

THE EFFECT OF TEACHER DESIGNED MULTIMEDIA ON STUDENT
COMPREHENSION AND RETENTION RATES WITHIN INTRODUCTORY COLLEGE
SCIENCE COURSES

by

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B.S., Kansas State University, 2001

M.S., Kansas State University, 2004

AN ABSTRACT OF A DISSERTATION

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Department of Curriculum & Instruction
College of Education

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Abstract

Compared to other nations, fewer American students are pursuing and completing degrees within the science, technology, engineering, and mathematics (STEM) fields. For the United States to remain competitive, the development of novel instructional techniques designed to reach students who might otherwise be lost from these majors is imperative.

This study examined the use of teacher designed multimedia within an introductory STEM course. Quantitative methods were used in a real classroom setting to examine the relationship between the use of multimedia and the amount of information students comprehended and retained when learning photosynthesis. Also, the relationship between the use of multimedia and the learning gains of female students within introductory STEM courses was examined, as their participation within the STEM fields has historically been low. Qualitative methods were employed to discern which multimedia features students and instructors found the most beneficial regarding the presentation of complex and abstract scientific concepts.

Using a quasi-experimental, design-based research approach, it was determined that the use of simple animations and corresponding narration increased student learning gains compared to the use of static pictures and text. This finding aligned well with theories regarding multimedia learning and its use of dual coding for reducing cognitive load. The value of multimedia for learning gains was greatest for females with lower prior knowledge levels, as defined by performance on a pre-test. However male students with low prior knowledge benefitted, although not to the same degree as females. In agreement with the fundamentals of constructivism, this finding supported the idea that basic schema construction is paramount for increasing comprehension. Results from the qualitative portion of the study indicated that students prefer multimedia over static text and pictures because: 1. Complex processes can unfold in motion while being described verbally 2. Schema construction is guided by a trusted source, and 3. Small chunks of information can be presented yet tied together in a larger sequence.

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Dedication

For Mom, the best role model a girl could have. Thank you.

Chapter 1 - Introduction

Overview

Over the past thirty years, the United States has experienced a decline in the number of students pursuing and completing science degrees at all levels (Astin, Parrott, Korn & Sax, 1997; Freeman, 2005). Because the U.S. employs nearly one-third of the world's scientific researchers and relies on the availability of new technological advancements to help support and maintain economic prosperity, the decline in science graduates could become a severe problem (Freeman, 2005, Volenec, Barbarick, Pierzynski, & Bergfeld, 2012). While some graduates will be needed to simply replace a generation of researchers who are quickly becoming eligible for retirement, many more will be needed to fill jobs that have yet to even be created considering the issues we are likely to face in the future.

But where will these scientists come from? In the year 2000, only 17% of all baccalaureate degrees granted in the U.S. were in science disciplines compared to a global average of 27%; even more startling is the fact that during this same time period 52% of all baccalaureate degrees granted in China were in science disciplines (NSF, 2004). Furthermore, in 1970, the U.S. graduated 30% of all tertiary level students in the areas of science, technology, engineering, and math (STEM); by 2002, that number had declined to fewer than 14% (Freeman, 2005). Unless this trend is reversed, there will not be enough scientists to fill the projected vacancies, leaving the United States in a vulnerable position in regards to economics, matters of national security, as well as a variety of issues related to human health (AAAS, 1990; Annetta, Cheng, & Holmes, 2010). For example, AAAS (1990) offers a sampling of issues that will require a sufficient supply of scientists and technological advancements:

Unchecked population growth, acid rain, shrinking tropical rain forests and other great sources of species diversity, pollution of the environment, disease, social strife, the extreme inequities in the distribution of the earth's wealth, the huge investment of human intellect and scarce resources in preparing for and conducting war, and the ominous shadow of nuclear holocaust (AAAS, 1990, p. xiii).

Traditionally, students majoring in and completing degrees in the STEM fields have been predominantly white and male; in addition, white males hold higher degrees within these fields (Banks, 2011; Falkenheim & Burrelli, 2012). However, given the shifting population demographics in the U.S. as well as changes in college enrollment, relying on this conventional pool of students to pursue and complete STEM degrees will no longer suffice if current and future vacancies are to be filled (NSF, 2010; Falkenheim & Burrelli, 2012). Instead, steps must be taken to encourage the participation of students who are currently underrepresented within the STEM fields. For example, the majority of students currently enrolled or planning to enroll in a four-year degree program at a U.S. college or university are female (NSF, 2010; Kahn, Brett, & Holmes, 2011; Kulterel-Konak, D'Allegro & Dickinson, 2011), and yet, females are underrepresented in the majority of STEM programs (Miller, Blessing & Schwartz, 2006; NSF, 2010; Kulterel-Konak et al., 2011; Falkenheim & Burrelli, 2012). Thus, a viable option for increasing the number of future scientists within the U.S. centers on increasing the participation of females.

Despite the need, however, changing the composition of students pursuing and completing STEM degrees is no small task. In fact, of all factors found to negatively correlate with a student's decision to pursue a STEM degree, being female ranked amongst the highest (Durante, 1989; Taskforce on Women, Minorities, and the Handicapped in Science and

Technology, 1989; Seymour, 1992; Astin & Astin, 1992; Hanson & Swann, 1993; Rosser, 1995; Miller & Pardo, 2000; Chang, 2002; Miller, 2004; Lehming & Frase, 2011). And while the reasons for this negative correlation have been adequately researched, few lasting solutions have been discovered. One reason is due to the notion that social pressures, which are placed on females quite early in their education, prevent them from seeking careers in the STEM fields and careers within these fields are often seen as unattractive options (Seymour, 1995; Miller et al., 2006; Papastergiou, 2008). Coinciding with this notion are the differential expectations of teachers and instructors in regards to students. Compared to female students, male students are still seen as being naturally more capable in the areas of math and science (Seymour, 1995; Chang, 2002). This hidden curriculum, which continues to fuel social reproduction both in and outside of the classroom, is difficult to change. While some progress has been made, focusing on other correlating factors is a more reasonable approach.

Contributing as much to the issue as gender is the factor of negative classroom experiences specifically due to mismatches occurring between pedagogy used and the learning preferences of females (Felder & Silverman, 1988; Astin & Astin, 1992; Rosser, 1995; Kultural-Konak et al., 2011). Not surprisingly, positive experiences in the classroom are highly correlated with a student's decision to continue in the STEM fields. Interestingly, the correlation is higher in regards to female students compared to males (Seymour, 1995). This finding is encouraging as much can be done to investigate and improve upon a student's classroom experience. It is here that researchers and educators alike have the ability to make timely progress in regards to increasing the number of females pursuing and completing STEM degrees. It is also the area that the majority of the research described in this dissertation addressed.

Grounded in educational theories such as hermeneutics, phenomenology and employing a constructivist framework, this research project investigated the benefits of using teacher-designed multimedia to increase the amount of information learned in an introductory biology course. Of specific interest was the relationship between the use of multimedia and student comprehension and retention of complex and abstract concepts. In addition, the relationship between the use of multimedia and female students was examined. The use of teacher-designed multimedia allowed for the development of novel instructional methodologies in accordance with the needs, abilities, and previous experiences of the students inhabiting a particular classroom when learning a particularly difficult concept.

Unlike commercially developed multimedia, designed for a broad population of students in a general classroom setting, multimedia developed by educators for their own students allows for a much more focused connection to be constructed between a student's existing knowledge base and wherever their potential may lie. Not only does this produce a much more effective pedagogical agent, but also highlights the critical role and enduring importance of the educator in education. As opposed to using media to remove or distance the educator from the student, this approach puts the focus squarely on the educator and empowers them to reach their students in ways that were perhaps previously underutilized.

This factor alone has the potential to separate multimedia from previously polarizing attempts regarding the use of technology in the classroom. Historically, administrators and program developers made decisions regarding the use of technology in classrooms; teachers were not typically consulted. As a result, educators have been chronicled as resisting its introduction (Schofield, 1995; Cuban, 2001). Technology was seen as a way to mechanize education, making

it more efficient and reducing human error. Educators were seen as technicians in need of direction and instruction designed by experts in other fields (Cuban, 1986).

Many forms of educational technology were developed from this viewpoint; for example, educational radio, film, television, educational broadcasts delivered from overhead airplanes staffed with “experts”, and to some extent commercially produced educational software (Cuban, 1986; Cajas, 2001; Click, A., 2012; Lamb, T.R., 2012). And yet none revolutionized education as it was once believed they would. A review of these failed attempts highlights an important lesson to be remembered when developing or implementing educational technology in the future: it must efficiently support, not detract from, the importance of the educator in the classroom. Any form of technology that does not enhance the ability of educators to efficiently reach his or her students will most likely not survive.

In light of this, it is important to note that multimedia, like all forms of technology, is simply a tool that can be used to enhance educators’ and learners’ experiences in the classroom. It is not the end-all, be-all solution for content delivery. Like any tool it must be designed correctly if it is to serve any real and meaningful purpose. In the case of educational multimedia, this means it must be grounded in theories related to learning, cognition, and the retention of information (Mayer, 2001). Poorly designed multimedia lacks this foundation and generally results in no - and sometimes even negative - learning gains. To be effective, multimedia must be designed to serve a very specific purpose and ideally a targeted student population. However, outside of a few theories regarding learning and cognition, very little information exists regarding the development and production of effective multimedia for use specifically within the college science classroom. A thorough review of the literature reflects this. Many inconsistencies and areas in need of further research exist.

Objectives

The shrinking number of scientists in total, and lack of diversity in particular, provided the impetus for this study. It is hypothesized that the development of novel pedagogical methods could help increase the number of students pursuing and completing STEM degrees by providing an alternative learning approach. In turn, this could help increase the number of scientists within the U.S.

This study examined the relationship between the use of multimedia, developed for a very targeted audience consisting of students enrolled in an introductory biology course, and performance on quizzes and an exam testing their understanding of a difficult concept, photosynthesis. Currently very little information exists regarding the design and production of multimedia for teaching complex and abstract scientific concepts. In addition, few studies have examined the use of teacher-designed multimedia within a real classroom setting. It is believed that the information produced from this project will help fill an obvious void within the literature while contributing practical advice to educators looking to expand their pedagogical options. To accomplish this, the following research questions will be examined:

1. Does the use of multimedia affect the amount of information students comprehend and retain when learning complex and abstract scientific concepts?
2. Is there a relationship between the use of multimedia, gender, and learning outcomes?
3. Which multimedia features influence the effectiveness of multimedia instruction?

Context

This study was conducted at Kansas State University, a land-grant institution located in Manhattan, Kansas. The focus of the study centered on students enrolled in an introductory

biology course, Principles of Biology, which is offered through the Division of Biology. In addition one particular topic, photosynthesis, was the sole focus.

Methods

The research questions posed will be examined using both quantitative and qualitative methods via a design-based research process. During this process, multiple iterations of a particular multimedia module will be produced and used within several sections of an introductory biology course. Both quantitative and qualitative data will be collected and analyzed after each iteration with the intent of using the information to improve future iterations of the multimedia module. While quantitative statistics will provide information about the relationship between the use of multimedia and student-learning gains, qualitative research methods will allow for additional insight to be gathered regarding multimedia features believed to be the most helpful and why. Thus, by employing both methodologies, a deeper understanding of the relationship between the use of multimedia and improvements in students' comprehension and retention of complex and abstract scientific concepts can be attained.

In regards to the quantitative portion of the design-based research process, several statistical analyses will be performed. Beginning with the selection of participating course sections, measures of central tendency will be performed to insure that the sections chosen to participate in the study represent a uniform distribution of all students enrolled in the course. While no randomization will occur as entire course sections will be placed in either experimental or control sections, the heterogeneity of students within each section will alleviate some concern related to this quasi-experimental design. Once treatment groups are established and a pre-test given to measure the base knowledge of students, the experimental group will receive a multimedia module covering the basics of photosynthesis while the control group will receive a

text document consisting of the narration as well as static images extracted from the multimedia module. A post-test and a daily online quiz will then be administered to both the experimental and control groups to assess the differential learning gains as related to the comprehension of the topic. In addition, questions embedded in a unit exam will be used to assess retention.

Descriptive statistics as well as ANOVA will be performed to evaluate the mean differences between the experimental and control groups regarding pre-test, post-test, daily online quiz, and unit exam scores.

Coinciding with the use of quantitative statistics to measure the effectiveness of multimedia for all students when learning complex and abstract biological concepts, additional analyses will be performed to determine multimedia's value as related to the learning gains of female students. These include comparing the mean scores of post-tests, daily online quiz scores, and unit exam scores between male and female students within experimental sections. Descriptive statistics and ANOVAs will be used to measure the differential learning gains between males and females within these sections.

In addition to the quantitative research to be performed, qualitative research methods will be used to assess the value of certain multimedia features as well as gain a deeper understanding of its perceived value in relation to the teaching and learning of complex biological concepts. To accomplish this, focus groups consisting of faculty, graduate teaching assistants, and undergraduate practicum students will be assembled and information gathered via a questionnaire. Information from these questionnaires will be analyzed for emerging themes; these themes will then be used to improve future iterations of the multimedia module. Seeking feedback from those directly involved with students on a daily basis is critical to the success of

multimedia development. This particular component has been overlooked by many previous studies and is believed to provide much needed information.

Limitations and Delimitations

The limitations of this study are related to the inherent complexities that come with conducting educational research in real classroom settings. For example, the level of enthusiasm and support received from faculty and course coordinators varied, as did the number of students choosing to participate in the study. These variations impacted the results of the study and will be further discussed in chapters 4 and 5. It is important to note, however, that even though these limitations represented factors beyond the control of the researcher, the approach tested in this study still made measurable contributions to learning despite being tested in less than ideal situations.

The delimitations of the study are related to the research setting, experimental design and data collection. In regards to the setting, research was only conducted at one particular university, Kansas State University. Furthermore, only one particular course, Principles of Biology, was used. And within this course, a very specific topic, photosynthesis, was the focus of the research. And while participants in the study did represent a rather large and heterogeneous sample of students at this university, the study only lasted for three academic semesters.

In regards to the experimental design and data collection, entire sections of the course were assigned to treatment groups as opposed to randomly assigning students contained therein; thus, the research design was quasi-experimental. Also, participation in the study was voluntary. Because of this, students choosing to participate may have been more motivated students in the first place.

In light of these limitations and delimitations, it is important to state that the overarching purpose of this research project was not to generalize the results to all introductory STEM courses. Instead, it was hoped that the results of this study could help other educators decide how best to design and use multimedia within their own classrooms as well as provide insight on expected benefits from the use of this technology.

Summary

As discussed in this chapter, the United States will need to attract and retain many additional students within STEM fields to remain economically competitive. Unfortunately, as the need for scientists is increasing, the number of students choosing to pursue the required degrees is decreasing. Relying on the traditional pool of white male students is no longer sufficient. Demographics are changing on a national level and college enrollments reflect this. For example, females now outnumber males at four-year institutions and earn the majority of baccalaureate degrees (NSF, 2010; Kulterel-Konak, D'Allegro & Dickinson, 2011; Kahn et al., 2011). Thus, a viable option for increasing the number of graduates within STEM fields is to increase the number of females in these disciplines. But, as demographics change, so too must the pedagogical methods used. Females face a number of challenges when pursuing STEM degrees, but encountering ineffective instructional approaches should not be one. Consequently, the creation of new pedagogical agents specifically designed to increase the learning gains of all students within STEM disciplines, but especially females, is sorely needed.

It is believed that the use of multimedia that harnesses the power of technology yet is grounded in current theories on learning is an option worthy of consideration. However, creating multimedia for the express purpose of increasing student-learning gains within the STEM fields is novel; very little information exists regarding its production, delivery, and use. The aim of

this proposed research project is to provide empirically based evidence regarding the value of using multimedia for this very purpose. The results from this project will not only fill a large hole in the literature, but will also offer practical information to other educators wishing to develop multimedia for use in their own classroom.

Chapter 2 - Review of Literature

Enrollment Trends within STEM Disciplines

Studies of undergraduates pursuing and completing degrees in science, technology, engineering and math highlight an alarming trend: there continues to be a loss of students from the STEM pipeline (Taskforce on Women, Minorities, and the Handicapped in Science and Technology, 1989; Seymour, 1992; Papastergiou, 2008; Lehming & Frase, 2011; Volenec et al., 2012). According to Astin and Astin (1992), “the science pipeline is an indicator that defines when and where students enter and leave the sciences” (p. 10). Studies reviewing long spans of time, valued for providing more accurate portrayals of national trends, indicate that this has been and continues to be a very critical issue. According to Frazier-Kouassi, Malanchuk, Shure, Burkam, Guirin, Hollenshead, Lews, Soellner-Younce, Neal and Davis (1992), “Drawing conclusions about trends based on data from any two to three year period can be quite misleading. To obtain a valid picture of trends, it is necessary to look at the relative enrollments of men and women across a long span of years” (p. 3). Thus, studies such as the one conducted by Astin, Parrott, Korn, and Sax (1997) assessing student tendencies from 1966-1996 provides invaluable information. According to Astin et al. (1997) “trends in undergraduate education reveal a steady decline in student interest for enrolling in science and math courses over the last thirty years” (p. 1). This same statistic is discussed by Chang (2002), who examined enrollment trends among college students in the STEM fields. And even when students do major in STEM subjects the retention rates are low compared to other academic majors as the number of seniors graduating with STEM degrees is significantly less than the amount of freshman entering. For example, Astin and Astin (1992) found that “Between freshman and senior years, the percent of

students majoring in the fields of natural science, mathematics, and engineering declined from 28.7% to 17.4%, a 40% relative decline” (p. 1). These statistics are consistent with findings from additional researchers who found that approximately half of all U.S. students entering college with the intent to major in a STEM field switch majors within the first two years (Center for Institutional Data Exchange and Analysis, 2000; Hurtado, Cabrera, Lin, Arellano, & Espinosa, 2008).

