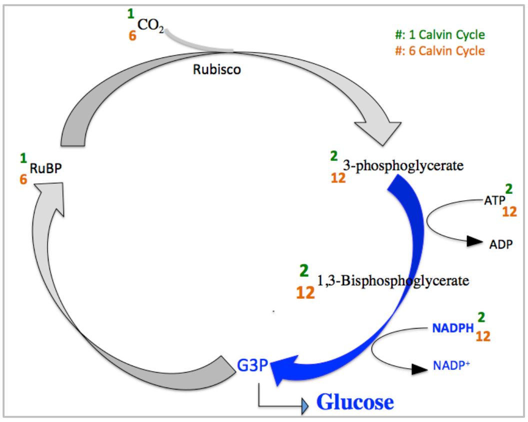

Question 6: What is the function of NADPH in Calvin cycle?

Answer: Donating electron to 1,3-Bisphosphoglycerate, resulting in formation of glyceraldehyde-3-phosphate

Incorrect options: Donating electron to 1,3-Bisphosphoglycerate, resulting in formation of glucose; Phosphorylation of 1,3-Bisphosphoglycerate, resulting in formation of G3P; Phosphorylation of 1,3-Bisphosphoglycerate, resulting in formation of glucose; None of the above

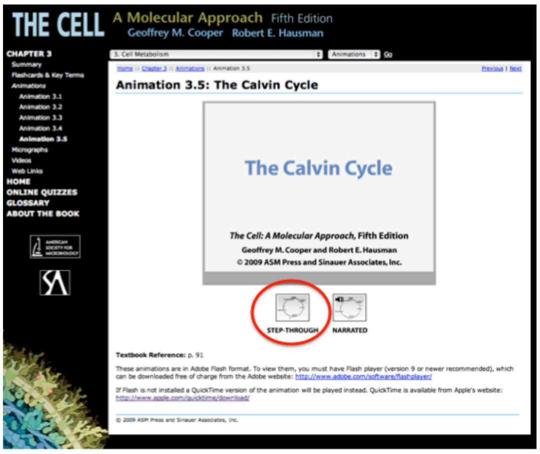
Feedback for correct answer:

- Correct, Good job!!!!!
- NADPH donates electrons to 3-carbon molecule (1,3-bisphosphoglycerate) to create glyceraldehyde-3-phosphate (G3P)




<u>Feedback for incorrect answer:</u>

- This option is Incorrect!!!!
- Click on the link below and review slide 3 of the step-through animation (<u>http://www.sinauer.com/cooper5e/animation0305.html</u>)
- Try to answer the question again for partial credit.

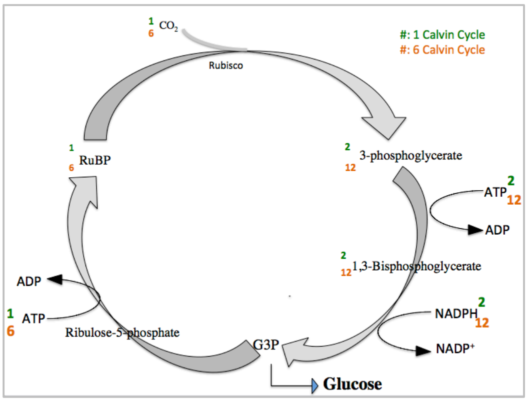


## Appendix 2d

Question bank for "General understanding of Calvin cycle" category
Question 1: Calvin cycle purpose is to:
Answer: use $CO_2$ and high-energy molecules to form sugar
Incorrect options: To create high-energy molecules; To utilized ATP and NADPH to produce $CO_2$; To create Glucose and $CO_2$ using sunlight; None of the above

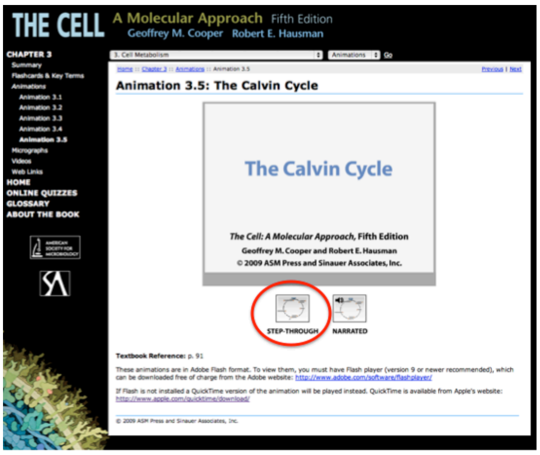
Feedback for correct answer:

- Correct, Great Job!!!!
- Plants use $CO_2$ (from atmosphere) and high-energy molecules of ATP and NADPH (from light-dependent reaction of photosynthesis) to form glucose molecules. See image below




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Review the step through animation (http://www.sinauer.com/cooper5e/animation0305.html), locate ATPs and NADPHs, count them. Try to answer the question again for partial credit. Hint: both NADPH and ATP are considered high-energy molecules.
- Try to answer the question again for partial credit.



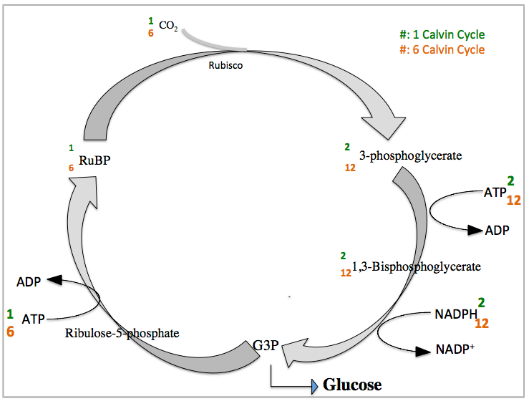

Question 2: Which high-energy molecule(s) is (are) utilized throughout Calvin cycle? Select all that applies

Answer: ATP and NADPH (must choose both answers)

Incorrect options: ADP, $NADP^+$, $FADH_2$

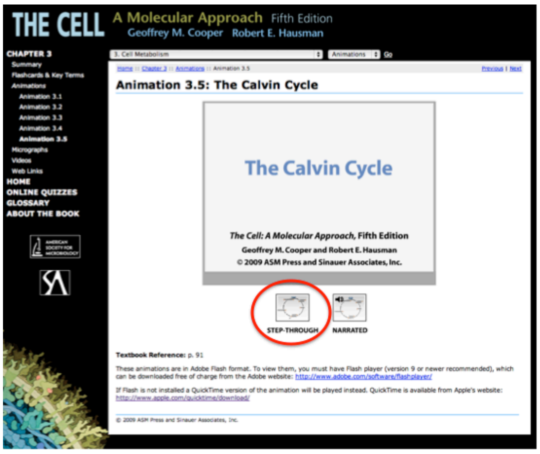
Feedback for correct answer:

- Correct, Good job!!!!
- ATP is used to form 1,3-bisphosphoglycerate and regenerate RuBP, while NADPH is used to form G3P




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Incorrect! Review slides 2-5 of the step through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question again for partial credit.



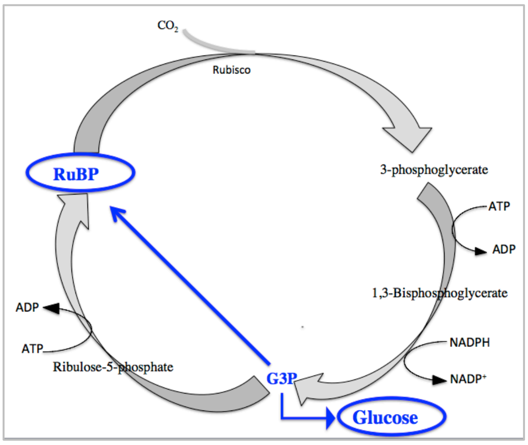

Question 3: Glycerlaldehyde-3-phosphate is utilized in Calvin cycle to form _____ and ________ molecules

Answer: glucose, RuBP

Incorrect option: RuBP, glucose; Glucose, G-3-P; G-3-P, glucose; RuBP, Rubisco

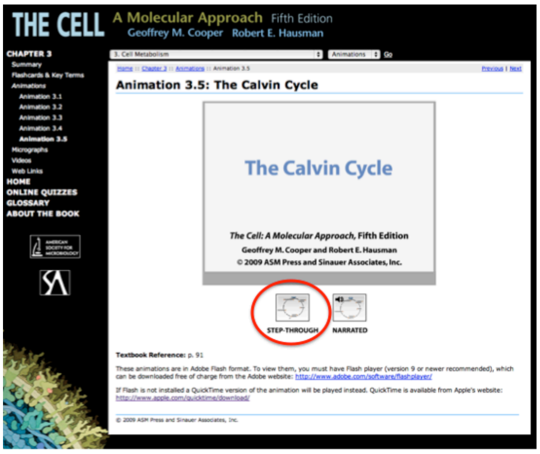
Feedback for correct answer:

- Correct, Good job!!!
- Glycerlaldehyde-3-phosphate is used to 1) form glucose molecules and 2) produce a new supply of RuBP, the $CO_2$ acceptor molecule.