Having fewer students enter and graduate with STEM degrees could present threats to the United States’ economic, human health, and national security interests to name a few. The continuing decline in STEM graduates “may lead to a shortage of skilled professionals that undermines the U.S. economy” (Andrade, Stigall, Kappus, Ruddock & Oburn, 2002, p. 1). According to Hurtado et al. (2008), “a declining cadre of skilled workers for scientific fields portends a decline in U.S. global competitiveness and the exportation of high-skilled jobs to other countries” (p. 1).

Due to increasingly competitive global economies, “analysts have determined that profound changes in the U.S. educational system will be required to ensure future prosperity” (Andrade et al., 2002, p. 3). Andrade et al. (2002) also emphasize that employers are seeking employees with certain skill sets such as the ability to think abstractly and conceptually as these capabilities are the ones that will most directly apply to the “complex, real-world problems facing our modern economy” and that “most of these problems and their potential solutions involve the use of scientific and technical knowledge” (p. 3). According to Marshall and Tucker (1992), “The key to both productivity and competitiveness is the skills of our people and our capacity to use highly educated and trained people to maximum advantage in the workplace” (p. xvi). As highlighted by Hurtado et al. (2008), this was the foundation for the passage of the

2007 America Competes Act, which aimed at strengthening science-related education and programs. However, despite the national recognition the issue is receiving, Hurtado et al. (2008) state that much more research is needed in order to help us understand and potentially reverse the trend. Thus, while the causes and solutions to STEM retention and completion are not completely clear, many agree upon the notion that more students will be needed to fill the STEM roles in the very near future if the U.S. is to remain competitive.

But where will the increase in STEM majors and eventually STEM professionals come from and how many will be needed? According to Chang (2002) who reviewed findings from the National Science Board regarding science and engineering indicators, “Over the next 10 years, the United States will need to train and educate an additional 1.9 million workers in the sciences” (p. 2). Relying on the traditional pool of students, the majority of which are male, might not be a viable long-term option considering the shifting demographic trends in the U.S. Given the projected population change scenarios and the impact that these could have on the ability of the U.S. to remain competitive in a global economy, increasing enrollment of historically underrepresented groups such as females within STEM majors provides a potential solution (Rosser, 1995; Andrade et al., 2002). This is in agreement with Chang (2002) who stated that “the participation and persistence rates of women in the STEM fields are lower than those of males” and that “increased involvement of underrepresented groups, especially females [in the STEM fields] is essential for meeting the demands” (p. 2). Dr. James Banks also highlighted this point during his presentation at Kansas State University on October 7, 2011. According to Dr. Banks, greater strides must be taken to improve education for underrepresented groups if the U.S. is to keep pace with other countries (Banks, 2011).

Despite the need to increase female participation within the STEM disciplines, a larger number of degrees that are conferred within these fields are still given to males. According to Kulturel-Konak, D'Allegro, and Dickinson (2011), "the proportion of earned degrees for women in some STEM fields continues to lag behind male baccalaureate completions" (p. 9). This fact remains despite the gains females have made regarding baccalaureate completion rates in general. According to Kulturel-Konak et al. (2011), 230,000 more baccalaureate degrees were conferred to females compared to males in 2008 (p. 9). And yet, higher education continues to experience a lack of female participation in and completion of STEM degrees (Bank, 2007, NSF, 2010, Kulturel-Konak et al., 2011). The lack of female participation within STEM disciplines becomes even more pronounced when looking at masters and doctoral degree completion rates. For example, data compiled by the NSF in 2006 revealed that men were more than twice as likely to hold a doctorate degree within a STEM discipline (NSF Division of Science Resources Statistics, 2006).

In March of 2012, the National Science Foundation (NSF) released multiple data sets regarding the most current status of females pursuing and graduating from the STEM disciplines as well as the number of females currently employed within STEM fields. A summary of these statistics revealed that, compared with their proportions in the U.S. population, women continue to be underrepresented (Falkenheim & Burrelli, 2012). Specifically it was found that "white men who are not of Hispanic origin account for half of the students receiving STEM degrees and working within the STEM fields, white women who are not of Hispanic origin account for 25%, and minority women account for 10% while minority men account for 15%" (Falkenheim & Burrelli, 2012, p. 1). In addition, Falkenheim & Burrelli (2012) found that male scientists and

engineers employed within STEM fields have higher levels of education than their female counterparts.

Factors Contributing to Enrollment Trends

In regards to recruiting and retaining students within a STEM discipline, many factors have been examined in an effort to discern which ones have the highest predictive value. Of those factors examined, being female and having negative classroom experiences within STEM courses have been found to negatively correlate with a student's decision to pursue and graduate from a STEM discipline and rank high amongst all factors leading to attrition (Durante, 1989; Taskforce on Women, Minorities, and the Handicapped in Science and Technology, 1989; Seymour, 1992; Astin and Astin, 1992; Hanson and Swann, 1993; Rosser, 1995; Miller and Pardo, 2000; Chang, 2002; Miller, 2004; Lehming & Frase, 2011). This is unfortunate considering the need to tap into underrepresented groups in order to fill projected STEM deficits. However, the fact that classroom experience contributes greatly to a student's decision to pursue and complete a STEM degree provides an opportunity, via research grounded in educational theory and practice, to potentially increase the number of females and minorities. To do so, however, it is necessary to examine the factors contributing to these underrepresented groups' disinterest in the STEM disciplines.

Gender

A review of the literature concerning lack of female participation within the STEM disciplines yields the conclusion that, in general, females do not see STEM courses nor the jobs available within STEM fields as appealing as do their male counterparts (Taskforce on Women, Minorities, and the Handicapped in Science and Technology, 1989; Seymour, 1992; Rosser, 1995; Farrell, 2002; Papastergiou, 2008; Kulturel-Konak et al., 2011). In addition, females

generally lack the confidence needed to successfully complete the demands of a STEM course and do not see the relevancy of the material taught within STEM courses to their daily lives (Chang, 2002; Papastergiou, 2008). Compounding these issues is the fact that, “many women lack the academic preparation which is necessary to pursue scientific fields in college” (Astin & Astin, 1992, p. 17) which may be a factor of teachers, specifically high school teachers, having “differential expectations for males and females in mathematics and science” (Seymour, 1995, p. 3).

For many females, STEM disciplines are believed to be highly competitive. The culture is perceived to be male-dominated and highly analytical which does not fit with their perceived strengths and abilities (Chang, 2002, Farrell, 2002, Papastergiou, 2008; Kulterel-Konak et al., 2011). According to Farrell (2002), the technical nature of STEM subjects does not suggest life skills or creative thinking and communication which are indicated by most females as being important when choosing a major and eventually a career. In addition, Farrell (2002) indicates that STEM fields have failed to highlight the social value and relevance of the subject material being taught. This is consistent with data reported by Seymour (1992, 1995), who found the image of scientific careers does not appeal to female students’ orientation towards helping others.

Contributing to the lack of confidence females experience within the STEM disciplines are factors such as traditional gender roles which start very early in school, differential treatment by instructors within high school and college, and the misconceptions between effort and ability. According to Seymour (1995), “disparities in [science] classroom interactions exist... males consistently receive more attention, praise, critical feedback, and support for assertiveness while the learning experiences of females are more passive, less demanding, and less experiential” (p.

3). Over time, these disparities lead females to believe that STEM subjects are more for males. This belief is encouraged by gender-based socialization, which originates in the social milieu beyond school and the societal expectations that exist for males and females (Seymour, 1995, p. 3; Hallstrom and Gyberg, 2009). The notion of societal pressures and how they ultimately translate into career choices is perhaps best explained by Michel Foucault. Foucault believed that the human subject is a medium for his or her specific socio-cultural context rather than an entity in itself and that an individual's actions are always a response to the relation between an experienced-based disposition and unique surroundings (1972).

Another contributing factor is that “teachers attribute a female’s success in mathematics and science to effort and a failure to a lack of ability, while the reverse is true among males” (Seymour, 1995, p. 3). This is consistent with findings by Tobias (1990) who found that negative self-perceptions expressed by females during college, in regards to their experiences with STEM courses, actually developed late during their childhood and substantially during their adolescence and those who left STEM disciplines cited their own inadequacies as the cause. Contributing to this is the lowered expectations many STEM instructors report having for female students, which, according to Chang (2002), “hinders women from participating” (p. 2).

In addition to encountering discouraging environments, some of the current instructional methods employed within STEM disciplines deter females from participating in and pursuing additional STEM courses (Felder & Silverman, 1988; Astin & Astin, 1992; Rosser, 1995; Kulteral-Konak et al., 2011). For example, according to Astin and Astin (1992),

Compared to faculty in other fields, science faculty use more hierarchical and authoritarian approaches in the classroom and are less likely to be student-centered in their pedagogy. Faculty are also more likely to lecture, to use multiple-choice exams,

and to feel that the quality of their students is poor. They are less interested in the student's personal development and less concerned with society's ills and problems than non-science faculty (p. 6).

The result of these mismatches between the pedagogy and methodologies currently employed in many college science classrooms and the learning preferences of females no doubt has an effect on the number wanting to pursue STEM disciplines (Felder & Silverman, 1988, Rosser, 1995; Kulteral-Konak et al., 2011). As Astin and Astin (1992) state, "the number of students who find science interesting seems to shrink as students progress through our educational system" (p. 11). This is congruent with an earlier study by Yager and Penick (1986) who concluded:

The more years students enroll in science courses, the less they like it. Obviously if one of our goals is for students to enjoy science and feel successful at it, we should quit teaching science in the third grade. Or, perhaps we should try teaching it differently (p. 360).

Teaching STEM subjects differently may prove especially beneficial for females. According to Rosser (1995) and Kulteral-Konak et al. (2011), many female students fail to thrive in introductory STEM courses because of a barrier that separates them from the information being presented by the instructor. "That invisible barrier may be due to teaching methods which favor one or two learning styles, ignoring the ones that women tend to prefer" (p. 10). This statement is in agreement with work performed by Tindal and Hamil (2003) who found that typical STEM courses are exceedingly competitive and fail to accommodate all learning styles.

The term "learning styles" refers to an individual's preferred method for perceiving and transforming his or her learning experiences (Lachenmayer, 1997). Thus, learning is not only defined by the type of information being delivered, but also the method in which it is delivered

and what the learner is able to do with the information once it is received. A lack of compatibility between the instructional methods used to deliver information and the preferred learning style of students diminishes academic success (Lachenmayer, 1997; Kulterel-Konak et al., 2011).

In a survey conducted by Philbin, Meier, Huffman and Boverie (1995) which examined pedagogical mismatches between female students and delivery of information within an introductory STEM course, one female respondent was quoted as saying, “I felt like I was talked at, no transfer of knowledge, really, just words without meaning spoken” (p. 491). While females may adapt to this type of instruction, they do not seem to thrive. When a student fails to thrive in a particular learning environment, they typically find other academic options to pursue. In fact, a study performed by Amany (2001) found that one of the main factors correlating highly with a student’s decision to pursue and complete any academic degree was the compatibility of the learning styles. And while accommodating every particular type of learning style is not feasible, Kulterel-Konak et al. (2011) highlight the need to incorporate more of a variety of instructional methods in an effort to offer something for everyone. “It is clear that the use of a variety of teaching techniques will provide the most success in appealing to the broadest range of student learning styles” (Kulterel-Konak et al., 2011, p. 10). STEM courses are particularly noted as traditionally relying on just a handful of instructional methods to deliver course content (Kulterel-Konak et al. 2011). The majority of these methods rely on the presentation of information using “inductive reasoning, theory, logic, and research” (Kulterel-Konak et al., 2011, p. 10). Work performed by Philbin et al. (1995) showed that males embrace this format of instruction while females preferred a different format, one that emphasized the organization of information and highlighted concrete connections between concepts. This finding agrees with

work by Lachenmayer (1997) who found that females excel when instructional strategies present concrete connections first and once these connections are clear, females are as comfortable with abstraction and ambiguity as their male counterparts. According to Kulteral-Konak et al. (2011), “females identify more and perform better with an instructor who facilitates this style of teaching and learning” (p. 10). Thus, the facilitation of learning is not simply the “transmission of knowledge from teacher to student” but rather allows the individual learner to create meaning for themselves out of the information being presented (p. 10).

But, how does one begin to make abstract concepts more concrete? According to Baker, Matulich, and Papp (2007), one of the better ways to address this issue is with the use of different pedagogical techniques that harness the power of technology. But simply stating that technology is useful is not much help either as many forms of technology exist. Thus, the statement by Baker et al. (2007), that “to be engaging and effective, a course must use multimedia” (p. 29) provides direction and clarity. This statement is in agreement with other authors who support the use of multimedia within introductory STEM courses as a method for reaching more female students. One reason for this is that multimedia has the power to make abstract concepts more concrete (Williams & Abraham, 1995; Sanger, Brecheisen, & Hynek, 2001; Stith, 2004; Steele & Aubusson, 2004; Dori & Belcher, 2005; Yarden & Yarden, 2009). Kulteral-Konack et al. (2011), in reference to learning styles and gender differences stated, “females score higher in the concrete learning mode whereas males score higher on the abstract conceptualization side of the continuum” (p. 11). Thus, the idea of using multimedia within STEM courses to help students make concrete connections when studying complex and abstract material is certainly viable. And, if multimedia truly does have the ability to facilitate learning in ways that are especially helpful for female students, it is possible that their overall experiences

within STEM courses might improve. As discussed in the next section, improving the overall classroom experience for all, but especially females, is of utmost importance for attracting and retaining students within the STEM disciplines. Of the factors contributing to the decline in STEM graduates, improving the classroom experience by tailoring instruction to preferred female learning styles is one of the few that can be controlled and improved upon.

Classroom Experience

Many studies have indicated that beyond gender, performance in the college science classroom was the most important variable in explaining student retention within the STEM disciplines (Tobias, 1990; Hanson & Swann, 1993; Andrade et al., 2002). According to Andrade et al. (2002), “While some attrition may be attributed to typical student behavior as they explore their career objectives, the classroom experiences students have will certainly drive their decisions about continuing in STEM majors” (p. 16). Holding all variables constant, the attrition rates within STEM majors are much higher than attrition rates within other majors (Andrade et al., 2002). And while research on retention has typically focused on demographic and socioeconomic factors, additional research in retention has begun to examine students’ formal and informal experiences at an institution such as the quality of their academic experience (Ruddock, Hanson, & Moss, 1999). According to Tobias (1990), “the major problem is the hemorrhaging of talent [from STEM courses] through the college years, especially after the experience of freshman courses” (p. 11). Tobias (1990) also discovered that in addition to the factors already working against women before they ever enroll in a college science course is the actual experience they have within the college science classroom itself. As described by Tobias (1990), many of the problems female students face in science education begins during their first college science class.

Of particular interest for Tobias (1990) are students labeled as “second tier”. This tier applies to many female students based upon their characteristics. When discussing the second tier, it is critical to emphasize that these students are not second rate. Second tier simply refers to the fact that these students “may have different learning styles, different expectations, different degrees of discipline, and different kinds of minds” (Tobias, 1990, p. 16). According to Astin and Astin (1992), Tobias’ work regarding retention of these students is important for several reasons. First of all, “students from the first tier are curriculum proof and will most likely succeed no matter what their experiences are in science classrooms” (p. 20). Pursuing second tier students who have “an aptitude for science and varying degrees of interest in science is important. Keeping students with high aptitude and high interest in science is not enough to meet the increased need for scientists in the future” (Astin & Astin, 1992, p. 20).

According to Tobias (1990), many of the students in the second tier have been discouraged from pursuing STEM disciplines because of their negative experiences in introductory college science courses. In response to this idea presented by Tobias (1990), Astin and Astin (1992) state, “if science education were to be restructured or reconfigured, many of these students would continue to pursue undergraduate science majors” (p. 20). Of utmost need of restructuring is the curriculum and method of instruction used in the science classroom (Tobias, 1990; Astin & Astin, 1992). Current introductory science courses are “designed to weed out all but those who are in the top tier” (Astin & Astin, 1992, p. 20). In addition, Astin and Astin (1992) state that, “science classes are extremely competitive, which proves to be intimidating for the majority of students who enter science courses” (p. 20). Students who do not thrive in “unapologetically competitive, selective, and intimidating environments of college introductory courses” often perceive that there is no place for them in science. This hidden

curriculum, which indicates to students that if they are not like the scientists teaching their courses then science perhaps isn't for them, offers an explanation as to why women continue to be underrepresented in STEM disciplines. As mentioned in the previous sections, these characteristics are not highly valued by women. "From this perspective, the low representation of women as well as racial and ethnic minorities in science may not be the result of social discrimination per se, but of too narrow a vision of what kinds of attributes, behaviors, and lifestyles the true scientist displays" (Tobias, 1990, p. 14).

Second tier students can also feel alienated by the common learning methodologies employed in most STEM courses. For example, much of the learning students are expected to do within these courses comes from reading their textbooks, listening to lectures where terms are defined but relevancy is lacking, and solving problems using methods defined by the instructor (Tobias, 1990). When interviewing a second tier female student who had experienced such alienation, Tobias (1990) notes that the student was particularly disappointed with the way in which the instructor taught the course. According to Tobias (1990), the student is quoted as saying, "He [the instructor] was not particularly good at explaining why he did what he did to solve the problems, nor did he have any real patience for people who wanted explanations" (p. 17). For first tier students, this style of teaching is adequate; after all, first tier students are generally curriculum-proof. But for second-tier students, especially women, this style of teaching and learning may prove to be the last straw when considering the additional factors that are already working against them such as lack of interest and relevancy as well as a deficit in basic science knowledge due to potentially poor instruction received during high school.

Refining Pedagogical Approaches in STEM Disciplines

In light of the low science literacy levels within the United States, and the factors known to be associated with STEM avoidance, many attempts at science education reform have been proposed and enacted. A metaphor used to describe these attempts and the characteristics that they have generally shared was made by Marsh and Odden (1991) who likened science education reform to ocean waves. Some of these waves brought momentum to the area of student enrollment and completion of STEM courses at both the high school and collegiate level. Even more brought awareness and inertia into the field of curriculum reform, including advocacy of the use of technology to improve learning (Tobin, Tippins, & Gallard, 1994). When discussing the improvements needed to increase learning, Tobin et al. (1994) specifically state that improvements are needed to “allow students to learn science as a process” and “emphasize the understanding of science concepts” (p. 46). They continue by contrasting these recommendations with the traditional methods still used to instruct students in the sciences at all levels. According to Tobin et al. (1994), “traditional approaches in science classes emphasize the learning of facts and memorization without necessarily providing an understanding to students” (p. 46).

When thinking of ways to move past the traditional approaches used in science education, one of the first issues in need of consideration is the theoretical framework that will be employed to ground future attempts at educational improvements. As described by Tobin et al. (1994), traditional approaches that rely on the learning, and sometimes even the memorization of facts, are not effective for fostering the true understanding of scientific concepts. Separating the “knower from the known” has unfortunately been a central tenet in traditional science education methodologies (Tobin et al., 1994, p. 46). Simply thinking of the mind as an empty vessel, capable of being filled with and retaining facts that have little to no context for the learner, is not

an effective approach. It is possible that this widespread positivistic approach to scientific education, which was used heavily in the past and is sometimes used in the present, might be contributing to the overall low scientific literacy rates within the United States.

In stark contrast to the traditional frameworks used in science curriculums, the theoretical framework known as constructivism posits that, “knowledge exists only in the minds of cognizing beings” (Tobin et al., 1994, p. 47). Furthermore, Tobin et al. (1994) state, “objectivity, as it has been envisioned traditionally is not possible. The categories of the mind, which are shaped by human experience and mediated by a sociocultural milieu, make no claim to represent the universe in a real way” (p. 47). Thus, what is seen as an undisputable and clear scientific idea to one learner may appear as complete mystery to the next. This notion, that ideas and concepts appear differently to each learner based on their prior experiences, is key for designing more effective methodologies for the STEM fields.

Hermeneutics, Phenomenology, and Constructivism

Offering insight into the development of effective methodologies to address the issues discussed thus far are three philosophies: phenomenology, hermeneutics, and constructivism. Educational research, especially within STEM subjects, grounded in these philosophies aims to understand the background and experiences of the students inhabiting STEM courses before ever attempting to change the curriculum. This is a key piece missing from many previous attempts at improving the STEM curriculum for underrepresented students.

While the linking of phenomenology, hermeneutics, and constructivism is understandably odd as the three philosophies are typically used to describe and understand different areas of the human condition, when linked together to describe the reasons why the current pedagogy used within STEM courses is not adequate for reaching the majority of underrepresented students the

synergistic effect is powerful. Tobin et al. (1994) express the connection between these three philosophies quite eloquently when they state, “any study of teaching and learning should focus not only on the manner in which an individual attempts to make sense of a phenomenon, but also on the mediation of meaning” (p. 47). This sentence alone highlights the critical connection between the philosophies of hermeneutics and phenomenology and the use of constructivism as both a philosophy and a theoretical framework.

Traditionally, phenomenology and hermeneutics have been used to describe the different interpretations individuals may develop when studying literary texts or artistic works (Linge, 1976; Teigas, 1995). And while the use of the word “text” has traditionally referred to ancient texts, according to Heelen, “the word ‘text’ can refer to both information and its meaning and content” (as cited by Silverman & Ihde, 1985, p. 45). Working off of this interpretation, ‘text’ can refer to any information presented to learners, whether it is in a written, oral, kinesthetic, or visual format. In much the same way that ancient texts mean different things to different people, the same holds true for the understanding and interpretation of complex scientific ideas. If one has a certain level of pre-understanding, which is influenced by his or her environment and culture, and has constructed a solid framework for interpreting new ideas, they are more likely to gain a higher level of understanding when presented with complex scientific ideas and the relevancy of these complex ideas will be self-evident. However, if one lacks this framework, the information presented in science courses will never amount to anything more than random facts that must be memorized and the constant questioning of “what does this have to do with me” will never be answered.

When students cannot see the application or use of the information being presented, they tend to rely on the memorization of facts in an effort to “get by”. Ricoeur warns that,

“understanding is not concerned with grasping a fact but with apprehending a possibility of being” (as cited by Thompson, 1981, p. 56). If facts have no context, sense, or relation to the being of a learner, they are nothing more than random bits of information incapable of being strung together to make meaning. This is a central problem with traditional teaching methodologies within STEM courses, according to Tobin et al. (1994). As Ricoeur states, “to understand a text is not to find a lifeless sense which is contained therein, but to unfold the possibility of being indicated by the text” (as cited by Thompson, 1981, p. 56). Thus, learners must be able to go beyond facts and find the meaning in a lesson as it personally applies to them. This is a necessary piece in bridging the gulf that exists between themselves and whatever learning goal might lie in their distance.

These statements by Ricoeur are in agreement with Tobin et al. (1994), specifically those regarding why scientific facts and knowledge cannot simply be handed down from instructor to learner as though they were tangible items being passed from one person to the next. The role of the educator is not to provide a lossless transfer of information. Instead, the role of the educator is mediating the gulf that exists between where a learner currently resides and where they need to be and have the potential to be. This requires a considerable amount of effort from both the learner and educator as they must construct the meaning of information and its application together. Oftentimes, this is where problems arise as many learners do not possess adequate background knowledge to accomplish this goal. A lack of background knowledge can stem from a variety of factors. From a phenomenological standpoint, it is possible that if the learner’s past experience with the subject was negative or the subject didn’t seem applicable to them personally or culturally, they are less likely to put in the effort required to understand, interpret, and extract real meaning. According to Linge (1976), “prejudices and distortions block valid understanding

and is precisely what the interpreter must transcend” (p. xv). To do so, Gadamer states “one must extricate himself from the immediate entanglements of history and the prejudices that come with that entanglement” (as cited by Linge, 1976, p. xv). But, like Gadamer, one wonders how students can accomplish this. How can they forget who they are, momentarily, in order to understand a concept that has perhaps alienated them in the past? What if the “blocking of knowledge” is due to a biological factor like sex or race, which has defined them from the very first moment of their existence? Can a learner just uncouple him or herself from this? No. Nor should they. Instead, the creator or author of the text must take into account a “knower’s boundness” and design effective lessons from where the learner currently resides, considering the learner as a whole person complete with unique and messy experiences (Linge, 1976, p. xv). The reason for this, Gadamer eludes, is that a learner’s current understanding of a concept is rooted in their past understanding of a concept which is rooted in their unique experiences. In fact, according to Gadamer, this is the “hermeneutical situation” (as cited by Linge, 1976, p. xv; Thompson, 1981, p. 106). Just supplying educational material, texts, and lectures or “objects” as Gadamer states, is not enough; when the “interpreter’s situation is neglected”, facts lack context, and messages lack relation (as cited by Linge, 1976, p. xii).

To understanding the philosophical side of a being, phenomenology and hermeneutics provide insight into the lack of diversity within science; they even help explain why fewer women pursue STEM disciplines. As previously mentioned, a learner’s relation to a subject is intertwined “in the interior of the historical connection, mediated by diverse social institutions, social roles, and collectivities (groups, classes, nations, cultural traditions)” (as cited by Thompson, 1981, p. 108). For many women, STEM disciplines fail to connect with their values, past experiences, and even learning styles. These disciplines are often regarded as being highly

analytical, requiring a great deal of linear and logical thinking. In addition, they are often taught by educators who identify as being highly analytical and logical and who often employ this thinking in their teaching. Thus the opportunity for a discrepancy, or gulf, between teaching and learning style exists and can add to an already discouraging distance between where the learner currently resides and the attainment of a learning goal. Collectively these mismatches can result in feelings of alienation, as explained by phenomenology and hermeneutics, as the learner's previous experiences and historicities are not considered. This likely contributes to what is known as the "leaky pipeline" within STEM disciplines and explains why the attrition rate of women from these disciplines to other academic areas is disproportionately high (Seymour, 1992).

For those who do choose to stay, an additional amount of effort is required; for them, the gulf between what they know and need to learn is larger than it is for others. It is here that educators stand to make the most difference and that educational research, grounded in phenomenology and hermeneutics, stands to make the most progress. After all, as stated by Gadamer, "the hermeneutical has to do with bridging the gap between the familiar world in which we stand and the strange meaning that resists assimilation into the horizons of our world" (as cited by Linge, 1976, p. xii). It is also here that the connections between phenomenology, hermeneutics, and constructivism begin to emerge. When educators know and understand a learner's gulf, more effective methods can be designed to bridge this gulf.

While phenomenology and hermeneutics allow us to understand why a gulf exists, other philosophies provide insight for helping learners close or narrow the gulf. As previously discussed phenomenology is the study of experience, hermeneutics the study of interpretation. Providing the next logical step in the closing of a gulf is the philosophy known as

constructivism. This view on learning posits that individuals construct new knowledge and understandings based on what they already know, believe, and have experienced (Ausubel, 1968; Cobb, 1994; Piaget, 1952, 1973, 1978; Vygotsky, 1962, 1978). Constructing new knowledge is a complex and sometimes painful process for learners. It involves mediation between their older, comfortable place of knowing, and a new and unfamiliar possibility of what could be. For many learners this will seem overwhelming, for others, exciting. However, in either case, it is critical that the process of mediation take place if real and meaningful learning is to occur.

According to Gadamer, “Understanding is not reconstruction but mediation” (as cited by Linge, 1976, p. xvi). Mediation refers to a continual process of conceptual change where “students understand the limitations of their current views and recognize the need to replace them” (Hodson & Hodson, 1998, p. 34). But the process of mediation is unique to every individual as it requires the learner to engage in an inner dialogue and judge competing concepts in an effort to decide which one is ultimately the best fit for them given their past experiences. Thus, the process of mediation and ultimately understanding is dynamic and fluid, constantly changing and evolving as new information is received and processed. This notion is consistent with Gadamer when he stated, “Understanding itself is not to be thought of so much as an action of subjectivity, but as the entering into an event of transmission in which past and present are constantly mediated” (as cited by Linge, 1976, p. xvi).

But who or what shapes the process of mediation? Is it an organic process, completely uninfluenced by outside factors, or is the process benefitted by outside forces working with the learner to aide in their mediation? According to the constructivist view on teaching and learning, the process of mediation requires guidance by outside forces and pinpoints the critical role of the instructor during the learning process. If left unchecked, the process of mediating and

constructing concepts for oneself opens the door for misconceptions to be propagated. Because constructivism involves the active construction of meaning as it appears to a learner, it is possible for completely incorrect ideas to be built and added to over time (Ausubel, 1968; Hodson & Hodson, 1998; Liu & Chen, 2010). Thus, a learner could be participating in the process of mediation and knowledge construction and feel as though they are learning or mastering a concept, and yet fail to accomplish the learning goal that has been set for them. According to Driver, Asoko, Leach, Mortimer, and Scott, (1994),

If knowledge construction is seen solely as an individual process, then this is similar to what has traditionally been identified as discovery learning. If, however, learners are to be given access to the knowledge systems, the process of knowledge construction must go beyond personal empirical inquiry. Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science (p. 7).

This highlights, more than ever, the role of the instructor in the constructivist approach. It is the instructor that introduces knowledge systems and concepts to learners while at the same time presenting them in ways that can be incorporated with what a learner already knows. Too much information presented too quickly and the opportunity will be missed for a learner to capitalize on the possibility of expanding their current understanding. Too little information presented too slowly will discourage others from staying engaged with the topic at hand. Knowing how to reach both ends of this continuum, allowing all learners to construct their own meaning while providing shape and guidance during the process, is the epitome of constructivist teaching.

In terms of guiding a learner's construction of meaning, perhaps no other subject benefits from this as much as science. Much of science cannot be experienced through normal, everyday interactions; rather, it requires an informed introduction to very specific concepts, processes, and

vocabulary. Thus, “learning science is not simply a matter of making sense of the world in whatever terms and for whatever reasons satisfy the learner” (Hodson & Hodson, 1998, p. 34). Hodson and Hodson (1998) continue by stating, “it is absurdly naive to expect learners to be able to invent for themselves the abstract notions such as gene, molecule, and magnetic fields that scientists have developed over many years” (p. 35). Instead, the learner must be guided by an instructor in the “ways of seeing, which have been established and found to be fruitful by the scientific community” (Driver, 1989, p. 482). In short, the instructor must play a role in helping the learner shape, mediate, and construct their own meaning so that it is useful and relevant in their future endeavors.

Providing insight on how to accomplish this is Lev Vygotsky’s view of constructivism. At the center of Vygotsky’s ideas is the use of speech, including the comprehension of words and the ways in which words and the interpretations of their meanings influence how a learner formulates a developing concept (Miller, 2011). While the same words may be equally given to all learners within a classroom, it is the meaning that the words conjure up for each learner that differs and impacts their overall ability to comprehend what is being presented. According to Vygotsky, learners who operate on a high level of understanding relate words to concepts while learners operating at a lower level do not have this ability (Miller, 2011). Those operating on a lower level simply see words as words and never associate them with a particular concept even though on a surface level it may appear as though they have an understanding. This aligns well with insight provided by Gadamer, especially when he stated, “Former concretizations mediate the text to us” (as cited by Linge, 1976, p. xvi). Thus, what a text, or any piece of instruction means to a learner is based on their past concrete connections between the words or signifiers used, and concepts signified.

In addition to the insight provided on language and concept formation is Vygotsky's idea of proximal development. In this case, proximal refers to the psychology of concept development via multiple iterations; the learner must pass through, and even revisit, a number of stages and phases in order for a concept to be fully formed (Miller, 2011). During these stages and phases, "Vygotsky states that the key to concept development turns on the way in which signs are used and maintains that the new use of the word as a signifier, that is its use as a means of concept formation, is the proximal psychological cause of this intellectual revolution that occurs on the threshold [of learning]" (as cited by Miller, 2011, p. 74). Thus, a concept is not understood or mediated correctly by the learner until a word is available for signifying or representing the concept being developed. From a practical standpoint, this indicates that even when a learner can correctly spell or use a word in a sentence (i.e. demonstrates that the cognitive structure for a certain vocabulary is in place) does not necessarily mean that they truly have a firm grasp of a concept or can apply it in a novel situation. According to Vygotsky, "Fundamental to the process of concept formation is the individual's mastery of his own mental processes through the functional use of the word or sign" (as cited by Miller, 2011, p. 75). In short, if the learner has not constructed their own framework for understanding, which is furnished by the words and language they have chosen to use, no real learning can take place; everything acquired by the learner would be rather superficial. Outside of the requirements of rote memorization, this kind of learning has no real value.

The ideas presented by Vygotsky, specifically those regarding proximal development, provide guidance for educators and educational researchers searching for ways to improve instructional methods via a constructivist approach. For example, the idea that words must be linked to concepts and that the learner must mediate the distance between what was previously

known about a concept with new, incoming information is quite powerful. In fact, it led Vygotsky to plainly state, “teachers should concentrate their efforts in the zone of proximal development” (Hodson & Hodson, 1998, p. 36). The zone of proximal development, which is based on Vygotsky’s notion of proximal development, is “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance” (Vygotsky, 1978, p. 86). Stated another way, the zone of proximal development is the “range between a lower limit and an upper limit of task difficulty” (Schnotz, 2008, p. 32).

This notion emphasizes the idea that the only way to increase the knowledge possessed by a learner is to present information that is slightly above their current developmental stage but is also delivered in a way that supports learning. According to Vygotsky, “the only good learning is that which is in advance of development” (Hodson & Hodson, 1998, p. 36). Schnotz (2008) echoes the ideas presented by Vygotsky when he states, “The lower limit of the zone of proximal development is defined as the most difficult task the learner can perform successfully without help. The upper limit of the zone of proximal development is defined as the most difficult task that the learner can perform successfully with optimal help” (p. 33). In addition, Schnotz (2008) declares, “any instruction that aims at promoting learning should include learning tasks within the limits of the zone of proximal development” (p. 33).