<u>Feedback for incorrect answer:</u>

- This option is Incorrect!!!!
- Review slide 4 of the step through animation (http://www.sinauer.com/cooper5e/animation0305.html)
- Try to answer the question for partial credit.



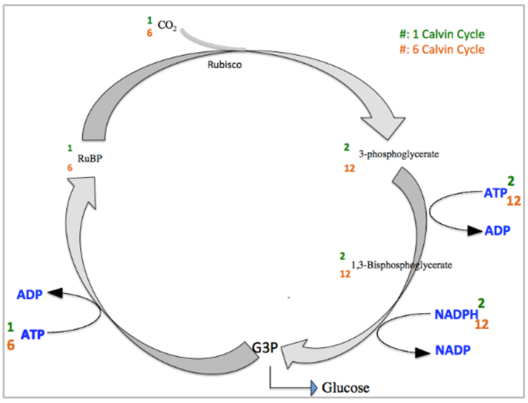

Question 4: Total of _________ ATP and _________ NADPH is utilized during Calvin cycle to produce one glucose molecule.

Answer: 18ATP, 12 NADPH

Incorrect options: 24ATP, 12 NADPH; 6 ATP, 6 NADPH; 12 ATP, 18 NADPH; 12 ATP, 12 NADPH

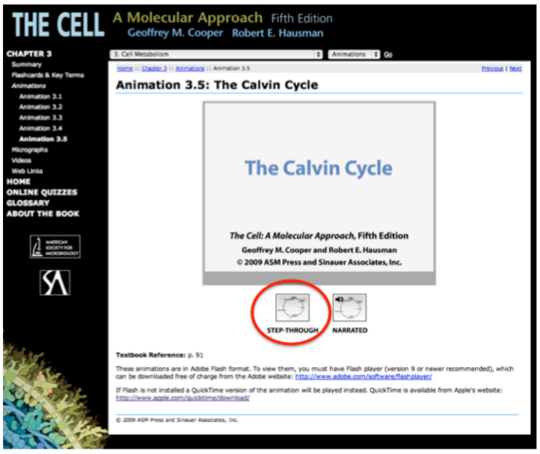
<u>Feedback for correct answer:</u>

- Correct, good job!!!!!
- 12 ATP utilized in converting 3-phosphoglycerate to 1,3-Bisphosphoglycerate
- 6 ATP utilized in regeneration of RuBP Total: 12+6= 18 ATP
- 6 NADPH is utilized to covert 1,3-Bisphosphoglycerate to G3P




Feedback for incorrect answer:

- This option is Incorrect!!!!
- Review the step through animation (http://www.sinauer.com/cooper5e/animation0305.html), locate ATPs and NADPHs, count them.
- Try to answer the question again for partial credit.



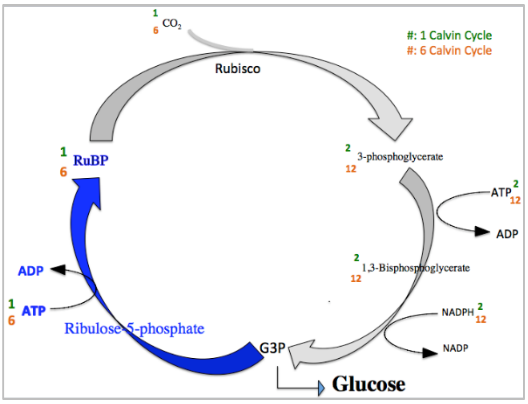

Question 5: Why is the regeneration phase (last phase) of Calvin cycle essential for plant survival?

Answer: This phase regenerates RuBP, allowing the Calvin cycle to be repeated

Incorrect option: The phase regenerates glucose; the phase produces $O_2$ produced by the plant; this phase regenerates G-3-P, None of the options

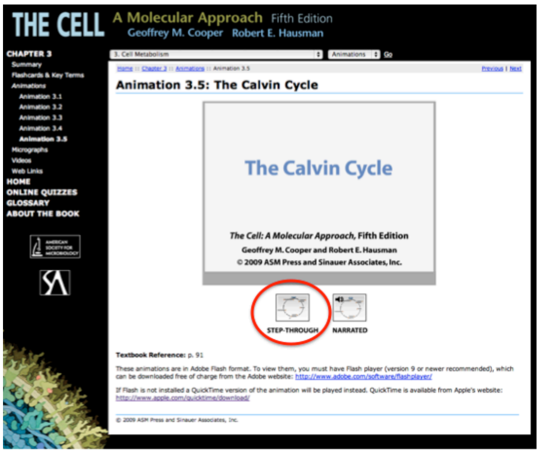
Feedback for correct answer:

- Correct, good job!!!!
- For Calvin cycle to process again, RuBP must be regenerated. This process is completed in the last phase of Calvin cycle where ATP molecule is utilized, converting ribulose-5-bisphosphate to RUBP. See image below




<u>Feedback for incorrect answer:</u>

- This option is Incorrect!!!!
- Review slides 4 and 5 of the step through animation (<u>http://www.sinauer.com/cooper5e/animation0305.html</u>)
- Try to answer the question again for partial credit.



**Appendix 3**

Students' responses to the demographic survey questionnaire

**Appendix 3A**

Representation of student's responses to the question "How many semesters have you been a student at CSUF?"

| Semesters at CSUF | One | Two | Three | Four | Five or more |
|---|---|---|---|---|---|
| Treat_02_Sp13 | 4 | 7 | 0 | 4 | 4 |
| Treat_06_Sp13 | 1 | 2 | 1 | 16 | 1 |
| Treat_10_Sp13 | 1 | 3 | 2 | 5 | 5 |
| Treat_14_Sp13 | 1 | 6 | 2 | 13 | 1 |
| Treat_18_Sp13 | 1 | 4 | 2 | 7 | 2 |
| Treat_10_Sp14 | 1 | 4 | 2 | 9 | 5 |
| Treat_12_Sp14 | 4 | 5 | 6 | 2 | 1 |
| Treat_14_Sp14 | 1 | 4 | 0 | 3 | 3 |
| Treat_18_Sp14 | 6 | 7 | 2 | 2 | 2 |
| Total | 20 | 42 | 17 | 61 | 24 |
| % Distribution | 12% | 26% | 10% | 37% | 15% |

| Semesters at CSUF | One | Two | Three | Four | Five or more |
|---|---|---|---|---|---|
| Con_04_Sp13 | 1 | 2 | 2 | 5 | 8 |
| Con_08_Sp13 | 3 | 6 | 1 | 11 | 0 |
| Con_12_Sp13 | 0 | 9 | 2 | 6 | 2 |
| Con_16_Sp13 | 2 | 12 | 1 | 2 | 1 |
| Con_20_Sp13 | 3 | 10 | 0 | 5 | 2 |
| Con_02_Sp14 | 2 | 7 | 3 | 5 | 8 |
| Con_04_Sp14 | 2 | 4 | 5 | 6 | 5 |
| Con_20_Sp14 | 6 | 4 | 0 | 3 | 2 |
| Con_32_Sp14 | 8 | 8 | 2 | 3 | 2 |
| Total | 27 | 62 | 16 | 46 | 30 |
| % Distribution | 15% | 34% | 9% | 25% | 17% |