But presenting information that is slightly in advance of where a learner currently resides can be a risky venture. As previously stated, if the new information is too complex, the learner will most likely miss the opportunity to make a meaningful connection between what is already known and that which is being presented. To aid in this venture, Wood, Bruner, and Ross (1976) introduced the idea of scaffolding which facilitates the zone of proximal development by

enabling teachers to present ideas that are a little beyond a learner's current position.

Scaffolding allows teachers to “create opportunities for students to use and take control of their own learning” (Hodson & Hodson, 1998, p. 36). The benefits of scaffolding are described by Bruner (1985):

If the learner is enabled to advance by being under the tutelage of an instructor or more competent peer, then the instructor or aiding peer serves the learner as a vicarious form of consciousness until such a time as the learner is able to master his own action through his own consciousness and control. When the learner achieves that conscious control over a new function or conceptual system, it is then that he is able to use it as a tool. Up to that point, the tutor in effect performs the critical function of scaffolding the learning task to make it possible for the learner, in Vygotsky's word, to internalize external knowledge and convert it into a tool for conscious control (p. 24-25).

From this, it becomes clear that scaffolding provides a graduated form of assistance. It does not change the nature of the task at hand, but rather holds the task constant while “adjusting the nature of the learner's participation” (Hodson & Hodson, 1998, p. 37). Perhaps a heightened level of assistance is provided at first but is scaled back as the learner progresses - the learner must resume control over their own learning at some point. “Judging when learners are ready, and when they need more responsibility, requires sensitivity on the part of the teacher to each learner's current framework of understanding” (Hodson & Hodson, 1998, p. 37). As stated by Bruner (1983), “where before there was a spectator, let there now be a participant” (p. 60).

When considering the philosophy of constructivism, Vygotsky's insight on the importance of language for conceptual formations, and the benefits provided by scaffolding, naturally the question arises regarding how to accomplish this. While the benefits are clear, the

methods that can be used to derive these benefits are not. However, Hodson and Hodson (1998) have described a few items that should be incorporated into any methodology utilizing the constructivist approach to teaching. First and foremost, the teacher “must identify students’ current ideas and views” (p. 34). Aligning well with phenomenology and hermeneutics, this salient point highlights the necessity of understanding a learner’s past experiences and interpretations. Without considering these, how could effective scaffolding ever be designed? Where would the starting point be located? Secondly, Hodson and Hodson (1998) state that methodologies should “create opportunities for students to explore their ideas” (p. 34). Going hand in hand with the exploration of their current ideas is the chance for learners to compare and contrast these with the ideas presented by their instructor and evaluate which ones make the most sense. This leads to the third item suggested by Hodson and Hodson (1998), which states that instructors should “provide stimuli for students to develop, modify, and, where necessary, change their ideas and views” (p. 34). It is here that we see the opportunity for mediation. Encouraging students to compare what they currently know to new information being presented motivates them to enter the process of mediation as they try to decide which path is the most correct.

Using Technology as a Constructivist Tool

Having discussed the foundations of constructivism, it is important to emphasize the connection between this philosophy and theoretical framework and the technological tools used with this approach. According to Nanjappa and Grant (2003), a strong symbiotic relationship exists between constructivism and technology as each benefits the other. Constructivism posits that learning takes place within certain contexts and that much of what a learner is able to understand, retain, and use depends on the experience or situation in which the information was

delivered. Technology has the ability to “produce particular environments that engage learning” (Jonassen, Peck, & Wilson, 1999, p. 12) by “providing knowledge-building tools capable of manipulating artifacts of understanding” (Hannifin & Hill, 2002, p 77). If used correctly, technology not only has the ability to encourage learners to take a constructivist approach to information acquisition by constructing rather than acquiring knowledge, but to also enable teachers to provide a form of instruction that supports the process of knowledge construction rather than simply the communication of knowledge.

Generally speaking, traditional pedagogical approaches do not encourage learners to construct meaning for themselves. Instead, traditional approaches “actually discourage constructive thinking with goals of transmitting existing knowledge that conflicts with any real attempt to generate new understanding. Constructivist thinking combines both the critical and creative intellectual processes” (Manzo, 1998, p. 287). When combined, these processes lead to deeper levels of understanding that are also longer lasting. When appropriate forms of technology are added to this combination, additional learning capabilities are supported. This idea is articulated by Duffy and Cunningham (1996) who state:

Technology is seen as an integral part of the cognitive activity... This view of distributed cognition significantly impacts how we think of the role of technology in education and training, the focus is not on the individual in isolation and what he or she knows, but on the activity in the environment. It is the activity – focused and contextualized – that is central... The process of construction is directed towards creating a world that makes sense to us, that is adequate for everyday functioning (p. 187-188).

Thus, as opposed to the traditional approach to teaching and learning, where the teacher is active and the learner assumes a fairly passive role, the constructivist approach encourages the learner

to take more of an active and dynamic role. Technology's power as a constructivist tool lies within its ability to support the cognitive and metacognitive processes of the learner as they engage in active learning.

Aligning with these ideas are the findings and suggestions of the National Research Council (NRC), (2000), in regards to the use of technology as a tool for supporting active learning. Specifically the NRC (2000) report states:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application
3. A metacognitive approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress (p. 14-18).

The use of technology has tremendous potential to address these issues. According to the NRC (2000), "Technologies can be used as learning and problem-solving tools to promote both independent learning and collaborative networks of learners and practitioners" (p. 243). However, the NRC (2000) also states, "educational software needs to be developed and implemented with a full understanding of the principles of learning and developmental psychology" (p. 244). Thus, without a firm understanding of how people learn and the cognitive processes involved, technology's value for improving student learning outcomes is significantly diminished.

Cognitive processes are defined as processes involved in the acquisition and integration of new information whereas metacognitive processes are defined as the self-monitoring or self-pacing portions of the learning process (Nanjappa & Grant, 2003; Tergan, Keller, & Burkhard, 2006). Technology supports both of these processes by “off-loading repetitive tasks and lower order tasks, thus freeing cognitive resources for deeper thinking (Duffy & Cunningham, 1996; Jonassen, 1999). To understand the significance of reducing or off-loading the amount of repetitive information and tasks, one must have a firm understanding of the Cognitive Load Theory. This theory, developed by John Sweller in 1988, serves as the foundation for designing effective pedagogical agents, to include those that rely on technology, due to the insight it provides for delivering content in ways that are most effective for comprehending and retaining new information. Therefore, before going any farther with the benefits of technology in regards to learning via a constructivist framework, a detailed description of the Cognitive Load Theory is necessary.

Cognitive Load and the Cognitive Load Theory

Cognitive load, as described by John Sweller’s Cognitive Load Theory (1988), refers to the load occupying an individual’s working memory while he or she is processing new information (Chien & Chang, 2012). Unlike long-term memory, which can hold vast amounts of information, working or short-term memory is limited (Sweller, 1988, Kalyuga, 2009, Chien & Chang, 2012). According to Chien and Chang (2012), “working memory can generally store about seven units of information at a time, but it processes just two to four units simultaneously” (p. 107). This is consistent with data from Baddeley (1992) as well as Sweller, van Merriënberger, and Paas (1998), specifically in regards to the amount of information that can be processed concurrently by working memory. Thus, reducing cognitive load is critical for the

acquisition of information. If learners are bombarded by copious amounts of complex information, they will have a difficult time processing and ultimately transferring information and ideas to long-term memory. This agrees with the conclusions of Kalyuga (2009) who states, “when memory load increases above a certain threshold, performance could be inhibited” (p. 3).

Reducing cognitive load requires an understanding of the factors involved. For example, both intrinsic and extrinsic loads contribute to overall cognitive load. And while little can be done to change the complexity or intrinsic load of some subjects, such as those within the STEM fields, much can be done to improve the ways in which information within STEM courses is delivered. When improvements within instructional methodologies are used to reduce the cognitive load on a learner’s working memory, a reduction in extrinsic load occurs, allowing the learner to process information more efficiently. According to the Cognitive Load Theory, the overall goal of instruction should be to limit, as much as possible, the extrinsic load placed on working memory (Chien & Chang, 2012).

Overloading working memory results in a degradation of the mental schemas constructed. Schemas are defined as mental representations stored in long-term memory (Sweller et al. 1998). In their most basic form, schemas are elements or chunks of knowledge, which form mental models (Rumelhart & Norman, 1983). These can be added to, combined, rearranged, and most importantly, built upon over time to resemble complex networks of information. It is the construction and reconstruction of schemas that allows knowledge to evolve, often through a constructive process (Sweller et al., 1998). As schemas are developed, organized, and used over time, they allow increased amounts of knowledge to be efficiently stored and recalled, thus reducing the overall load on working memory (Sweller et al., 1998, Kalyuga, 2009). More importantly, “schemas represent a major mechanism for extracting meaning from new

information, storing knowledge, circumventing limitations and increasing the strength of memory, and recalling information while also imposing organization to the information, guiding retrieval, and providing connections to prior knowledge” (Kalyuga, 2009, p. 11). Simply put, schemas allow for the incorporation and use of huge amounts of information to be recalled and used efficiently.

But, the ability to recall and use large amounts of information correctly depends upon how schemas were constructed in the first place as schemas form the knowledge base from which most cognitive processes in most situations arise. According to Kalyuga (2009):

Previously acquired schematic knowledge structures are the most important factor that influences learning new material. A student’s understanding of an instruction means instantiation of appropriate familiar schemas that would allow her or him to assimilate new information with prior knowledge. A failure to comprehend instruction might be caused by the lack of appropriate schemas in long-term memory (p. 12).

To build an adequate knowledge base requires a learner to accurately attain and organize small sets of information into lower level schemas, which are then organized and classified into larger and more complex schemas (Sweller et al. 1998). The importance of constructing accurate foundational schemas cannot be overemphasized. According to Kalyuga (2009), “student’s preexisting schemas often resist change: everything that cannot be understood within the available schematic frameworks is ignored or learned by rote” (p. 13). These statements by Kalyuga (2009) are in agreement with previous research performed by Sweller et al. (1998) who concluded that schema construction should be of utmost importance for any methodology aimed at increasing knowledge acquisition in students. This same conclusion was reached by Kalyuga (2009) who stated, “approaches that focus on connections between the content being presented

and the operations occurring between working and long-term memory (schema construction) are highly relevant and productive” (p. 5).

Work performed by Baddeley (1992) highlighted the relationship between schema construction, working memory, and particular types of instructional input. According to Baddeley’s Working Memory Theory, visually based information and auditory, primarily speech-based, information are processed most efficiently by working memory (1992). This statement is in agreement with work performed by Kalyuga (2009) who found that “performance of complex cognitive tasks requires simultaneous use and integration of various sources of information, coordination of separate processes and representations” (p. 4). It has been hypothesized that when presented simultaneously, auditory and visual inputs are processed independently within working memory, leading to a synergistic effect (Baddeley, 1992, Sweller et al., 1998). This synergy is especially important considering that the outputs from working memory are added to what is already held in long-term memory and both are then used to construct mental models or complex schemas of the new information being presented (Schnotz, 2008, Kalyuga, 2009). Thus, visual and auditory inputs allow for increased amounts of information to be held and processed by working memory, resulting in additional long-term memory, and ultimately leading to the production of more complex mental models. According to Schnotz (2008), “the process of constructing these mental models is referred to as comprehension” (p. 19).

Reducing Cognitive Load with Technology

Considering the connection between auditory and visual inputs and schema construction, the value of certain pedagogical tools that can facilitate this becomes quite clear. As stated by Kalyuga (2009), “instructional techniques should include auditory and visual inputs in order to

establish links with existing knowledge while activating existing relevant schemas or even providing new ones” (p. 13). This is echoed by Verhoeven and Graesser (2008) who posited that it is widely known that knowledge construction is facilitated by technology that uses multiple forms or channels of communication. When thinking of technological tools that have the ability to accomplish the challenges outlined so far very few, if any, come as close to presenting a viable solution as does the use of multimedia.

The use of multimedia, from a cognitive as well as a philosophical perspective, has the potential to be highly beneficial. For example, Kalyuga (2009) states that, “Students’ understanding of instructional material is based on their available schemas. Resolving the conflict between a learner’s available schemas and conceptual models presented during instruction may require a significant mental effort and cause a negative learning effect” (p. 92). Thus when designing instructional materials, the pursuit of methodologies that reduce the distance between the information being delivered and the current location of the learner in regards to their knowledge level is of utmost importance. The use of multimedia for reducing this distance aligns not only with Sweller’s Cognitive Load Theory (1988) due to the reduction in cognitive processes required to facilitate incoming information, but is also in agreement with Kalyuga’s (2009) conclusions regarding schema construction, specifically the benefits provided by integrating multiple forms of information into one presentation. The use of multimedia also aligns with the guidance provided by both hermeneutics and phenomenology, specifically the bridging of a learner’s knowledge gap.

But what exactly is multimedia? This term is often used to encompass a wide variety of instructional methods and can refer to rather ambiguous practices. According to Richard Mayer (2001, 2009), multimedia is defined simply as “any presentation involving words and pictures

that is intended to foster learning”, with the “express purpose of taking advantage of the full capacity humans have for processing incoming information” (p. 5). While the forms of multimedia vary greatly, from the basic chalk and talk to incredibly complex 3-D graphics, the goal is the same: to improve a student’s construction of knowledge. According to Mayer (2001, 2009), “words and pictures, while qualitatively different, can complement one another and human understanding occurs when learners are able to mentally integrate corresponding pictorial and verbal representations” (p. 7). Aligning with the constructivist view of learning as well as information regarding the value of schema construction, multimedia instruction is based on the premise that understanding occurs when learners are able to build meaningful connections between pictorial and verbal representations. According to Mayer (2001, 2009), “in the process of trying to build connections between words and pictures, learners are able to create a deeper understanding than they could from words or pictures alone” (p. 7). This very much echoes Vygotsky’s views on learning (1978), specifically that meaningful learning occurs when words are associated with entire concepts and are not just seen as mere words. Multimedia instruction has the potential to do just this, to help learners construct a concrete connection between words and concepts. These connections, in turn, have a high potential to evolve into schemas that can then be added to over time, increasing a learner’s overall knowledge base. This could prove to be especially helpful for novice learners as well as those engaged in complex coursework where complex and abstract concepts are difficult to visualize due their inability to be experienced in everyday life.

Having described the overall benefits afforded by the use of multimedia, it is important to note that not all multimedia is equally effective at increasing the amount of information learners are able to comprehend and retain. Using a multimedia presentation that is of poor design will

not increase learning outcomes. As with any instructional tool, the use of current theories concerning teaching and learning must be utilized in order to make multimedia useful. Thus, the use of Richard Mayer's (2001/2009) Cognitive Theory of Multimedia Learning, one of the most complete and detailed theories regarding the design, development, and implementation of multimedia for the express purpose of increasing student-learning outcomes, is an important component for any study involving this technology.

Cognitive Theory of Multimedia Learning

Richard Mayer's Cognitive Theory of Multimedia Learning (2001, 2009) provides guidance related to the construction of meaning or personal knowledge from the simultaneous use of words and pictures and is based on a learner-centered approach. According to Mayer (2001, 2009), "Learner-centered approaches begin with an understanding of how the human mind works and asks how can we adapt multimedia technology as an aid to human cognition." (p. 13). Mayer (2001, 2009) is quick to point out that a variety of tools can be used to accomplish this; the use of a computer or certain program is not necessary. Thus, less emphasis is placed on the type of software used or specific device required and more on molding technological tools around the needs of learners. For example, as opposed to the development of multimedia for response strengthening, otherwise known as drill-and-kill where learning occurs only by association, or the development of multimedia for the sole purpose of filling up a learner's "empty vessel" with facts and information, the creation of multimedia for aiding in the construction of knowledge helps the learner "build a coherent mental representation from the presented material" (Mayer, 2001, 2009, p. 17). According to Norman (1993), when multimedia is designed with the learner's needs in mind, it has the potential to promote human cognition.

The Cognitive Theory of Multimedia Learning is the result of several decades of work in what Mayer describes as “use-inspired basic research” (p. 58). The theory was designed to provide guidance in two main areas: how to increase retention and understanding in learners as measured by their ability to transfer or apply information to a new situation. As stated by Mayer (2001, 2009), “meaningful learning is the result of multimedia that was designed to present material in a coherent structure” (p. 69) and “is distinguished by good transfer as well as good retention performance” (p. 21).

According to Mayer (2001, 2009), the principles that form the foundation of his theory “must meet two criteria: (a) be theory-grounded – the principles are derived from a cognitive perspective on learning – and (b) be evidence-based – the principles are consistent with empirical research on multimedia learning” (p. 58). This two-pronged approach not only provides guidance for instructional designers but also educators in regards to evaluating, using, and perhaps even producing their own multimedia. Thus, it serves as a very appropriate choice for researchers looking into both of these fields.