**Appendix 3B**

The following tables represent student's responses to question, "Did you transfer from either a community college or another university?

| | Yes | No |
|---|---|---|
| Treat_02_Sp13 | 7 | 13 |
| Treat_06_Sp13 | 0 | 19 |
| Treat_10_Sp13 | 1 | 16 |
| Treat_14_Sp13 | 3 | 21 |
| Treat_18_Sp13 | 0 | 16 |
| Treat_10_Sp14 | 4 | 17 |
| Treat_12_Sp14 | 2 | 15 |
| Treat_14_Sp14 | 2 | 10 |
| Treat_18_Sp14 | 1 | 18 |
| Total | 20 | 145 |
| Percent Distribution | 12% | 88% |

| | Yes | No |
|---|---|---|
| Con_04_Sp13 | 5 | 13 |
| Con_08_Sp13 | 0 | 21 |
| Con_12_Sp13 | 1 | 19 |
| Con_16_Sp13 | 0 | 17 |
| Con_20_Sp13 | 0 | 21 |
| Con_02_Sp14 | 9 | 15 |
| Con_04_Sp14 | 4 | 18 |
| Con_20_Sp14 | 2 | 14 |
| Con_32_Sp14 | 5 | 18 |
| Total | 26 | 156 |
| Percent distribution | 14% | 86% |

## Appendix 3C

The following tables represent students' responses to question, "What was the primary language spoken in your home during your childhood?"

| | English | Spanish | Vietnamese | Other |
|---|---|---|---|---|
| Treat_02_Sp13 | 14 | 3 | 2 | 1 |
| Treat_06_Sp13 | 11 | 1 | 6 | 2 |
| Treat_10_Sp13 | 5 | 5 | 1 | 6 |
| Treat_14_Sp13 | 11 | 2 | 5 | 5 |
| Treat_18_Sp13 | 12 | 2 | 0 | 1 |
| Treat_10_Sp14 | 9 | 7 | 2 | 3 |
| Treat_12_Sp14 | 7 | 3 | 2 | 5 |
| Treat_14_Sp14 | 7 | 2 | 1 | 2 |
| Treat_18_Sp14 | 13 | 4 | 1 | 1 |
| Total | 89 | 29 | 20 | 26 |
| Percent distribution | 54.3% | 17.7% | 12.2% | 15.9% |

| Language | English | Spanish | Vietnamese | Other |
|---|---|---|---|---|
| Con_04_Sp13 | 10 | 5 | 2 | 1 |
| Con_08_Sp13 | 15 | 2 | 1 | 3 |
| Con_12_Sp13 | 8 | 2 | 6 | 4 |
| Con_16_Sp13 | 10 | 2 | 0 | 6 |
| Con_20_Sp13 | 10 | 4 | 6 | 1 |
| Con_02_Sp14 | 18 | 1 | 0 | 4 |
| Con_04_Sp14 | 11 | 6 | 4 | 2 |
| Con_20_Sp14 | 10 | 0 | 3 | 3 |
| Con_32_Sp14 | 13 | 3 | 3 | 2 |
| Total | 105 | 25 | 25 | 26 |
| Percent distribution | 58.0% | 13.8% | 13.8% | 14.4% |

## Appendix 3D

The following tables represent students' responses to question, "What biology course did you complete in high school? (Select all that apply)"

| High school courses | General | Human biology | AP biology | Other | None |
|---|---|---|---|---|---|
| Treat_02_Sp13 | 17 | 4 | 4 | 1 | 2 |
| Treat_06_Sp13 | 17 | 8 | 7 | 1 | 0 |
| Treat_10_Sp13 | 14 | 6 | 7 | 3 | 0 |
| Treat_14_Sp13 | 23 | 11 | 7 | 1 | 0 |
| Treat_18_Sp13 | 14 | 6 | 8 | 0 | 0 |
| Treat_10_Sp14 | 16 | 4 | 7 | 3 | 2 |
| Treat_12_Sp14 | 16 | 8 | 3 | 0 | 0 |
| Treat_14_Sp14 | 12 | 5 | 1 | 1 | 0 |
| Treat_18_Sp14 | 18 | 6 | 5 | 2 | 0 |
| Total | 147 | 58 | 49 | 12 | 4 |
| % Distribution | 89.1% | 35.2% | 29.7% | 7.3% | 2.4% |

| High school courses | General | Human biology | AP biology | Other | None |
|---|---|---|---|---|---|
| Con_04_Sp13 | 17 | 4 | 3 | 1 | 0 |
| Con_08_Sp13 | 17 | 5 | 11 | 3 | 0 |
| Con_12_Sp13 | 18 | 6 | 6 | 2 | 0 |
| Con_16_Sp13 | 15 | 8 | 5 | 2 | 0 |
| Con_20_Sp13 | 18 | 8 | 10 | 3 | 0 |
| Con_02_Sp14 | 22 | 4 | 4 | 0 | 0 |
| Con_04_Sp14 | 17 | 10 | 4 | 3 | 0 |
| Con_20_Sp14 | 15 | 7 | 5 | 2 | 0 |
| Con_32_Sp14 | 20 | 10 | 10 | 2 | 0 |
| Total | 159 | 62 | 58 | 18 | 0 |
| % Distribution | 87% | 34% | 32% | 10% | 0% |

## Appendix 3E

The following tables represent students' responses to question, "What college level biology courses have you completed prior to this semester? (Include Biology 172 only if repeated)"

| Undergraduate major | Undecided | Cell/Mol. | Biochem. | Kinesiology | Psych | Hlth. Sci. | Marine | Ecology | Other |
|---|---|---|---|---|---|---|---|---|---|
| Treat_02_Sp13 | 9 | 1 | 7 | 1 | 2 | 0 | 0 | 0 | 0 |
| Treat_06_Sp13 | 12 | 3 | 4 | 0 | 0 | 1 | | 0 | 1 |
| Treat_10_Sp13 | 9 | 3 | 3 | 1 | 0 | 1 | 0 | 0 | 1 |
| Treat_14_Sp13 | 14 | 0 | 6 | 0 | 1 | 0 | 1 | 0 | 0 |
| Treat_18_Sp13 | 7 | 2 | 2 | 0 | 2 | 2 | 0 | 1 | 0 |
| Treat_10_Sp14 | 5 | 4 | 6 | 2 | 0 | 1 | 0 | 0 | 3 |
| Treat_12_Sp14 | 8 | 3 | 3 | 2 | 0 | 1 | 0 | 0 | 1 |
| Treat_14_Sp14 | 8 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 1 |
| Treat_18_Sp14 | 11 | 0 | 3 | 0 | 0 | 1 | 1 | 0 | 0 |
| Total | 83 | 16 | 36 | 7 | 5 | 8 | 2 | 1 | 7 |
| % Distribution | 50.3% | 9.7% | 21.8% | 4.2% | 3.0% | 4.8% | 1.2% | 0.6% | 4.2% |

| Undergraduate major | Undecided | Cell/Mol. | Biochem. | Kinesiology | Psych | Hlth. Sci. | Marine | Ecology | Other |
|---|---|---|---|---|---|---|---|---|---|
| Comp_04_Sp13 | 8 | 3 | 3 | 2 | 0 | 2 | 0 | 0 | 1 |
| Comp _08_Sp13 | 7 | 3 | 5 | 0 | 0 | 1 | 2 | 1 | 2 |
| Comp_12_Sp13 | 8 | 1 | 8 | 1 | 0 | 1 | 1 | 0 | 1 |
| Comp_16_Sp13 | 9 | 5 | 3 | 0 | 0 | 1 | 0 | 0 | 1 |
| Comp_20_Sp13 | 9 | 4 | 1 | 0 | 0 | 2 | 1 | 1 | 0 |
| Comp_02_Sp14 | 3 | 1 | 7 | 5 | 4 | 2 | 1 | 0 | 0 |
| Comp_04_Sp14 | 8 | 2 | 10 | 1 | 0 | 0 | 1 | 0 | 0 |
| Comp_20_Sp14 | 6 | 0 | 5 | 0 | 0 | 2 | 1 | 2 | 0 |
| Comp_32_Sp14 | 8 | 2 | 8 | 1 | 1 | 0 | 0 | 2 | 1 |
| Total | 66 | 21 | 50 | 10 | 5 | 11 | 7 | 6 | 6 |
| % Distribution | 36.3% | 11.5% | 27.5% | 5.5% | 2.7% | 6.0% | 3.8% | 3.3% | 3.3% |

**Appendix 3F**

The following tables represent students' responses to question, "What college level biology course have you completed prior to this semester? (Include Bio 172 if repeated)" College biology (other: genetics, molecular, organismal & bio 102, zoology)

| | Bio101 | Bio 171 | Bio 172 (repeat) | None | A/P | Other |
|---|---|---|---|---|---|---|
| Treat_02_Sp13 | 5 | 11 | 2 | 3 | 0 | 4 |
| Treat_06_Sp13 | 0 | 16 | 2 | 4 | 0 | 1 |
| Treat_10_Sp13 | 1 | 12 | 2 | 4 | 0 | 0 |
| Treat_14_Sp13 | 3 | 16 | 7 | 1 | 0 | 0 |
| Treat_18_Sp13 | 1 | 14 | 0 | 1 | 0 | 0 |
| Treat_10_Sp14 | 4 | 12 | 0 | 5 | 1 | 0 |
| Treat_12_Sp14 | 2 | 10 | 0 | 4 | 1 | 0 |
| Treat_14_Sp14 | 1 | 8 | 0 | 2 | 0 | 0 |
| Treat_18_Sp14 | 0 | 10 | 2 | 3 | 1 | 0 |
| Total | 17 | 109 | 15 | 27 | 3 | 5 |
| % Distribution | 10.3% | 66.1% | 9.1% | 16.4% | 1.8% | 3.0% |

| | Bio101 | Bio 171 | Bio 172 (repeat) | None | A/P | Other |
|---|---|---|---|---|---|---|
| Comp_04_Sp13 | 2 | 12 | 3 | 1 | 1 | 0 |
| Comp_08_Sp13 | 2 | 11 | 1 | 6 | 0 | 0 |
| Comp_12_Sp13 | 5 | 10 | 0 | 5 | 0 | 0 |
| Comp_16_Sp13 | 0 | 14 | 2 | 2 | 0 | 0 |
| Comp_20_Sp13 | 0 | 18 | 1 | 0 | 1 | 0 |
| Comp_02_Sp14 | 10 | 7 | 3 | 5 | 2 | 0 |
| Comp_04_Sp14 | 6 | 4 | 4 | 3 | 0 | 1 |
| Comp_20_Sp14 | 2 | 10 | 0 | 4 | 0 | 0 |
| Comp_32_Sp14 | 3 | 15 | 0 | 2 | 4 | 0 |
| Total | 30 | 101 | 14 | 28 | 8 | 1 |
| % Distribution | 16.4% | 55.2% | 7.7% | 15.3% | 4.4% | 0.5% |

**Appendix 3G**

The following tables represent students' responses to question, "What is your GPA as of Fall 2012 or Fall of 2013?"

| GPA | 3.6-4 | 3-3.59 | 2.6-2.99 | 2-2.59 | 1.60-1.99 | 1.59-0 |
|---|---|---|---|---|---|---|
| Treat_02_Sp13 | 4 | 7 | 6 | 1 | 0 | 1 |
| Treat_06_Sp13 | 1 | 4 | 12 | 3 | 0 | 1 |
| Treat_10_Sp13 | 3 | 8 | 3 | 3 | 0 | 0 |
| Treat_14_Sp13 | 5 | 12 | 3 | 3 | 0 | 0 |
| Treat_18_Sp13 | 2 | 9 | 4 | 0 | 1 | 0 |
| Treat_10_Sp14 | 9 | 6 | 4 | 1 | 1 | 0 |
| Treat_12_Sp14 | 2 | 12 | 2 | 1 | 0 | 0 |
| Treat_14_Sp14 | 3 | 6 | 1 | 2 | 0 | 0 |
| Treat_18_Sp14 | 5 | 6 | 6 | 1 | 1 | 0 |
| Total | 34 | 70 | 41 | 15 | 3 | 2 |
| % Distribution | 20.6% | 42.4% | 24.8% | 9.1% | 1.8% | 1.2% |

| GPA | 3.6-4 | 3-3.59 | 2.6-2.99 | 2-2.59 | 1.60-1.99 | 1.59-0 |
|---|---|---|---|---|---|---|
| Comp_04_Sp13 | 3 | 11 | 4 | 0 | 0 | 0 |
| Comp_08_Sp13 | 5 | 9 | 5 | 2 | 0 | 0 |
| Comp_12_Sp13 | 4 | 9 | 4 | 3 | 0 | 0 |
| Comp_16_Sp13 | 4 | 6 | 4 | 2 | 1 | 0 |
| Comp_20_Sp13 | 1 | 11 | 6 | 1 | 1 | 0 |
| Comp_02_Sp14 | 6 | 11 | 6 | 1 | 0 | 0 |
| Comp_04_Sp14 | 1 | 15 | 6 | 0 | 0 | 0 |
| Comp_20_Sp14 | 3 | 7 | 4 | 1 | 0 | 1 |
| Comp_32_Sp14 | 3 | 15 | 3 | 2 | 0 | 0 |
| Total | 30 | 94 | 42 | 12 | 2 | 1 |
| % Distribution | 16.6% | 51.9% | 23.2% | 6.6% | 1.1% | 0.6% |

**Appendix 3H**

The following tables represent students' responses to question, "On average, how many hours do you spend per week studying for this course?"

| | < 1hr | 2-4 hrs. | 5-7 hrs. | 8-10 hrs. | 11-13 hrs. | > 13hrs |
|---|---|---|---|---|---|---|
| Comp_04_Sp13 | 1 | 7 | 4 | 5 | 0 | 1 |
| Comp_08_Sp13 | 1 | 10 | 7 | 2 | 1 | 0 |
| Comp_12_Sp13 | 3 | 5 | 7 | 4 | 1 | 0 |
| Comp_16_Sp13 | 0 | 6 | 6 | 1 | 4 | 0 |
| Comp_20_Sp13 | 2 | 10 | 3 | 6 | 0 | 0 |
| Comp_02_Sp14 | 1 | 17 | 3 | 2 | 0 | 1 |
| Comp_04_Sp14 | 2 | 12 | 6 | 1 | 0 | 1 |
| Comp_20_Sp14 | 1 | 9 | 6 | 0 | 0 | 0 |
| Comp_32_Sp14 | 1 | 9 | 9 | 2 | 1 | 0 |
| Total | 12 | 85 | 51 | 23 | 7 | 3 |
| % Distribution | 6.6% | 47.0% | 28.2% | 12.7% | 3.9% | 1.7% |

| | < 1hr | 2-4 hrs. | 5-7 hrs. | 8-10 hrs. | 11-13 hrs. | > 13hrs |
|---|---|---|---|---|---|---|
| Treat_02_Sp13 | 2 | 4 | 13 | 1 | 0 | 0 |
| Treat_06_Sp13 | 1 | 4 | 12 | 3 | 0 | 1 |
| Treat_10_Sp13 | 2 | 6 | 5 | 2 | 0 | 2 |
| Treat_14_Sp13 | 3 | 5 | 11 | 4 | 1 | 0 |
| Treat_18_Sp13 | 0 | 6 | 9 | 0 | 0 | 1 |
| Treat_10_Sp14 | 1 | 6 | 8 | 5 | 0 | 1 |
| Treat_12_Sp14 | 0 | 4 | 11 | 2 | 0 | 0 |
| Treat_14_Sp14 | 0 | 5 | 4 | 2 | 1 | 0 |
| Treat_18_Sp14 | 2 | 7 | 7 | 1 | 1 | 1 |
| Total | 11 | 47 | 80 | 20 | 3 | 6 |
| % Distribution | 6.7% | 28.7% | 48.8% | 12.2% | 1.8% | 3.7% |