In addition to providing both theory and evidence-based suggestions, both of which are fairly broad, Mayer’s theory also dives into the detailed and fine-grained technical components required for the actual design of multimedia intended for the express purpose of increasing student-learning gains. Mayer (2001, 2009) accomplishes this by describing, “three assumptions of multimedia learning” that must be considered before any design issues are ever contemplated (p. 60). These assumptions, which are based on vast amounts of research regarding how people learn, set Mayer apart from other attempts at provisional guidance in this particular area. For example, the first assumption is related to the methods in which incoming information is processed. Known as the “dual channel” assumption and based off of work performed by Paivio

(1991) and Baddeley (1992), this assumption states that humans possess separate channels for processing auditory and visual information (Mayer, 2001/2009, p. 63). The second assumption is related to the amount of information that humans are capable of processing at any one time and that this amount of information depends on a particular learner's attributes and skill level. Referred to as "limited capacity" this assumption is the result of research performed by Chandler and Sweller (1991) as well as Baddeley (1992) and aligns with the guidance provided by both phenomenology and constructivism. The third assumption, known as "active processing" is based on work performed by Wittrock (1989). As stated by Mayer (2001/2009), "humans engage in active learning by attending to relevant incoming information, organizing selected information into coherent mental representations, and integrating mental representations with other knowledge" (p. 63). This assumption aligns not only with constructivism, but also with Kalyuga's (2009) conclusions about the importance of schema construction. Once these assumptions have been taken into account and incorporated into the design of a multimedia presentation, additional factors can then be considered.

Many researchers have come to recognize that Mayer's (2001, 2009) Theory of Multimedia Learning represents a unique blend of both basic and applied research practices. Instead of strictly focusing on basic research, which does not test predictions in authentic settings, or strictly focusing on applied research, which does not explain why or how something works, a blended approach has the ability to provide much deeper insight (Stokes, 1997). Therefore, this theory provides an excellent starting point for the design of effective multimedia for the express purpose of increasing the knowledge base of underrepresented students within STEM courses.

Relation to Present State of Knowledge in the Field

The guidance provided by Mayer (2001, 2009) regarding specific design features for multimedia production has been cited and used by numerous authors in the last ten years, with the majority simply adding to or refining the original guidance provided by Mayer. However, despite the information regarding the sound theoretical potential multimedia could have as an instructional tool, its actual worth in the classroom remains unclear. Many issues are still in need of in-depth research due to the inconsistencies found when performing a thorough review of studies conducted in this area. According to Rouet et al. (2008), research regarding the effectiveness of multimedia needs to not only be grounded within learning theories, but also “needs to focus on the differential effects of a particular environment, learner characteristics, and the broader learning context” (p. 12).

Taking this statement into consideration, the first and foremost issue concerning the value of multimedia relates to its use in science education, specifically for increasing student-learning outcomes. While many studies have examined this exact issue, results are inconsistent at best (Large, Beheshti, Breuleux, & Renaud, 1994; Tversky, Morrison, & Betrancourt, 2002; Hegarty, 2004; Yung, 2009, Lowe & Boucheix, 2011). In fact, the use of multimedia to improve student-learning outcomes within science courses at all levels has a contested history. The range of studies conducted over this topic span several decades, beginning in the early 1990s when commercially produced CD-ROMs first became widely available, and continuing today with studies looking into the effects of multimedia combined with Web 2.0 capabilities and mobile learning technologies. Below, table 1 shows a sampling of studies undertaken in this area:

Author	Date	Focus
Huang & Aloï	1991	Use of interactive videos with high school biology students
Flagg & Kosinski	1996	Use of interactive CD-ROMs with introductory biology students
Sanger & Greenbowe	1997	Use of computer-generated animations with graduate level biochemistry students
Ashburn et al.	2002	Use of BioScope interactive CD-ROMs with high school biology students
Stith	2004	Use of commercially produced multimedia with college biology students
McClean et al.	2005	Use of 3-D animations with high school biology students
Avraamidou	2008	Use of mobile technologies with college science students
Uzunboylu et al.	2009	Use of mobile learning devices to increase college students' awareness of environmental issues
Chen et al.	2010	Use of multimedia with introductory physics students
Mbarika	2010	Use of multimedia with information technology and computer science graduate students
Annetta et al.	2010	Use of video games with high school biology students
Woodward et al.	2011	Use of multimedia with non-English speaking medical students
Rieber & Zellner	2012	Creation of web apps for mobile learning with students of all ages
Freudenberger et al.	2012	Use of blended learning to increase amount learned in face-to-face settings
Doolittle & Brill	2012	Testing effects of segmentation and undergraduates' attitudes on amount learned from multimedia
Tu et al.	2012	Use of digital game-based learning to improve education for all levels of students
Chang	2012	Use of multimedia design principles to aid under-performing college students in STEM courses

Table 1: Sampling of studies undertaken in the last thirty years highlighting the use and trends of educational technology in the science disciplines. Studies from 2012 represent abstract presentations given at recent conferences.

However, despite the large time frame and topics researched, no clear results exist. Questions such as, “does multimedia improve learning for students in science courses?” and “does multimedia provide any additional benefits over traditional learning methodologies?” remain as relevant today as they did twenty years ago. Although it is commonly believed that learning is enhanced through the use of technology such as multimedia, and many learning

initiatives exist to increase its inclusion in education due to the need for graduates to have technological competencies (U.S. Department of Education, 2001; Dani & Koenig, 2008; Greenhow, Robelia, & Hughes, 2009; Annetta, Cheng, & Holmes, 2010; Davies, 2011) many issues remain regarding its effectiveness. For every study indicating a positive relationship between the use of multimedia and student-learning outcomes, another study exists indicating just the opposite.

Studies indicating that multimedia has a positive impact on student-learning outcomes, regardless of the age of students involved or subject matter explored, seem to share three main characteristics. All are based on current learning theories such as constructivism, using multimedia as scaffolding to aid the learner in constructing their own meaning. Theories related to the design and development of multimedia, such as Mayer's (2001/2009) Cognitive Theory of Multimedia Learning and Paivio's (1991) Dual Coding Theory, were also used. In addition, many employed a design-based research strategy, producing multiple iterations of the multimedia that were evaluated by a team of students, educators, and subject matter experts, before launching the final product for use within the classroom (Simon, 2001; Ashburn, Krockover, Eichinger, Pae, Witham, Islam, Cross, & Robinson, 2002). Feedback from students, and especially educators, is crucial if any form of educational technology is to thrive and aid in student learning outcomes. An in-depth review of the failed history of the many forms of technology used in the classroom reveals that one of the key factors leading to their demise was lack of educator participation during development and implementation (Cuban, 1986). And finally, the majority of successful research projects were conducted within actual classrooms as opposed to educational laboratory settings, allowing researchers to observe students in a natural setting while using the multimedia (Simon, 2001; Yarden & Yarden, 2009).

Interestingly, despite these common characteristics, none of the aforementioned studies generated a clear set of guidelines or best practices for the production of multimedia. In fact, a variety of formats have been used and that many features such as overall running length, use of text, use of narration, use of embedded questions, and complexity of graphics have varied significantly. Similarly, while many have reported that successful multimedia included the use of simple and non-distracting graphics (Rieber, 1996; Sperling, 2003), some found that 3-D graphics benefitted students the most (Stith, 2004). In addition, many authors described that their multimedia simply provided an overview of a concept, giving students an introduction before coming to class, while others used multimedia to completely teach an entire concept (Stith, 2004; Stelzer, Gladding, Mestre, & Brookes, 2008). Also, several authors (Guertin, 2007; Chen, Stelzer, & Gladding, 2010) reported that multimedia was most effective if given to students before they came to class, used as part of a pre-learning or Just-in-Time Teaching strategy (Novak et al., 1999), while a few used it during class as a supplement or even replacement for laboratory or lecture activities (Ralph, 1996).

In response to the variety of multimedia formats used in educational research and the inconsistencies produced, Lowe and Boucheix (2011) state that the use of multimedia can be a double-edged sword for learners. Specifically Lowe and Boucheix (2011) state, “animated displays can benefit learners by providing explicit information about temporal change, but their dynamic character can also introduce [cognitive] costs” (p. 650). This additional cognitive cost is the result of poorly designed multimedia that requires extraneous processing for the learner and contributes nothing to the overall learning value.

Consequently many additional questions regarding what makes multimedia successful as a pedagogical tool, as well as its design and development, remain and represent obvious areas in

need of further research (Large, Beheshti, Breuleux & Renaud, 1994; Flagg & Kosinski, 1996; Wouters, Paas, & van Merriënboer, 2008; Greenhow et al., 2009; Yung, 2009; Downey, 2011; Lowe and Boucheix, 2011, Merkt, Weigand, Heier, & Schwan, 2011). While almost all of the studies evaluated reported following or at least incorporating the suggestions produced by Mayer's Cognitive Theory of Multimedia Learning (2001, 2009) or Paivio's Dual Coding Theory (1991), outcomes varied greatly. The only general consensus was that multimedia designed to explain abstract, complex, and molecular processes that were unfamiliar and unobservable to students were the most successful (Williams & Abraham, 1995; Sanger, Brecheisen, & Hynek, 2001; Stith, 2004; Steele & Aubusson, 2004; Dori & Belcher, 2005; Yarden & Yarden, 2009; Lowe and Boucheix, 2011).

This notion, that multimedia is especially helpful for students learning complex and abstract ideas, is explained in detail by Lowe and Boucheix (2011) who advocate for the development of multimedia that encourages the development and linking together of ideas by students as they create their own mental models. According to Lowe and Boucheix (2011), "Because they [students] lack the domain-specific knowledge required for compensatory top-down processing, learners in this situation are mainly reliant on information that can be extracted directly from animation (p. 651). This idea is in agreement with Merkt et al. (2011) who stated that multimedia, designed specifically to present complex information to learners in appropriately sized chunks, aided in schema construction as their working memory was not overtaxed. When first presented with complex and abstract information, a learner's cognitive capacities can be overloaded, reducing the overall amount of information they are able to take in and process (Paivio, 1991; Sweller, van Merriënboer, & Paas, 1998). This is critical to remember when designing effective multimedia as "the recipients' cognitive resources in the

working memory are limited and transient information can result in a cognitive overload if there is a mismatch of the presentation pace and recipients' cognitive capacities" (Merkt et al., 2011, p. 689). However, no guidelines exist explaining exactly how to create multimedia that prevents this. According to Lowe and Boucheix (2011), the widespread use of multimedia in education is a relatively new phenomenon and because of this, "scant research-based evidence exists to guide the practice of instructional designers who produce these displays" (p. 650).

Adding to the inconsistencies noted already regarding the use of multimedia for improving student learning outcomes, specifically within the STEM disciplines, are studies that have actually reported a decline in learning gains when multimedia was used as opposed to traditional learning methodologies. However, these studies lacked some very important components that most likely contributed to their failure. For example, studies in this category made no mention of basing their multimedia design on a particular theory such as Mayer's (2001, 2009) Theory of Multimedia Learning, nor did they attempt to use multimedia as a scaffolding tool, aiding the learner as they constructed their own mental models. Instead, these studies shared a different set of characteristics. For example, the majority of studies indicating negative results were attained from the use of multimedia relied on commercially produced media that was designed to impact a variety of learning and age levels (Large, et al, 1994; Tsui & Treagust, 2004). Many of these proved beneficial for high-achievers or first-tier students, but did nothing for middle to low-achievers (Huang & Aloï, 1991; Tsui & Treagust, 2004). Those that did create their own multimedia gave no details regarding its design or development nor did they attempt to understand why their multimedia failed to produce any significant learning gains; the authors had a tendency to rely solely on quantitative data, foregoing the insight provided by qualitative methods (Flagg & Kosinski, 1996; Sanger et al., 2001).

The majority of studies reporting that no significant learning gains occurred with the use of multimedia were plagued by poor experimental designs, contained many confounds, and had both internal and external threats to validity. For example, many of the studies occurred before the majority of students had ubiquitous access to computers at home or school or before the majority of students had been exposed to multimedia on a regular basis (Education Week, 2007; Rosen, 2011). Thus, novelty effect was a large problem. Additionally, many studies recruited students into an educational laboratory where they were paid simply to participate. Not only does this reduce the generalizability of the results of such studies to similar populations using multimedia in a contrived setting, but also negates any motivation the participants might have had for learning the material (Merkt et al., 2011). But, of all confounds existing within these failed studies, the most obvious was the lack of true control groups. Many studies attempted a “one and done” approach concluding that if students liked the technology it was a success and that other educators should try it themselves. However, comparison groups receiving a control treatment were not included so these conclusions are suspicious. Furthermore, many studies employed a one-shot case study design. In this design, neither the previous knowledge of participants is evaluated, nor are the methods repeated (Campbell & Stanley, 1963).

In addition to the inconsistencies found within the literature, another, even larger, issue looms and that is the question concerning the use of multimedia to increase learning gains amongst underrepresented students, specifically females. As previously discussed, a substantial gap exists between males and females pursuing and completing STEM degrees. However, very few studies have examined the impact multimedia has on certain types or demographics of learners. While some have indicated that multimedia helps those with low prior knowledge (Yarden & Yarden, 2009), or might prove beneficial for females (Large et al., 1994; Ralph,

1996), or eluded to the fact that those in large, public urban high schools benefit more (Ashburn, et al., 2002), these findings were not the focus of the research and received only a brief mention in the results sections. After a thorough literature review regarding this issue, only one publication specifically focusing on the use of multimedia to increase the learning outcomes of underrepresented students within STEM courses was found.

And finally, very few studies have examined the effects of multimedia within college biology courses; middle and high school students have been the focus of the majority of existing research (Stith, 2004; Yarden & Yarden, 2009). Almost no studies have examined the impact of multimedia within a general introductory-level college biology course. In fact, to gain an understanding of the effects multimedia has on learning outcomes specifically within collegiate STEM courses taught at the introductory level where the majority of students are lost from science disciplines, one must review research conducted within the physical, chemical, and computer sciences. Many well-designed studies have been conducted within these areas and positive relationships have been found between the use of multimedia and improvements in student learning outcomes (Dori & Belcher, 2005; Holzinger et al., 2008; Chen et al., 2010).

Given these issues, as well as time-sensitive nature of research involving technology, an extreme need exists for a fresh, in-depth look at the development and use of multimedia within STEM disciplines, specifically biology, to increase student learning outcomes. As depicted within this review of studies performed in this area, three large holes still exist regarding the relationship between the use of multimedia and student learning outcomes. First, what benefit, if any, does multimedia provide to the general population of students enrolled in an introductory college biology course? Second, are students possessing certain characteristics helped more than

others? And finally, what design and development parameters contribute to the production of effective multimedia?

Chapter 3 - Methodology

This chapter describes specific details of the study such as the design and development of the multimedia used as well as the overarching framework, which employed a design-based research process. In addition, participants, specific procedures, instrumentation and methods of data analysis are discussed.

Given the holes that currently exist in the literature, the overarching goal of this research project was to explore the effect of using teacher designed multimedia on students' understanding of complex and abstract scientific concepts within a real classroom setting. To accomplish this, three main research questions were posed:

1. Does the use of multimedia affect the amount of information students comprehend and retain when learning complex and abstract scientific concepts?
2. Is there a relationship between the use of multimedia, gender, and learning outcomes?
3. Which multimedia features influence the effectiveness of multimedia instruction?

Context

This study took place at Kansas State University, which began as Bluemont College in 1858. With the passage of the Morrill Act in 1862, Kansas State became the first true land-grant university in 1863. Land-grant institutions historically focused on teaching practical subjects such as agriculture, engineering and military science. While the number and types of majors offered at Kansas State has certainly broadened over the past 150 years and the background and interests of students in attendance have definitely become more diverse, the underlying emphasis on the importance of practical information remains apparent.

According to the Office of Planning and Analysis, the official enrollment at Kansas State University during the fall of 2012 was 23, 463. This included both full-time and part-time students as well as undergraduate and graduate students. Kansas State University offers associate, bachelor's, master's, and doctoral degrees. Undergraduate student body composition is comprised of 10, 141 male students, representing 52% of the total population, and 9, 244 female students, representing 48% of the population. Acceptance rate for first-time freshman applying to Kansas State is 99% (KSU Office of Planning & Analysis, 2012).

Students participating in this study represent a heterogeneous mix of all undergraduates attending Kansas State as the course used in the study, Principles of Biology, is required for almost every major. In addition, participants were diverse in academic backgrounds and preparation levels as freshman through seniors enroll in this course.

The Principles of Biology course, delivered through the Division of Biology, is offered in a studio format. This format combines lecture and laboratory activities. Students work in groups of four and work through exercises as guided by a laboratory manual and a course website. Every course section is led by two full-time faculty instructors and two graduate teaching assistants; student to instructor ratio is 20:1. Over the course of a semester, seven main topics are covered: introduction to science, ecology, cell biology, genetics, energetics, plant biology, and animal biology. Students' grades are determined by performance on biweekly quizzes and seven unit exams.

The topic of photosynthesis was chosen as the focus for this study. Covered during the energetics portion of the course, the ability of students to understand and apply the concepts related to photosynthesis has historically been quite low. Pre-semester tests given the first day of every semester indicate that questions related to energetics give students the most trouble.

Specifically, questions related to photosynthesis receive the lowest or second lowest number of correct answers.