**Appendix 3I**

The following tables represent students' responses to question," Which of the following statements applies the most to you? I learn best when I ..."

| | See a picture, model, animation | Listen to lecture and take notes | Reading | Discuss topics with others | Handle models or act out a concept |
|---|---|---|---|---|---|
| Treat_02_Sp13 | 8 | 1 | 1 | 5 | 4 |
| Treat_06_Sp13 | 10 | 2 | 2 | 2 | 2 |
| Treat_10_Sp13 | 7 | 3 | 3 | 3 | 1 |
| Treat_14_Sp13 | 10 | 3 | 1 | 7 | 2 |
| Treat_18_Sp13 | 7 | 1 | 3 | 5 | 1 |
| Treat_10_Sp14 | 11 | 1 | 3 | 3 | 3 |
| Treat_12_Sp14 | 9 | 3 | 3 | 2 | 0 |
| Treat_14_Sp14 | 7 | 1 | 2 | 2 | 0 |
| Treat_18_Sp14 | 11 | 6 | 2 | 1 | 0 |
| Total | 80 | 21 | 20 | 30 | 13 |
| % Distribution | 48.8% | 12.8% | 12.2% | 18.3% | 7.9% |

| | See a picture, model, animation | Listen to lecture and take notes | Reading | Discuss topics with others | Handle models or act out a concept |
|---|---|---|---|---|---|
| Comp_04_Sp13 | 8 | 2 | 3 | 4 | 1 |
| Comp_08_Sp13 | 9 | 3 | 2 | 3 | 3 |
| Comp_12_Sp13 | 9 | 5 | 1 | 3 | 2 |
| Comp_16_Sp13 | 6 | 3 | 2 | 6 | 0 |
| Comp_20_Sp13 | 7 | 3 | 5 | 5 | 1 |
| Comp_02_Sp14 | 9 | 8 | 3 | 4 | 0 |
| Comp_04_Sp14 | 12 | 3 | 5 | 1 | 1 |
| Comp_20_Sp14 | 7 | 3 | 3 | 3 | |
| Comp_32_Sp14 | 9 | 4 | 2 | 7 | 1 |
| Total | 76 | 34 | 26 | 36 | 9 |
| % Distribution | 42.0% | 18.8% | 14.4% | 19.9% | 5.0% |

**Appendix 3J**

The following tables represent students' responses to question, "What is your opinion of the following statement? Computer animations are a very helpful tool for learning biology."

| Animation a helpful teach tool? | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Treat_02_Sp13 | 8 | 10 | 1 | 1 | 0 |
| Treat_06_Sp13 | 8 | 10 | 2 | 1 | 0 |
| Treat_10_Sp13 | 4 | 9 | 4 | 0 | 0 |
| Treat_14_Sp13 | 9 | 10 | 5 | 0 | 0 |
| Treat_18_Sp13 | 5 | 8 | 3 | 0 | 0 |
| Treat_10_Sp14 | 8 | 10 | 3 | 0 | 0 |
| Treat_12_Sp14 | 7 | 8 | | 0 | 0 |
| Treat_14_Sp14 | 4 | 7 | 1 | 0 | 0 |
| Treat_18_Sp14 | 8 | 8 | 3 | 0 | 0 |
| Total | 61 | 80 | 22 | 2 | 0 |
| % Distribution | 37.0% | 48.5% | 13.3% | 1.2% | 0.0% |

| Animation a helpful teach tool? | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Comp_04_Sp13 | 9 | 7 | 1 | 1 | 0 |
| Comp_08_Sp13 | 11 | 6 | 4 | 0 | 0 |
| Comp_12_Sp13 | 6 | 10 | 3 | 0 | 0 |
| Comp_16_Sp13 | 9 | 4 | 4 | 0 | 0 |
| Comp_20_Sp13 | 5 | 13 | 2 | 1 | 0 |
| Comp_02_Sp14 | 14 | 9 | 1 | 0 | 0 |
| Comp_04_Sp14 | 14 | 3 | 3 | 2 | 0 |
| Comp_20_Sp14 | 5 | 10 | 1 | 0 | 0 |
| Comp_32_Sp14 | 7 | 12 | 4 | 0 | 1 |
| Total | 80 | 74 | 23 | 4 | 1 |
| % Distribution | 44.0% | 40.7% | 12.6% | 2.2% | 0.5% |

**Appendix 3K**

The following tables represent students' responses to question, "What is your age?"

| Age distribution | Under 18 | 18-20 | 21-24 | 25-30 | Over 30 |
|---|---|---|---|---|---|
| Treat_02_Sp13 | 0 | 10 | 8 | 2 | 0 |
| Treat_06_Sp13 | 0 | 20 | 1 | 0 | 0 |
| Treat_10_Sp13 | 0 | 13 | 4 | 0 | 0 |
| Treat_14_Sp13 | 0 | 20 | 4 | 0 | 0 |
| Treat_18_Sp13 | 0 | 14 | 2 | 0 | 0 |
| Treat_10_Sp14 | 0 | 15 | 3 | 2 | 1 |
| Treat_12_Sp14 | 0 | 14 | 2 | 1 | 0 |
| Treat_14_Sp14 | 0 | 8 | 4 | 0 | 0 |
| Treat_18_Sp14 | 0 | 16 | 3 | 0 | 0 |
| Total | 0 | 130 | 31 | 5 | 1 |
| % Distribution | 0% | 78% | 19%` | 3% | 1% |

| | Under 18 | 18-20 | 21-24 | 25-30 | Over 30 |
|---|---|---|---|---|---|
| Comp_04_Sp13 | 0 | 9 | 7 | 2 | 0 |
| Comp_08_Sp13 | 0 | 20 | 1 | 0 | 0 |
| Comp_12_Sp13 | 0 | 14 | 6 | 0 | 0 |
| Comp _16_Sp13 | 0 | 17 | 0 | 0 | 0 |
| Comp _20_Sp13 | 0 | 18 | 2 | 0 | 0 |
| Comp _02_Sp14 | 0 | 8 | 12 | 2 | 2 |
| Comp _04_Sp14 | 0 | 17 | 3 | 2 | 0 |
| Comp _20_Sp14 | 0 | 10 | 5 | 0 | 0 |
| Comp _32_Sp14 | 0 | 17 | 4 | 1 | 1 |
| Total | 0 | 130 | 40 | 7 | 3 |
| % Distribution | 0% | 72% | 22% | 4% | 2% |

**Appendix 3L**

The following tables represent students' responses to question, "What is your gender?"

| Section | Male | Female |
|---|---|---|
| Treat_02_Sp13 | 6 | 13 |
| Treat_06_Sp13 | 8 | 13 |
| Treat_10_Sp13 | 4 | 13 |
| Treat_14_Sp13 | 10 | 13 |
| Treat_18_Sp13 | 1 | 15 |
| Treat_10_Sp14 | 2 | 19 |
| Treat_12_Sp14 | 11 | 6 |
| Treat_14_Sp14 | 4 | 8 |
| Treat_18_Sp14 | 7 | 12 |
| Total | 53 | 112 |
| % Distribution | 32% | 68% |

| Section | Male | Female |
|---|---|---|
| Comp_04_Sp13 | 6 | 12 |
| Comp_08_Sp13 | 8 | 12 |
| Comp_12_Sp13 | 11 | 8 |
| Comp_16_Sp13 | 3 | 14 |
| Comp_20_Sp13 | 8 | 12 |
| Comp_02_Sp14 | 9 | 15 |
| Comp_04_Sp14 | 11 | 11 |
| Comp_20_Sp14 | 7 | 9 |
| Comp_32_Sp14 | 11 | 12 |
| Total | 74 | 105 |
| % Distribution | 41% | 59% |

**Appendix 3M**

The following tables represent students' responses to question, "Was the concept of the Calvin cycle new to you this semester? "

| | No Prior Knowledge | Prior Knowledge |
|---|---|---|
| Comp_04_Sp13 | 7 | 11 |
| Comp_08_Sp13 | 7 | 13 |
| Comp_12_Sp13 | 8 | 12 |
| Comp_16_Sp13 | 5 | 12 |
| Comp_20_Sp13 | 11 | 10 |
| Comp_02_Sp14 | 12 | 12 |
| Comp_04_Sp14 | 14 | 8 |
| Comp_20_Sp14 | 7 | 9 |
| Comp_32_Sp14 | 10 | 13 |
| Total | 81 | 100 |
| % Distribution | 44.8% | 55.2% |

| | No Prior Knowledge | Prior Knowledge |
|---|---|---|
| Exp_02_Sp13 | 11 | 9 |
| Exp_06_Sp13 | 9 | 11 |
| Exp_10_Sp13 | 4 | 13 |
| Exp_14_Sp13 | 9 | 15 |
| Exp_18_Sp13 | 6 | 9 |
| Exp_10_Sp14 | 10 | 11 |
| Exp_12_Sp14 | 9 | 8 |
| Exp_14_Sp14 | 8 | 4 |
| Exp_18_Sp14 | 11 | 8 |
| Total | 77 | 88 |
| % Distribution | 46.7% | 53.3% |

**Appendix 3N**

The following tables represent student's' responses to questions "How many hours do you work a week?"

| Hrs/wk | 0 | 1_15 | 16_25 | 26_35 | 36_40 | Over 40 |
|---|---|---|---|---|---|---|
| Comp_04_Sp13 | 6 | 4 | 6 | 2 | 0 | 0 |
| Comp_08_Sp13 | 12 | 2 | 6 | 0 | 0 | 1 |
| Comp_12_Sp13 | 10 | 7 | 2 | 0 | 0 | 0 |
| Comp_16_Sp13 | 10 | 3 | 2 | 1 | 0 | 0 |
| Comp_20_Sp13 | 12 | 6 | 2 | 0 | 1 | 0 |
| Comp_02_Sp14 | 4 | 8 | 7 | 1 | 4 | 0 |
| Comp_04_Sp14 | 10 | 7 | 4 | 0 | 0 | 1 |
| Comp_20_Sp14 | 9 | 4 | 3 | 0 | 0 | 0 |
| Comp_32_Sp14 | 10 | 3 | 8 | 2 | 0 | 0 |
| Total | 83 | 44 | 40 | 6 | 5 | 2 |
| % Distribution | 46% | 24% | 22% | 3% | 3% | 1% |

| Hrs/wk | 0 | 1_15 | 16_25 | 26_35 | 36_40 | Over 40 |
|---|---|---|---|---|---|---|
| Exp_02_Sp13 | 4 | 8 | 7 | 1 | 0 | 0 |
| Exp_06_Sp13 | 11 | 5 | 5 | 0 | 0 | 0 |
| Exp_10_Sp13 | 6 | 7 | 2 | 0 | 0 | 1 |
| Exp_14_Sp13 | 11 | 8 | 3 | 0 | 2 | 0 |
| Exp_18_Sp13 | 5 | 6 | 4 | 0 | 0 | 0 |
| Exp_10_Sp14 | 8 | 7 | 3 | 2 | 1 | 0 |
| Exp_12_Sp14 | 11 | 4 | 1 | 1 | 0 | 0 |
| Exp_14_Sp14 | 6 | 3 | 3 | 0 | 0 | 0 |
| Exp_18_Sp14 | 8 | 8 | 2 | 1 | 0 | 0 |
| Total | 70 | 56 | 30 | 5 | 3 | 1 |
| % Distribution | 42% | 34% | 18% | 3% | 2% | 1% |

**Appendix 4**

Consent form provide to students during spring 2013 and spring 2014 semester prior to their participation in the research study.

**Consent Form**

Dear participant:

My name is Soha Sobhanian. I am a graduate student under the direction of Dr. David Treagust at Curtin University.

I am conducting a study to better understand the effectiveness of interactive multimedia on student's comprehension of the processes of the light independent reaction of photosynthesis. Participants (students enrolled in lower division biology course at CSUF) would be assigned to either control group (non-interactive multimedia) or treatment group (interactive multimedia) based on their lab sections. Prior to photosynthesis lecture, participants are asked to answer basic questions about the process of photosynthesis to create a base line for the research. Following the lecture, Participants in the control group would watch a 3-minute animation during their weekly laboratory meeting and complete an online demographic survey as part of the class activity for that day. Participants assigned to the treatment group would watch the same 3-minute animation, followed by a quiz, and an online demographic survey. Students could access the material (animation and/or activity quiz) for a short time period following the completion of the assignment. Participants' knowledge and retention would be tested during the midterm and final exam using instructor-approved questionnaire.

Moreover, participants from both groups are asked to volunteer for individual interviews that would help assess the activity and whether or not it affected participants' attitude toward learning the scientific concept.

This research protocol contains no foreseeable physical, psychological, social, or legal risks to participants.

To ensure participants anonymity and confidentiality, all identifiable marks (i.e. student name or ID number) will be removed prior to analysis. Interview participants are only identified through their assigned groups (control or experimental). Personal information that may lead to identification of students would not be asked prior, during, or after the interview. Demographic survey excludes any question that may jeopardize participants' anonymity or confidentiality. Research records will be kept confidential to the extent allowed by law.

Your participation in this research is voluntary and you are free to withdraw from participation at any time without suffering penalty or loss of benefits or services you may otherwise be entitled to.

If you have additional questions please contact me, Soha Sobhanian, at 714-900-3068, or email sohasobhanian@fullerton.edu, or contact faculty advisor, David Treagust, at +61 8 9266 7924, or email D.Treagust@curtin.edu.au. If you have additional concern or questions about your role as a research participant, you may contact Institute Review Board, at 657-278-7640 or email ndelrio@fullerton.edu.

I do not have any financial conflict of interest relating to results of this study.

I have carefully read the terms used in this consent form. By signing below, I agree that I am at least 18 years of age and agree to participate in this project.

Participant name: ___________________ Signature: ________________________

Date: ____________________________

## Appendix 5

Post-assessment questions used prior to assess students' level of comprehension following the intervention implementation

1) Which of the following statements is true about one of the ways ATP is utilized during the Calvin cycle?
   a) To 'fix' carbon molecules onto RuBP, forming 3-phosphoglycerate
   b) For the regeneration of RuBP at the last phase of the Calvin cycle
   c) To convert 1,3 bisphosphoglycerate to G3P
   d) To produce of NADPH from $NADP^+$
   e) Both a and b

2) Which of the following statements is true about the Calvin cycle?
   a) The enzyme Rubisco is essential for regeneration of RuBP molecule
   b) The enzyme Rubisco initiates the carbon fixation step of the Calvin cycle
   c) The $CO_2$ used in the Calvin cycle originated from light-dependent reaction of photosynthesis
   d) NADPH donates electron during the carbon fixation step of the Calvin cycle
   e) Both a and d

3) What molecule(s) produced during the light dependent reaction of photosynthesis is used during the Calvin cycle?
   a) ATP
   b) NADH
   c) ADP
   d) $NADP^+$
   e) Both a and b

4) What happens to the ADP and $NADP^+$ molecules that are produced during the Calvin cycle?
   a) Return to light-dependent reaction of photosynthesis
   b) Return to light-independent reaction of photosynthesis
   c) Utilized to form new glucose molecules
   d) Removed from the plant cell via stomata
   e) None of the above choices

## Appendix 6

Seventeen-point assessment originally used to assess second open-ended question

Question 2: Draw a diagram of the Calvin cycle. Label and describe in as much detail as possible
Response: A complete answer includes all the listed components:

1. Calvin cycle is drawn
2. Start with RuBP (arrow)
3. Addition of 1, 3, or 6 carbon dioxide (arrow)
4. Name of enzyme rubisco
5. Production of either 2, 6, or 12 of 3-phosphoglycerate
6. Use of 2, 6, or 12 ATP and conversion to ADP (arrow)
7. Production of 2, 6, or 12 of 1, 3 bisphosphate
8. Utilization of 2, 6, or 12 NADPH to NADP+ (arrow)
9. Production of 1, 2, (no number) G3P
10. Conversation of 2 (no number) G-3-P to glucose (or simply G-3-P leaves cycle)
11. Takes 6 cycles (or production of two G-3-P
12. Eventual conversation to Ribulose 1, 5-biphosphate (or mention of 5 glyceraldehyde 3-phosphate)
13. Utilization of 1, 3, or 6 ATP and production of ADP (arrow)
14. Conversion of ribulose 1,5-biphospahate to RuBP (arrow)
15. Labeling of 3 phases of carbon fixation, reduction, and rearrangement/regeneration
16. Number of ATP utilized
17. Number of NADPH utilized