Multimedia Design and Development

The very first component of this research project entailed the selection of an appropriate scientific topic to be covered within the multimedia module. According to Mayer (2001, 2009), the use of multimedia is especially helpful for students learning complex and abstract topics. However, according to Rouet et al. (2008), multimedia used to explain such topics is most effective when learners have low prior knowledge about the subject being explained.

With this in mind, pre-semester test scores from previous semesters of BIOL 198 were examined in an effort to elucidate which topic was least familiar to students. Making the top of the list was the subject of photosynthesis. Because this topic is both complex and abstract and pre-semester exam scores indicated that most students have very little prior knowledge about photosynthesis, it was an acceptable candidate for explanation via multimedia.

With the topic selected, development of the first multimedia module ensued using the principles outlined for multimedia development by Mayer (2001, 2009). Special attention was given to Mayer's (2001, 2009) principles for reducing extraneous processing and managing essential processing. The following table provides an overview of these principles:

Principles for Reducing Extraneous Processing in Multimedia Learning	
Coherence	Exclude unnecessary words, pictures, sounds, music, and symbols from a multimedia presentation.
Signaling	Highlight the organization of the multimedia presentation using verbal or pictorial cues and signal the end of one segment or beginning of another.
Redundancy	Present graphics and a spoken narration simultaneously.

Spatial Contiguity	Place graphics and their corresponding labels as close to each other as possible.
Temporal Contiguity	Spoken words and the presentation of graphics should occur simultaneously.
Principles for Managing Essential Processing in Multimedia Learning	
Segmenting	Include controls that allow the user to set the pace of the lesson such as start, stop, fast-forward, and rewind buttons.
Modality	Use spoken narration as opposed to on-screen text whenever possible to reduce cognitive overload within the visual system.

Table 2: Mayer’s (2001/2009) principles of multimedia learning used to design first iteration of the multimedia module. The pre-training principle was not included.

Content included in the multimedia module was driven by the explanation of photosynthesis within the student textbook, “Biology: Concepts and Application”, 7th edition. The initial narration developed was a summary of the process of photosynthesis, as described in this book, while visuals used in the multimedia module were not at all related to those in the textbook but rather developed in accordance with Mayer’s (2001/2009) principles.

The creation of animated visuals used in the multimedia module was done on a MacBook Pro running Mac OS X (version 10.7.5) using Apple’s Keynote (version 5.2), along with programs from Apple’s Final Cut Pro Suite (version 7.0.3). Once developed, ScreenFlow (version 3.0.4) was used to capture the animations and import them into Final Cut Pro. The narration used within the multimedia narration was recorded directly into Final Cut Pro using a Blue Microphone™. Once recorded, the narration and animations were knit together and exported using QuickTime Conversion, a feature within Final Cut Pro. As a result, the file was compressed and prepared for streaming and fast start once opened. The initial multimedia module developed, which was 8:06 in length, was 15.2 MB in size.

The finished multimedia module was uploaded to K-State Online, a course management program used by students and faculty. This site allowed for the distribution and viewing of the QuickTime file without downloading.

Development of Control Media

Control media consisted of a Microsoft Word (version 14.2.4) document containing text and static images. The text was the exact narration verbalized within the multimedia module and images used were created from still shots taken from the animation. The file was uploaded and made accessible to students via K-State Online.

Design-Based Research

With the development of the initial multimedia module and control media complete, the process of design-based research began. According to Sandoval (2004), design-based research is defined as the “systematic study of designed interventions” (p. 215). Traditionally, the term “intervention” has referred to instructional programs such as textbooks or policies (The Design-Based Research Collective, 2003). The term designed interventions, however, has been expanded to include innovative learning technologies designed for the express purpose of fostering learning in a particular context or setting as well as any curricular materials and participant activities associated with the technology (Sandoval, 2004; Sandoval & Bell, 2004). According to Kelly and Lesh (2000), design-based research is a sound choice for developing technologies to support learning in real classrooms given the situated nature of learning and need to evaluate empirically. This is in agreement with Sandoval and Bell (2004) who described design-based research as a method for “combining theoretical insights with educational practice” to produce “methodological alignment” (p. 199,200). According to Sandoval and Bell (2004),

One of the most commonly faced methodological issues in design-based research is the tension between making an intervention work in a complex setting, which often necessitates changing the intervention as it unfolds (in a way that directly mirrors the dynamic, contingent nature of decision making during teaching) with the researchers' need for empirical control, which argues against changing the planned treatment (p. 200).

Despite these potential complications, design-based research is one of the few methodologies that have the ability to “bridge theoretical research and educational practice” (Design-Based Research Collective, 2003, p. 8). However, in order to maximize the value of design-based research, the Design-Based Research Collective (2003) suggests that studies using this methodology meet the following five criteria:

1. The central goals of designing learning environments and learning theories are intertwined
2. Development and research should take place through continuous cycle of design, enactment, analysis, and redesign
3. Research on designs must lead to sharable information that helps communicate relevant implications to practitioners and other educational designers
4. Research must account for how designs function in real learning environments
5. Development of these accounts should rely on methods that can be documented and connected to processes of enactment to outcomes of interest

The process of design-based research is often described as the ontogeny of innovation (Sandoval, 2004) where a new concept is introduced and refined via multiple iterations of development, testing, analyzing, and editing (Design-Based Research Collective, 2003; Sandoval, 2004; Sandoval and Bell, 2004). To accomplish these steps, a quantitative and

qualitative approach was taken during this research study. Three iterations, or cycles of research, were conducted during three consecutive semesters of BIOL 198 at Kansas State University following approval from Dr. Brian Spooner, Department Head of the Division of Biology. Results of the multiple research iterations were used to answer the main research questions of the study as well as produce a set of guidelines for other educators to use when designing multimedia for their own students. These results and guidelines are discussed in chapter 4.

The following table provides a simplified overview of the steps taken during each research iteration. A more detailed description of the steps undertaken within each iteration follows within the next section labeled “Detailed Iterative Research Procedures”.

	<u>Design</u>	<u>Test</u>	<u>Analyze</u>	<u>Edit</u>
<u>Iteration 1</u> <i>Spring 2012</i>	Original multimedia module developed during Fall 2011 using Mayer’s (2001) principles of multimedia learning	Released media to experimental and control course sections. Quantitative: Administered pre-module 5 test, online quiz, post-module 5 test, unit exam Qualitative: Collected student feedback via in-class surveys, conducted focus groups with graduate teaching assistants and faculty members	Quantitative: Conducted descriptive statistics, ANOVAs Qualitative: Reviewed student feedback for emerging themes, reviewed focus group surveys for emerging themes	Quantitative and qualitative feedback used to revise, edit, and improve multimedia module for next iteration
<u>Iteration 2</u> <i>Summer 2012</i>	Improved and edited original multimedia in accordance with	Released multimedia to one available BIOL 198 course section	Quantitative: Conducted descriptive statistics,	Quantitative and qualitative feedback used to revise, edit, and improve

	<p>quantitative and qualitative feedback</p> <p>Revised control media to reflect changes in multimedia narration and included static pictures taken from animation to improve robustness of control treatment</p>	<p>Quantitative: Administered pre-module 5 test, online quiz, post-module 5 test, unit exam</p> <p>Qualitative: Collected student feedback via social construct questions embedded within online quiz, conducted focus groups with graduate teaching assistants and faculty members</p>	<p>ANOVAs</p> <p>Qualitative: Reviewed social construct responses for emerging themes, reviewed focus group surveys for emerging themes</p>	<p>multimedia module for next iteration</p>
<p>Iteration 3 <i>Fall 2012</i></p>	<p>Improve and edit original multimedia in accordance with quantitative and qualitative feedback</p> <p>Revised control media to reflect changes made in multimedia</p>	<p>Released media to experimental and control course sections.</p> <p>Quantitative: Administered pre-module 5 test, online quiz, post-module 5 test</p> <p>Qualitative: Collected student feedback via social construct questions embedded within online quiz</p>	<p>Quantitative: Conducted descriptive statistics, ANOVAs</p> <p>Qualitative: Reviewed social construct responses for emerging themes</p>	<p>No editing of media. Final results used to make suggestions regarding use of multimedia in introductory STEM courses</p>

Table 3: Chart illustrating design-based research process used in study during the Spring 2012, Summer 2012, and Fall 2012 semesters.

Participants

Participants in this study consisted of students enrolled in Principles of Biology, BIOL 198, at Kansas State University. This course is required for almost all majors at Kansas State and each course section consisted of approximately 75 students, both science and non-science majors. This course is a studio course meaning that a combination of lecture and laboratory activities are used throughout class time to introduce, describe, and convey scientific principles to students. The course is staffed with two full-time faculty members as well as two graduate teaching assistants.

Each research trial conducted during the spring and fall semesters of 2012 involved four of seven or eight respective sections of BIOL 198. In addition, the summer 2012 section of BIOL 198 was used. Research trials conducted during the spring and fall semesters consisted of 300 students each while the summer research trial consisted of 75 students as only one section was offered during the summer.

Detailed Iterative Research Procedures

This study was only concerned with aggregate data; individual student performances were not assessed. Participating course sections were chosen based on a pre-semester exam given to all sections of BIOL 198 on the first day of the semester. With the exception of the summer section, the four course sections selected to participate in the study were chosen based on their pre-semester test scores which were closest to the mean for all course sections as determined by descriptive statistics. Eliminating course sections with higher or lower pre-semester scores was important for insuring the validity of the study. In addition, course sections that had been reserved for pre-medicine majors were excluded. After analyzing pre-semester test scores, participating course sections were randomly assigned to either the experimental or

control treatments by rolling a die. During the summer semester, only one section of BIOL 198 was offered. This section received the experimental treatment.

Following the assignment of course sections to treatments, permission was requested and received from faculty instructors of each course. Not only was access to their specific course listing on K-State Online required in order to distribute media to students, but also a brief amount of time was needed during several class periods to discuss the study with students and collect data. While instructors of each course section were allowed to view the media their course was to receive, they did not know which media constituted the experimental or control treatment. Instructors were asked not to discuss the study with students and to defer answering any questions about the media or study.

One week prior to the start of the course module covering photosynthesis, students were given a brief presentation describing the study and potential benefits that may come from their participation. A verbal statement of informed consent was read to the students by the researcher. It was made clear that participation in the study was voluntary and that their participation could end at any time without any penalty. In addition, it was made clear that no extra credit or inducements of any kind were being offered in exchange for their participation. The verbal statement of informed consent was important; because all participants in the study were to remain confidential, documentation of individual participation was avoided whenever possible. Adherence to the approved Institutional Review Board protocol (#5571) involving the use of human subjects in research was maintained.

Immediately following this presentation, students volunteering to participate were asked to take another pre-test, referred to as the pre-module 5 test. This pre-test was used to verify once more that the participating course sections contained students whose knowledge of

photosynthesis was similar; insuring that a section did not contain many agronomy or botany majors by chance was important. This pre-module 5 test was also used to gauge the amount of improvement between treatments as a post-module 5 test was administered following the use of the experimental media or control narration.

The administration of the pre-module 5 test and collection of data was done in class. A multiple-choice test, consisting of ten questions, was used. Students were asked to use a scantron card, provided by the researcher, to answer the questions in an effort to expedite grading and reduce errors. Questions on this test were derived from exams used in previous semesters and related specifically to the process of photosynthesis. These questions had been reviewed by multiple faculty members over a number of semesters and were not known to contain misleading words or phrases that could impact a student's understanding of the question or possible answers. Results of the pre-module 5 test were analyzed using quantitative measures.

One week after the administration of the pre-module 5 test, media was released to students via K-State Online. The release of the media was timed to correspond with a daily online quiz that students were accustomed to taking as a normal part of their course work. Within the instructions of this daily online quiz was a hyperlink to the respective media assigned to their course section and a brief statement of informed consent. Students in course sections assigned to the experimental treatment were asked to view the multimedia. Students in course sections assigned to the control media were asked to read the word document and view static pictures before taking their quiz.

Student use of the assigned media was recorded automatically by K-State Online. Every student access was time/date stamped and logged in chronological order. This allowed the researcher to analyze how many students had viewed their assigned media.

The daily quiz consisted of ten questions. The first five were social validity questions and were not worth any points. This was made clear to students within the instructions of the quiz. Being short-answer in format, the purpose of these questions was to gauge student use of and thoughts about the assigned media they had been asked to view. Comments received on these five questions were recorded and analyzed for emerging themes. The following five questions found on the daily quiz were worth 0.2 points each and related specifically to the process of photosynthesis. Answers to these content-related questions could be found within either form of media made available to students. Content-related questions were analyzed using quantitative measures.

Following the completion of the daily online quiz and viewing of assigned media, the researcher returned to all participating course sections and administered a post-module 5 test. As with the pre-module 5 test, the post-module 5 test was administered in class and consisted of the same questions contained within the pre-module 5 test. Students were again asked to record their answers using a scantron card provided by the researcher. Students who had chosen not to participate in the study were asked not to complete a post-module 5 test. Results of the post-module 5 test were analyzed using quantitative measures.

Both the online daily quiz and post-module 5 tests were designed and used to measure student comprehension of a complex and abstract science concept. Both assessments were taken not more than 24 hours after the use of assigned media. Two weeks after the administration of the post-module 5 test, all students enrolled in BIOL 198 were given a unit exam. The unit exam was used to assess student retention. Results of the unit exam were analyzed using quantitative measures.

After the unit exam, faculty instructors and graduate teaching assistants were invited to participate in focus group sessions. During each session, the multimedia module was shown and participants were asked to answer questions regarding the content, presentation, and design of the multimedia using a set of questions adapted from Dr. Peter Albion's survey regarding the design and development of educational multimedia. Results of the focus group surveys were analyzed for emerging themes using qualitative measures.

Instrumentation

The daily online quizzes and unit exams used during this study were part of the normal course curriculum. However, specific questions were embedded within these routine assessments to gauge the effect of different media on student learning outcomes. Both forms of media contained the same information, giving all students access to the information needed to perform well on these assessments. In addition, students in course sections not participating in the study were instructed to read their textbook before taking their online quiz or exam. This is standard practice within this course. Thus, regardless of the form of media used, all students had access to the information needed to perform well on these assessments. Because these daily online quizzes and unit exam scores applied towards students' semester grades, it was imperative that all had equal access to content and to insure that the only difference between sections was simply the format of information delivery.

Data Analysis

To test the effects of multimedia on student comprehension, data were analyzed using quantitative and qualitative methods. A description of both analytical methods is discussed in this section.

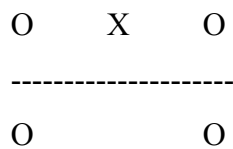
Due to the lack of true randomization of subjects placed within treatment groups, the research design chosen was quasi-experimental and known specifically as the nonequivalent control group design (NEGD). This design was used to analyze data during each of the three iterations used during the design-based research process. NEGD was chosen due to the independent variables, multimedia versus static pictures and text, being offered to entire course sections and not to individual students who had been randomized within those sections.

According to Campbell & Stanley (1963), this design,

involves an experimental group and a control group both given a pretest and a posttest, but in which the control group and the experimental group do not have pre-experimental sampling equivalence. Rather, the groups constitute naturally assembled collectives such as classrooms (p. 47).

This statement is in agreement with Trochim (2001) when he stated, “in the NEGD, you most often use intact groups that you think are similar as the treatment and control groups. In education, you might pick two comparable classrooms” (p. 216).

As depicted by Campbell and Stanley (1963), the process of NEGD involves:



where “O” refers to pre-test or post-test and “X” to the experimental treatment received by a group of people.

Quantitative statistical analyses were performed using IBM’s Statistical Package for the Social Sciences (version 21). Results were considered to be statistically significant at a p-value < 0.05. The study included the following statistical analyses:

1. Descriptive statistics including the distribution, central tendency, and dispersion of scores for pre-semester tests for all BIOL 198 sections, as well as descriptive statistics for pre-module 5 tests, post-module 5 tests, daily online quiz, and unit exam scores for each course section participating in the study.
2. One-way ANOVAs to test for statistical differences between the means of the pre-semester test, pre-module 5 test, post-module 5 test, the daily online quiz, and unit exam scores between course sections as well as between males and females.
3. Nonparametrics to test for statistical differences between the mean scores of the post-module 5 test and daily online quiz between males and females when sample sizes were small and assumptions of normality had been violated.

In addition to these quantitative statistical analyses, feedback from social validity questions embedded in the daily quiz as well as feedback attained from focus group sessions was analyzed for emerging themes. Steps included during this portion of the data analysis included organizing the feedback received, coding the data by reducing it into meaningful segments, and condensing segments into meaningful themes (Creswell, 2007).

Limitations and Delimitations

Admittedly, limitations and delimitations exist within this study. The limitations of this study are related to the inherent complexities that come with conducting educational research in real classroom settings. For example, the level of enthusiasm and support received from faculty and course coordinators varied. During the Spring 2012 and Summer 2012 semesters, faculty and course coordinators were open to the idea of research being conducted within their course sections. However, the Fall 2012 semester resulted in a different set of instructors teaching the various sections of the course and a different course coordinator in charge of all course sections.

Enthusiasm of the course coordinator towards the research project was low and this seemed to influence faculty instructors attitudes and enthusiasm for the research as well. As faculty enthusiasm fell, so did the numbers of student participants. It is important to note, however, that even though these limitations represented factors beyond the control of the researcher, the approach tested in this study still made measurable contributions to learning despite being tested in less than ideal situations. In addition, the variety of attitudes and levels of enthusiasm encountered represents the reality of conducting educational research in a real classroom setting.