Scale for question 2:

| | |
|---|---|
| 5 out of 5 | Student has drawn/labeled at least 14of the 17 items available |
| 4 out of 5 | Student has drawn/labeled at least 11 of the 17 items |
| 3 out of 5 | Student has drawn/labeled at least 9 of the available 17 items |
| 2 out of 5 | Student has drawn/labeled at least 6 of the 17 items |
| 1 out of 5 | Student has drawn/labeled at least 3 of the 17 items |
| 0 out of 5 | Student did not answer the question |

## Appendix 7

Table representing common mistakes presented in students' drawing.

| Comparison Group | 4_13 | 8_13 | 12_13 | 16_13 | 20_13 | 2_14 | 4_14 | 32_14 | 20_14 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| G-3-P final product of the cycle | 3 | 1 | 3 | 4 | 3 | | | | | 14 |
| Molecules involved but unclear how | 6 | 3 | 6 | 4 | 4 | 13 | 8 | 5 | 8 | 57 |
| Misunderstanding of cellular respiration vs. Calvin cycle | 4 | 10 | 4 | 4 | 2 | 5 | 5 | 3 | 3 | 40 |
| Assuming ADP and NADP+ and FADH+ become regenerated in the Calvin cycle | | | | | | | | | | |
| unsure about the number of ATP/high energy molecules used in the cycle | 6 | | 8 | 1 | 8 | 6 | 7 | | | 36 |
| misunderstanding of the generation and use of ATP and NADPH (light rxn) | | | | | | | | | | |
| Glucose as part of the cycle | | | | | | | | | | 0 |
| Visual imagery | | | | | | | | | | 0 |
| Confusion about rubisco | 5 | | | | 5 | | | | | 10 |
| No understanding of the Calvin cycle | 3 | | | | | | 1 | 5 | | 9 |
| High E. mole. as part of cycle | 2 | 1 | | 7 | 1 | 1 | | | 1 | 13 |
| Role of high-E mole. | 3 | | | 8 | | 5 | | 2 | | 18 |
| Identification of high-E mole. | 3 | 1 | | | 5 | 5 | | 1 | 2 | 17 |

| Treatment group | 2_13 | 6_13 | 10_13 | 14_13 | 18_13 | 14_14 | 10_14 | 12_14 | 16_14 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| G-3-P final product of the cycle | 3 | 4 | 3 | 1 | | | 1 | | 2 | 14 |
| Molecules involved but unclear how | 4 | | 2 | 4 | 1 | 4 | 9 | 4 | 4 | 32 |
| Misunderstanding of cellular respiration vs. Calvin cycle | 3 | 5 | 1 | 2 | 5 | | 4 | 3 | 1 | 24 |
| Assuming ADP and NADP+ and FADH+ become regenerated in the Calvin cycle | | | | | | | | | | |
| unsure about the number of ATP/high energy molecules used in the cycle | 2 | | 3 | 1 | 1 | | 1 | 1 | | 9 |
| misunderstanding of the generation and use of ATP and NADPH (light rxn) | | | | | | | | | | |
| Glucose as part of the cycle | | | | 2 | | | | | | 2 |
| Visual imagery | 2 | | | 1 | 3 | | | 5 | | 11 |
| Confusion about rubisco | | | | | 1 | | 2 | 1 | | 4 |
| No understanding of the Calvin cycle | 6 | 1 | | 1 | 2 | 10 | | | | 20 |
| High E. mole. as part of cycle | 2 | | | | 4 | | | | | 6 |
| Role of high-E mole. | 2 | 3 | | 1 | 7 | 2 | 8 | 6 | 2 | 31 |
| Identification of high-E mole. | | | 4 | | 5 | 2 | 5 | 6 | 5 | 27 |

## Appendix 8

The following tables represent students' responses to the pre-assessment questionnaire. The breakdown represents the four principle concepts that students will be assessed on.

## Appendix 8A

Reassessment questions with focus of carbon fixation phase of the Calvin cycle (3 questions)

Question 1. Where does carbon fixation occur in the plant cell?

| | No answer | chloroplast | mitochondria | stroma | cell wall | cytoplasm | ER | chlorophyll | inside the cell | plasma membrane | cytosol | Thylakoid membrane | leaf | unrelated | nucleus | vacuole | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 74 | 34 | 10 | 6 | 2 | 10 | 1 | 0 | 0 | 0 | 2 | 1 | 1 | 1 | 0 | 0 | 142 |
| Treatment | 74 | 19 | 13 | 11 | 3 | 7 | 0 | 3 | 1 | 4 | 4 | 1 | 1 | 0 | 1 | 1 | 143 |

Question 2. What is the final molecule produced at the end of carbon fixation?

| | no answer | glucose | oxygen | pyruvate | CO2 | ribose | sucrose | ATP | carbon | Carbon & ATP | Sugar & $O_2$ | CO2 & $H_2O$ | NADH & ATP | $O_2$ & NADPH | ATP, $CO_2$ & NAD | NADPH | G3P& $O_2$ | NADH | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 68 | 30 | 14 | 2 | 10 | 1 | 1 | 5 | 4 | 0 | 0 | 2 | 2 | 1 | 2 | 0 | 0 | 0 | 142 |
| Treatment | 75 | 12 | 18 | 3 | 17 | 0 | 1 | 8 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 143 |

Question 3. What enzyme catalyzes Calvin cycle reaction?

| | No answer | acetyl CoA | rubisco | Catalase | Protein | (ATP) synthase | cellulose | kinase | hexokinase | Phosphor fructokinase | ATP | stroma | chlorophyll | glucogan kinase | CAMP | ATP phosphoylase | coenzyme A | photosynthesis | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 113 | 1 | 4 | 2 | 2 | 2 | 1 | 7 | 0 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 142 |
| Treatment | 109 | 0 | 2 | 5 | 1 | 2 | 0 | 19 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 143 |

## Appendix 8B

Pre-assessment questions with focus of the location for production of high energy molecules (two questions).

Question 1. Where does the ATP that is used during the Calvin cycle come from?

| | No answer | sun or light | Krebs cycle | NAD | glycolysis | mitochondria | $CO_2$ | glucose | NADPH | Phosphorylation | ADP | phosphate | $H_2O$ | ETC | H2O &CO2 | Cell respiration | mole breakdown | carbon fixation | ADP Phosphorylation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 81 | 16 | 2 | 1 | 6 | 5 | 2 | 2 | 1 | 4 | 4 | 2 | 1 | 1 | 0 | 6 | 0 | 0 | 2 |
| Treatment | 80 | 20 | 3 | 0 | 6 | 3 | 0 | 5 | 0 | 4 | 2 | 0 | 0 | 1 | 1 | 2 | 1 | 2 | 8 |

| | GTP | ER | NAD & ADP | chloroplast | acetyl CoA | cytoplasm | enzyme | $H^+$ gradient | $NAD^+$ | total |
|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 142 |
| Treatment | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 143 |

Question 2. Where does the NADPH that is used during the Calvin cycle come from?

| | no answer | glycolysis | $NAD^+$ | Krebs cycle | Pyruvate oxidation | NADH | $NADP^+$ | ATP | Cell | Cellular respiration | Breakdown of molecule | ADP | light reaction | sun | cytoplasm | Carbon fixation | Electron carrier | mitochondria | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 109 | 5 | 6 | 4 | 1 | 1 | 4 | 4 | 1 | 0 | 0 | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 142 |
| Treatment | 110 | 5 | 6 | 5 | 2 | 2 | 4 | 2 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 3 | 0 | 1 | 143 |

## Appendix 8C

Pre-assessment questions with focus of the utilization of high-energy molecules (two questions).