The delimitations of the study are related to the research setting, experimental design and data collection. In regards to the setting, research was only conducted at one particular university, Kansas State University. Furthermore, only one particular course, Principles of Biology, was used. And within this course, a very specific topic, photosynthesis, was the focus of the research. And while participants in the study did represent a rather large and heterogeneous sample of all undergraduate students at this university, the study only lasted for three academic semesters.

In regards to the experimental design and data collection, entire sections of the course were assigned to treatment groups as opposed to randomly assigning students contained therein; thus, the research design was quasi-experimental employing a non-experimental group design. Also, participation in the study was completely voluntary; no inducements of any kind were given. Because of this, students choosing to participate may have been more motivated students in the first place. Another limitation of this study involved accessibility issues a very select number of students encountered when attempting to access the multimedia module, which was offered as a QuickTime file. Although the QuickTime platform is common and the file size of the multimedia small, a minor complication existed in that a few student devices were not able to

facilitate or open the file. This bias may have influenced the results by only including those who had more current internet-ready devices that had the ability to access and play a QuickTime file of a certain size.

These limitations and delimitations may impact the overall generalizability of this study. However, the focus of the study was not to make recommendations that would be applicable to the majority of the introductory STEM courses offered at all large universities. Instead, the main focus was to explore the potential benefits multimedia provided as well as the production of a set of guidelines that could help other science educators produce multimedia for their own students.

Chapter 4 - Results

In order to assess the value of using multimedia in an introductory STEM course for improving student comprehension, quantitative and qualitative results from the study outlined in the previous chapter are highlighted. This chapter begins with results from a pre-study component, which was important for the initial development of the multimedia module used during the design-based research process. Following the pre-study component are the results from each of the three design-based research iterations. Within each of the three research iterations, results regarding the three main research questions are addressed:

1. Does the use of multimedia affect the amount of information students comprehend and retain when learning complex and abstract scientific concepts?
2. Is there a relationship between the use of multimedia, gender, and learning outcomes?
3. Which features do students and instructors believe are most helpful regarding the effectiveness of multimedia instruction?

Pre-Study Component

A pre-semester test, given the first day of class to all BIOL 198 course sections during fall and spring semesters, revealed that students struggle the most with photosynthesis. Fewer than 25% of students were able to correctly answer questions related to this topic. This has been a consistent trend within BIOL 198. As a result, photosynthesis was chosen as the focus for the development of the multimedia module, which was used to answer the three research questions. A copy of the pre-semester test used at the beginning of every semester is located within Appendix B.

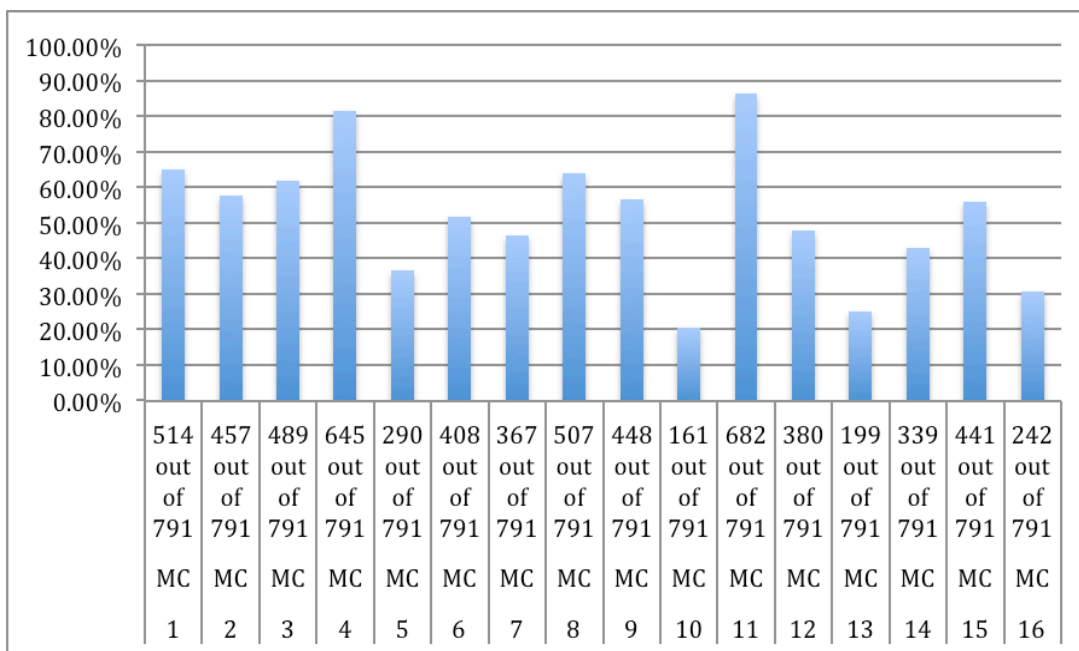


Figure 1: Results from Fall 2011 pre-semester test. Multiple-choice question 10 (MC 10) directly tests students' understanding of photosynthesis. Multiple-choice questions 5 (MC 5) and 16 (MC 16) are related to the process of photosynthesis. Multiple-choice question 13 (MC 13), while low, was not related to the process of photosynthesis but rather to calculations regarding dilutions.

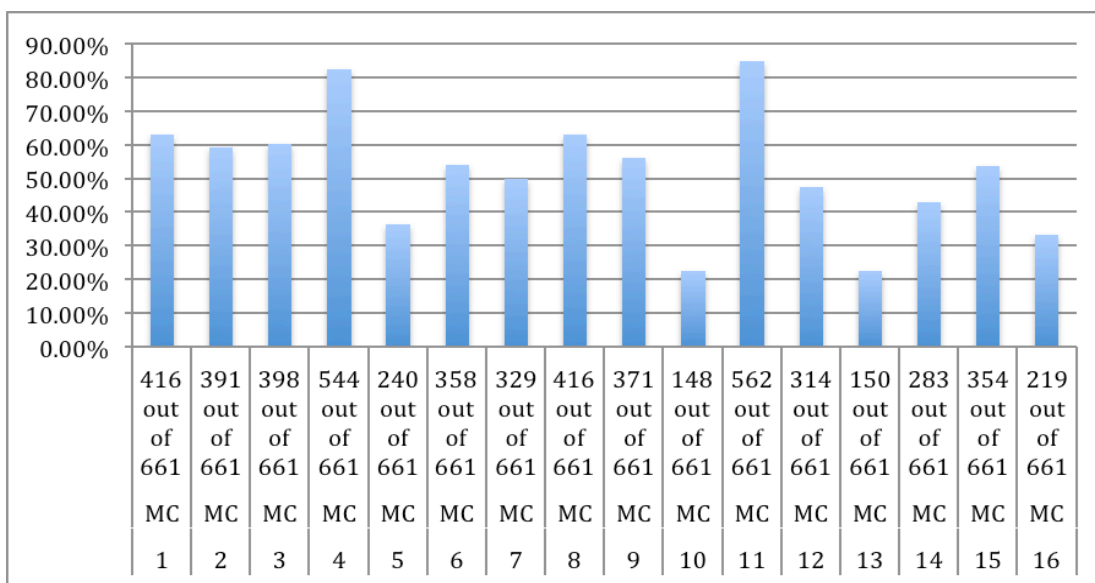


Figure 2: Results from Spring 2012 pre-semester test. Multiple-choice question 10 (MC 10) directly tests students' understanding of photosynthesis. Multiple-choice question 5 (MC 5) and 16 (MC 16) are related to the process of photosynthesis.

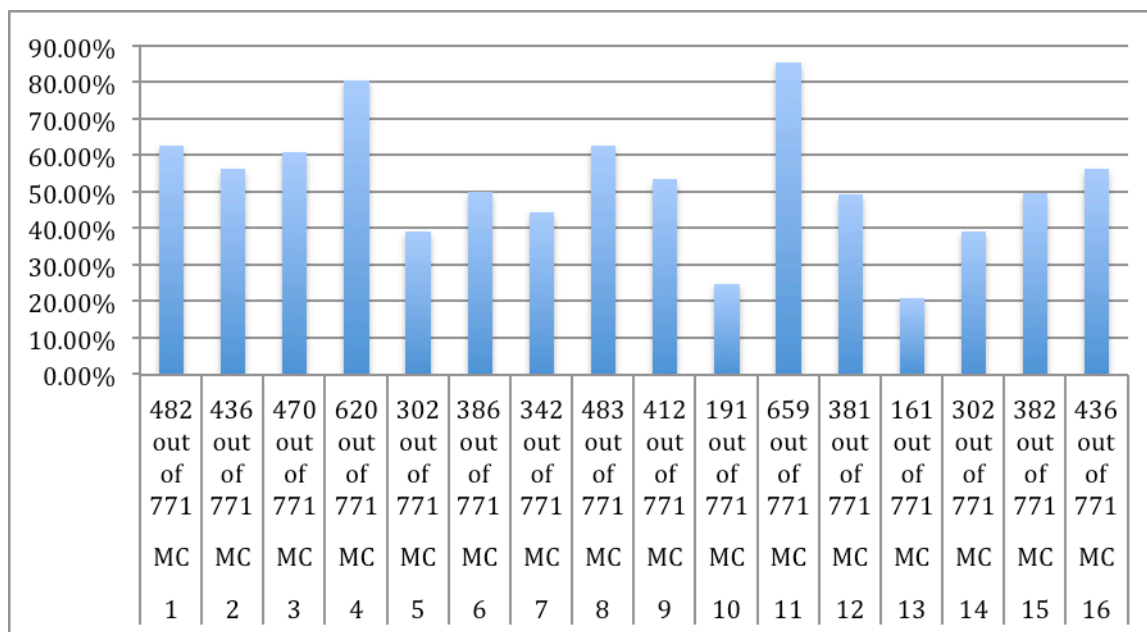


Figure 3: Results from Fall 2012 pre-semester test. Multiple-choice question 10 (MC 10) directly tests students’ understanding of photosynthesis. Multiple-choice question 5 (MC 5) and 16 (MC 16) are related to the process of photosynthesis.

Research Iteration 1

The first iteration of the design-based research process took place during the Spring 2012 semester. After assessing descriptive statistics on pre-semester test scores for all seven sections of BIOL 198 offered, four sections were selected to participate. These four sections performed similarly on the pre-semester test and fit the requirements of NEGD. Results of the pre-semester test given to all sections of BIOL 198 are shown in figure 4. Selected sections include TU 730, TU 930, TU 1130, and WF 130. Sections labeled WF 930 and WF 1130 were not included as their means represented outliers. In addition, the section labeled TU 130 was not chosen to participate as it was reserved for pre-med majors and did not contain the same student body composition as other sections. Descriptive statistics for the pre-semester test are shown in figure 4.

Spring 2012

	TU730	TU930	TU1130	TU130	WF930	WF1130	WF 130
N	73	72	75	75	74	75	71
Minimum	3.00	2.00	4.00	2.00	5.00	3.00	3.00
Maximum	13.00	14.00	14.00	13.00	14.00	16.00	13.00
Mean	8.7808	8.2778	8.4133	8.3600	8.9324	7.8000	8.3521
Std. Deviation	2.53447	2.30872	2.22452	2.18496	2.25335	2.60457	2.38506

Figure 4: Descriptive statistics from the Spring 2012 pre-semester test given to all course sections of BIOL 198.

The TU 730 and TU 1130 course sections were randomly assigned to receive the experimental treatment and the TU 930 and WF 130 course sections were randomly assigned to receive the control treatment.

Approximately one week before the beginning of the photosynthesis module another test, the pre-module 5 test, was administered to the four participating course sections. The purpose of this test was to assess if any differences existed amongst the participating course sections specifically regarding their pre-existing knowledge of photosynthesis. Because this test occurred approximately 2 months after the pre-semester exam had been given, the number of students enrolled in each section had changed. Figure 5 shows the results of the pre-module 5 test.

Spring 2012

	TU 730 (EXP)	TU 930 (CON)	TU 1130 (EXP)	WF 130 (CON)
N	70	59	68	67
Minimum	1.00	.00	1.00	2.00
Maximum	9.00	8.00	8.00	8.00
Mean	5.3714	4.7627	5.0441	5.2985
Std. Deviation	1.75426	2.00292	1.54952	1.51772

Figure 5: Descriptive statistics from the Spring 2012 pre-module 5 test.

In addition to the descriptive statistics, a one-way ANOVA was performed to assess if the differences between the pre-module 5 test means were significantly different amongst the participating course sections before the treatment was administered. The results, shown in figure

6, reveal that pre-module 5 test score means between sections were not statistically significantly different.

Spring 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.740	1	1.740	.591	.443
Within Groups	770.620	262	2.941		
Total	772.360	263			

Figure 6: One-way ANOVA results from the Spring 2012 pre-module 5 test.

Data gathered from both the pre-semester and pre-module 5 tests indicated that the four participating course sections were similar. The requirements for NEGD were met. As a result, data analyses regarding the three main research questions continued.

Quantitative analyses supporting the first research question included results from the post-module 5 test, the daily online quiz, and the unit exam. Figures and a brief description of each are discussed in turn.

Results from the post-module 5 test include descriptive statistics and ANOVAs. Because participation in the study was completely voluntary, the number of participants is lower than the number enrolled in each section. In addition, the number of participants receiving the experimental treatment differed from the number of participants receiving the control treatment. Due to this, results were stratified by treatment when performing ANOVAs. Figures 7 and 8 illustrate the means and standard deviations of the post-module 5 test for each participating course section.

Spring 2012

	TU730 (EXP)	TU930 (CON)	TU1130 (EXP)	WF130 (CON)
N	63	38	52	46
Minimum	1.00	.00	2.00	3.00
Maximum	10.00	10.00	9.00	10.00
Mean	7.3810	6.3158	6.9808	6.7174
Std. Deviation	1.98729	2.31453	1.56544	1.75958

Figure 7: Descriptive statistics from the Spring 2012 post-module 5 test.

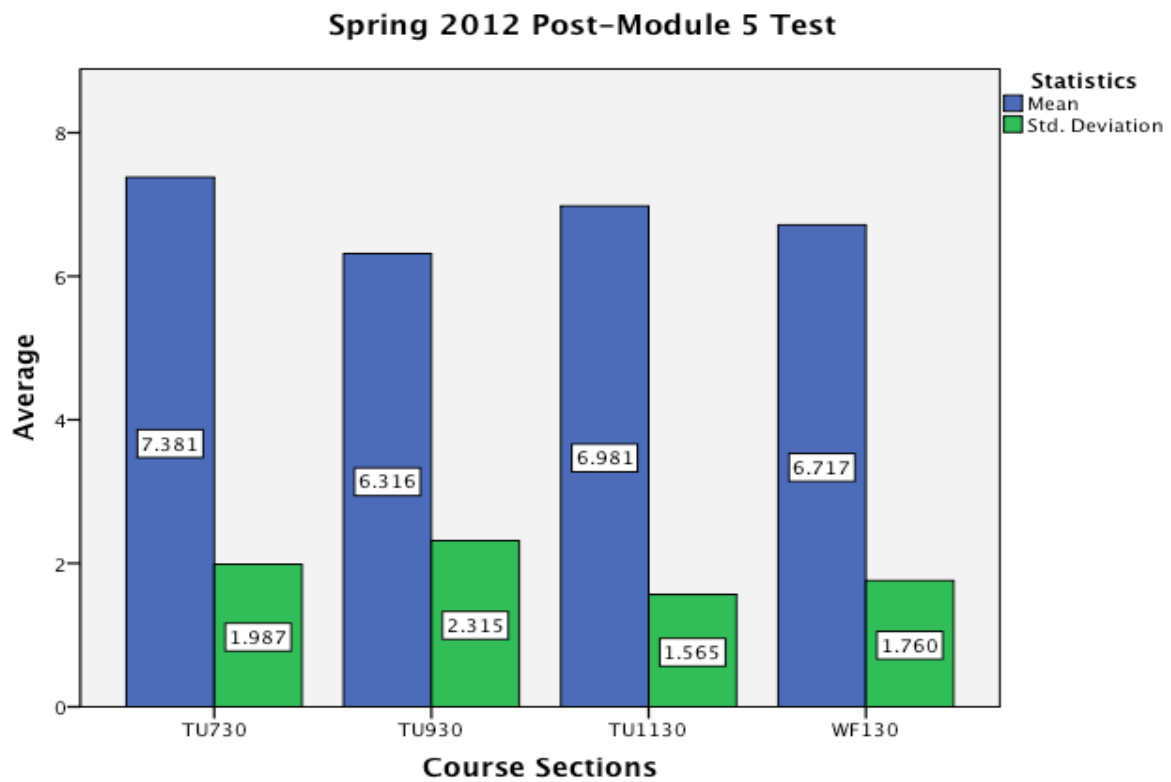


Figure 8: Descriptive statistics from the Spring 2012 post-module 5 test.

Results from the one-way ANOVA, shown in figure 9, indicate that post-module 5 test score means were statistically significantly different suggesting that students in experimental course sections gained a better understanding of photosynthesis.