Question 1. What function does ATP play in Calvin cycle?

| | no answer | oxygen | Provide E/ E to cycle | Rxn Energy/ keeps cycle going | make sugar | Start reaction | Power for carbon fixation | light to ATP | Catalyze reaction | donate phosphate | help enzyme | phosphorylation of pyruvate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 79 | 1 | 34 | 13 | 1 | 2 | 1 | 0 | 2 | 3 | 0 | 1 |
| Treatment | 82 | 0 | 32 | 12 | 2 | 0 | 0 | 1 | 4 | 1 | 1 | 0 |

| | Endothermic Rxn | Make NADPH | Coenzyme | Make ADP | Bind protein | Phosphoryl | Process $CO_2$ | Propel | Produce NADPH | Electron move Calvin cycle | total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 142 |
| Treatment | 0 | 0 | 0 | 3 | 0 | 1 | 1 | 1 | 1 | 1 | 143 |

Question 2. What function does NADPH play in Calvin cycle?

| | Endothermic Rxn | Make NADPH | Coenzyme | Make ADP | Bind protein | Phosphoryl | Process $CO_2$ | Propel | Produce NADPH | Electron move Calvin cycle | total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 142 |
| Treatment | 0 | 0 | 0 | 3 | 0 | 1 | 1 | 1 | 1 | 1 | 143 |

**Appendix 8D**

Reassessment questions with focus of general understanding of the Calvin cycle (two questions).
Question 1. What molecule(s) is/are recycled in Calvin cycle?

| | No answer | H2O | NADH | ATP | NADPH | oxygen | $CO_2$ | carbon | ADP | ATP & NADH | ADP & NADP | ATP, NADPH & NADH | $G_3P$ | $CO_2$ & $H_2O$ | Hydrogen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 86 | 3 | 2 | 6 | 7 | 3 | 5 | 5 | 3 | 5 | 1 | 1 | 1 | 2 | 2 |
| Treatment | 87 | 1 | 6 | 7 | 5 | 3 | 4 | 3 | 0 | 1 | 2 | 0 | 0 | 0 | 1 |

| | $O_2$ & $H_2O$ | Carbon & $O_2$ | Nitrogen & carbon | ATP & NADPH | Enzyme | Glucose | Glucose & $H_2O$ | Nitrogen | Acetyl CoA | ADP &NADPH | $CO_2$ & FADH | $NAD^+$ | $NAD^+$ & $CO_2$ | $CO_2$ & $O_2$ | RuBP | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 2 | 1 | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 142 |
| Treatment | 1 | 1 | 1 | 7 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 143 |

Question 2. How many “rotation” of Calvin cycle produce a single molecule of glucose?

| | no answer | one | two | three | Four | Six | Ten | Twelve | Total |
|---|---|---|---|---|---|---|---|---|---|
| Comparison | 94 | 10 | 26 | 3 | 1 | 5 | 1 | 2 | 142 |
| Treatment | 78 | 19 | 32 | 8 | 1 | 1 | 3 | 1 | 143 |

**Appendix 9**

Analysis of students' responses to question "explains the Calvin cycle in one sentence". Students' were assessed for four main elements.

| | Location | Reactants | Product | High-energy molecules |
|---|---|---|---|---|
| Exp_02_Sp13 | 5 | 4 | 10 | 4 |
| Exp_06_Sp13 | 8 | 5 | 11 | 4 |
| Exp_10_Sp13 | 11 | 10 | 13 | 4 |
| Exp_14_Sp13 | 10 | 9 | 16 | 7 |
| Exp_18_Sp13 | 7 | 9 | 10 | 3 |
| Exp_10_Sp14 | 7 | 5 | 13 | 2 |
| Exp_12_Sp14 | 9 | 7 | 14 | 0 |
| Exp_14_Sp14 | 7 | 5 | 13 | 2 |
| Exp_18_Sp14 | 4 | 4 | 6 | 2 |
| Total | 68 | 58 | 106 | 28 |

| | Location | Reactants | Product | High-energy molecules |
|---|---|---|---|---|
| Comp_04_Sp13 | 4 | 8 | 11 | 3 |
| Comp_08_Sp13 | 6 | 4 | 9 | 6 |
| Comp_12_Sp13 | 7 | 7 | 11 | 5 |
| Comp_16_Sp13 | 4 | 5 | 6 | 0 |
| Comp_20_Sp13 | 5 | 8 | 5 | 3 |
| Comp_02_Sp14 | 6 | 4 | 7 | 2 |
| Comp_04_Sp14 | 5 | 11 | 7 | 3 |
| Comp_20_Sp14 | 5 | 6 | 9 | 1 |
| Comp_32_Sp14 | 4 | 11 | 11 | 5 |
| | 46 | 64 | 76 | 28 |

## Appendix 10

Questions used to collect qualitative data from comparison (Q1-11) and treatment (Q 1-18).

Influence of multiple representation of information on students' learning process:

1. How helpful did you find the subtitles (available at the bottom of the animation) in your learning process?
2. How helpful did you find the subtitles (available at the bottom of the animation) in your understanding of the Calvin cycle?
3. Was the labeling on the animation (identifying different molecules and components) beneficial to your learning process or did you find it confusing?
4. What type(s) of information representation (narration/graphics/step through/subtitles) did you find most helpful in your learning process?

Students' learning styles and attitude toward multimedia implementation in classrooms

5. Do you consider yourself a visual learner (learn through image/graphic/written notes, or animation), auditory learner (learn through listening), Kinesthetic learner (learn through action) or a combination of the three? Explain.
6. In your opinion, what would be a more effective way to learn about the Calvin cycle: (you can choose more than one option)
    a) Reading the text and reviewing a diagram, treatment the Calvin cycle (text book)
    b) Review of the power points with diagrams and text (bulletin point style)
    c) Viewing a narrated version of the animation with subtitles and the detail animation
    d) Viewing a step-through version of the animation (no narration) with subtitles and detail graphic (treatment group)
7. Was animation and narration beneficial in helping you create a working model (a model to refer back to when answering questions regarding the concept) of the Calvin cycle? Please explain
8. How do you feel about implementation of multimedia in classroom?
9. What is your opinion about using multimedia as a learning tool in science classes?
10. Do you think animation, on its own, had any effect on your retention ability?
11. Any comments

Evaluation of the interactive activity quiz

12. Was interactive aspect of the activity quiz beneficial in addressing your questions about the Calvin cycle? (Treatment group only). Please explain.
13. You received two different feedback depending on your answer in the activity quiz:
    a) Correct answer: graphic combined with a written statement explain the answer
    b) Incorrect answer: reference to specific segment of the step-through animation

    Which one of the two did you find more useful/ helpful (option of receiving information as a statement combined with a diagraph or option of referencing the animation and extracting your own information)

14. Did you find the interactive nature of quiz difficult to follow (ex. immediate feedback, followed by animation review, and second try to answer the question)?
15. Would you prefer interactive activity quiz (immediate feedback after each question with the option to answer the question again) or traditional quiz (feedback to all questions at the end of the quiz and you have the option to repeat the quiz)?
16. Which version of information was more beneficial to you? Were subtitles useful?
    a) Narrated version with subtitles
    b) Step-through version with subtitles
17. What aspect of the activity did you find most helpful?
18. Any additional comments?

**Appendix 11**

Student questionnaire utilized during spring 2015 interview sessions to better assess the role of multimedia in students' comprehension and retention of the Calvin cycle process.

1. What did you notice in this video?
2. Were there any distinctive features of the video that interested you?
3. Was the concept discussed in the video new to you?
4. Was there anything different about the information provided in the video and your prior knowledge about the topic? Explain.
5. Did you find the animation helpful? If so, in what aspect?
6. Did you find the narration helpful? If so, in what aspect?
7. How would your understanding of the topic be different, if information was presented only as animation?
8. How would your understanding of the topic be different, if information was presented only as narration?
9. How was your interpretation of the topic affected when information was presented both as animation alongside narration?
10. How beneficial did you find the subtitles?
11. Please take a few minutes and draw/write out and talk about your understanding of the Calvin cycle.