Spring 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	21.421	1	21.421	5.900	.016
Within Groups	715.293	197	3.631		
Total	736.714	198			

Figure 9: One-way ANOVA results from the Spring 2012 post-module 5 test

Results from the daily online quiz only included students who had been verified by K-State Online as having viewed their assigned media. Because the daily online quiz is part of the normal coursework required by all BIOL 198 students and applies to their final grade, it was imperative to only record and analyze scores for those who had chosen to participate in the research study. Results of descriptive statistics for the daily online quiz are shown in figures 10 and 11.

Spring 2012

	TU730 (EXP)	TU930 (CON)	TU1130 (EXP)	WF130 (CON)
N	54	58	43	47
Mean	.7926	.6828	.7581	.6596
Std. Deviation	.25168	.23406	.26388	.28564

Figure 10: Descriptive statistics from the Spring 2012 daily online quiz.

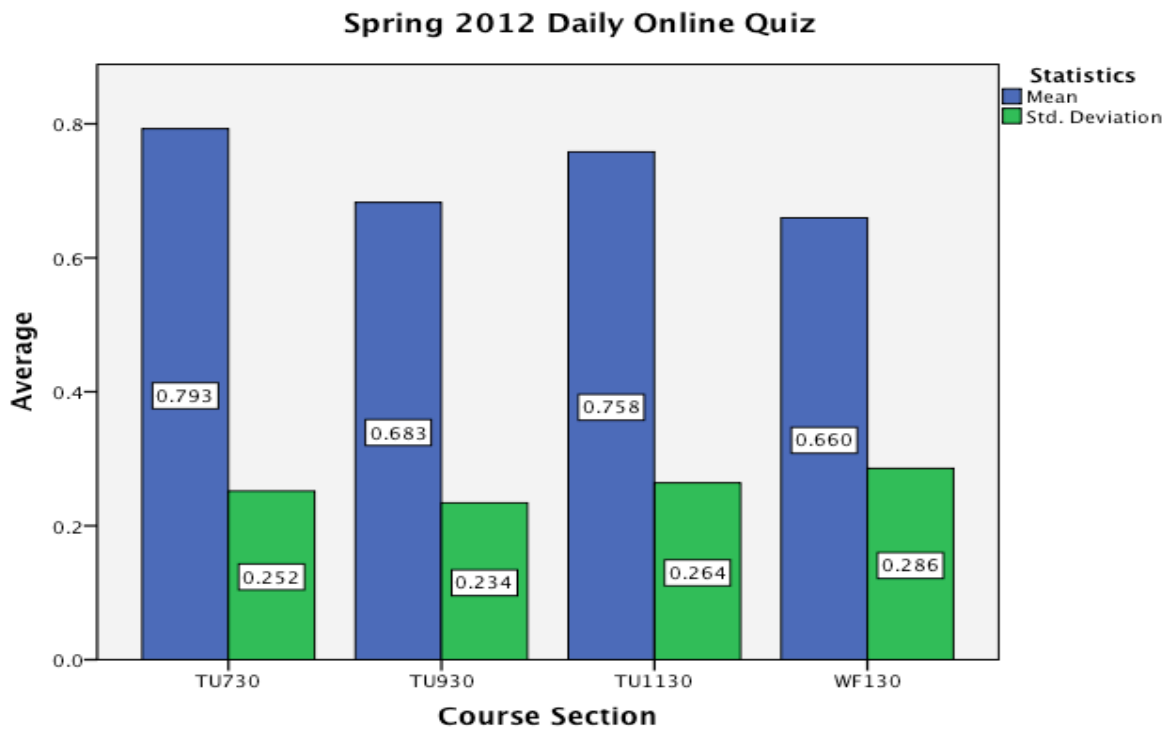


Figure 11: Descriptive statistics from the Spring 2012 daily online quiz.

In addition to descriptive statistics, a one-way ANOVA was performed to assess if the daily quiz score means were significantly different between treatments. Results, shown in figure 12, indicate that a statistically significant difference exists between the daily online quiz score means between treatments, suggesting that students in experimental course sections gained a better understanding of photosynthesis.

Spring 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.555	1	.555	8.413	.004
Within Groups	13.200	200	.066		
Total	13.755	201			

Figure 12: One-way ANOVA results from the Spring 2012 daily online quiz.

Unit exam scores were also assessed between treatments. Descriptive statistics are shown in figures 13 and 14.

Spring 2012

	TU730 (EXP)	TU930 (CON)	TU1130 (EXP)	WF130 (CON)
N	68	70	73	72
Minimum	7.00	9.00	7.00	7.00
Maximum	30.00	29.00	30.00	30.00
Mean	22.0441	21.1000	21.5342	19.6667
Std. Deviation	5.34883	5.03077	5.09107	5.37076

Figure 13: Descriptive statistics from the Spring 2012 unit exam.

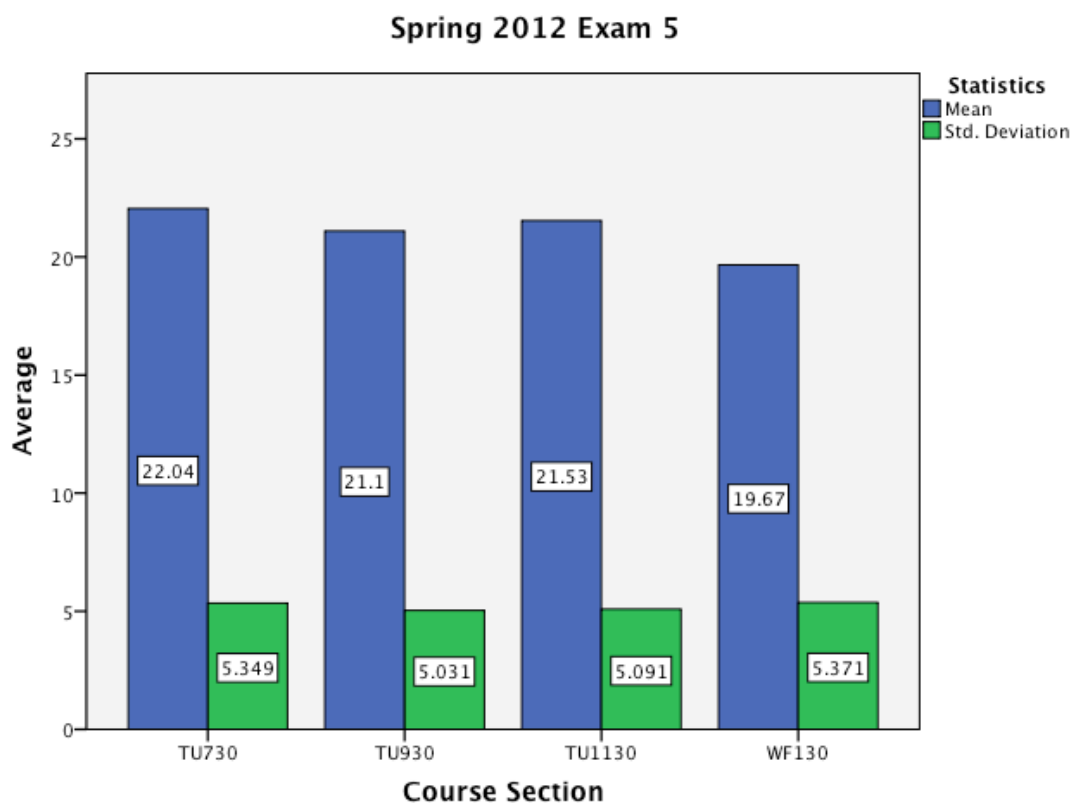


Figure 14: Descriptive statistics from the Spring 2012 unit exam.

In addition to descriptive statistics, a one-way ANOVA was performed to assess if unit exam score means were significantly different between treatments. Results, shown in figure 15, indicate that a statistically significant difference exists between unit exam scores by treatment, suggesting that students in experimental course sections not only gained a better understanding of photosynthesis, but were also able to retain this information.

Spring 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	140.039	1	140.039	5.138	.024
Within Groups	7659.403	281	27.258		
Total	7799.442	282			

Figure 15: One-way ANOVA results from the Spring 2012 unit exam.

Results supporting the second research question include data from the post-module 5 test between treatments by gender. Because the control group contained fewer female participants (n=44) than the experimental group (n=66), data was stratified by treatment before analyses were completed. Results are shown in figure 16.

Spring 2012

TREATMENT	N	Mean	Std. Deviation	Std. Error Mean
SCORE Multimedia	66	7.1818	1.88034	.23145
Text	44	6.3864	2.13733	.32221

Figure 16: Post-module 5 test results of female participants stratified by treatment.

As shown in figure 17, there is a statistically significant difference between mean post-module 5 scores of females between treatment groups, suggesting that females benefit from the use of multimedia.

Spring 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	16.705	1	16.705	4.232	.042
Within Groups	426.250	108	3.947		
Total	442.955	109			

Figure 17: Results of one-way ANOVA performed on post-module 5 test results of female participants stratified by treatment.

Descriptive statistics were performed on the post-module 5 scores for males between treatment groups. Results are shown in figure 18.

Spring 2012

TREATMENT	N	Mean	Std. Deviation	Std. Error Mean
SCORE Multimedia	49	7.2245	1.73524	.24789
Text	40	6.7000	1.91083	.30213

Figure 18: Post-module 5 test results of male participants by treatment.

The difference between the mean post-module 5 scores of males between treatment groups was not statistically significant, as depicted in figure 19, suggesting that the use of multimedia for learning complex and abstract scientific concepts is not as beneficial for males as it is for females. The number of participants in the control group (n=39) was similar to the number of participants in the experimental group (n=49). Stratification by treatment was not performed.

Spring 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.058	1	6.058	1.837	.179
Within Groups	286.931	87	3.298		
Total	292.989	88			

Figure 19: Results of one-way ANOVA performed on post-module 5 test results of male participants stratified by treatment.

Comparing the pre-module 5 test scores by gender with post-module 5 test scores by gender within experimental groups provided additional support regarding the effects of multimedia by gender. As shown in figures 20 and 21, the pre-module 5 test descriptive statistics highlight a lower prior knowledge level for females. However, descriptive statistics for the post-module 5 test illustrate equivalent scores for males and females suggesting that the use of multimedia for females is beneficial. While the difference between scores was not statistically significant, the implications of these results are discussed in the following chapter.

Spring 2012

GENDER		N	Mean	Std. Deviation	Std. Error Mean
SCORE	Female	80	5.0325	1.70140	.19022
	Male	58	5.4138	1.58982	.20875

Figure 20: Descriptive statistics for the pre-module 5 test by gender within experimental groups.

Spring 2012

GENDER		N	Mean	Std. Deviation	Std. Error Mean
SCORE	Female	66	7.1918	1.88034	.23145
	Male	49	7.2045	1.73524	.24789

Figure 21: Descriptive statistics for the post-module 5 test by gender within experimental groups.

The third research question entailed the use of qualitative methods for gaining feedback about the content and specific features of the multimedia module. This information was attained from students, graduate teaching assistants, and faculty instructors directly involved with the BIOL 198 course during the Spring 2012 semester. Feedback was condensed into two groups, students and instructors, and assessed for emerging themes. These themes were compared to Mayer's (2001, 2009) principles of multimedia learning. Collectively this information was used to improve the multimedia for the next research iteration. Figures 22 and 23 illustrate the emerging themes garnered from students and instructors.

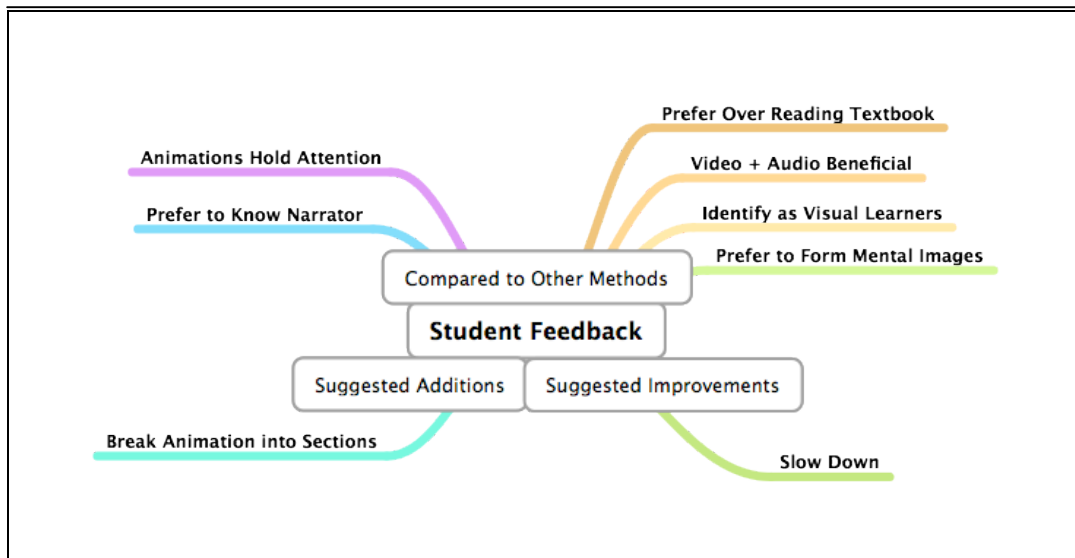


Figure 22: Emerging themes from students regarding their use of the multimedia module for learning concepts related to photosynthesis.

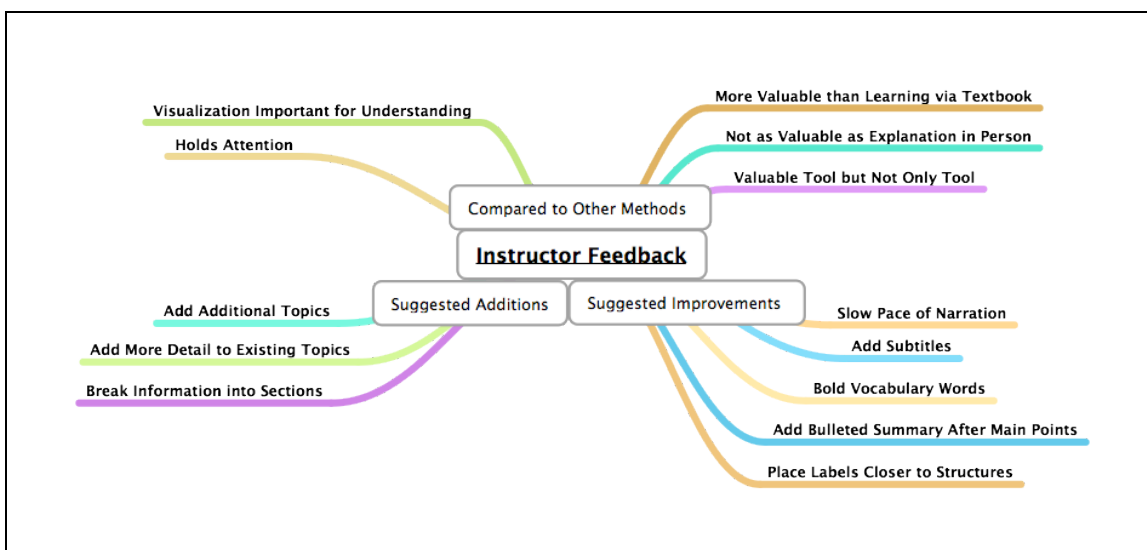


Figure 23: Emerging themes from instructors regarding their views of using multimedia as a tool for teaching photosynthesis.

Emerging themes from students and instructors were then compared to Mayer’s (2001, 2009) principles for multimedia learning, which included coherence, signaling, redundancy, spatial contiguity, and temporal contiguity. Feedback received was divided into two sections: comments related to format or design and comments related to content perhaps in need of correction. Results are shown in tables 4 and 5.

	Coherence	Signaling	Redundancy	Spatial Contiguity	Temporal Contiguity
Student Comments	Helpful to have a familiar narrator using familiar words	Break into sections	Video + audio beneficial	N/A	Slow down
Instructor Comments	Use same phrasing throughout narration	Break into sections, Add bulleted summaries after each section	More valuable for learning photosynthesis than textbook, Visualization of processes important for understanding	Add subtitles, Bold vocabulary words, Place labels closer to structures	Slow pace of narration, Narration and visuals need better alignment

Table 4: Comments on format or design from students and instructors organized by Mayer’s (2001, 2009) principles of multimedia learning.

Feedback from instructors regarding inaccuracies or confusing concepts found within the multimedia was also compiled. Most of these centered on the chemical reactions taking place during the reduction and oxidation reactions of the Calvin-Benson Cycle and the way in which the reactions had been portrayed in the multimedia. These corrections, and their relation to Mayer's (2001, 2009) principles of multimedia learning, are detailed in figure 25. For example, clarifying the inaccuracies regarding the reduction of NADP to NADPH in an effort to increase student comprehension agrees with Mayer's (2001, 2009) multimedia principle of coherence.

	Coherence	Signaling	Redundancy	Spatial Contiguity	Temporal Contiguity
Edits	Simplified visuals related to addition of electrons to NADP to form NADPH, Simplified photosynthesis equation, Clarified thylakoid membrane structure, Clarified difference between thylakoids and granum, Clarified difference between rubisco and ribulose biphosphate, Describe process of photolysis, Clarified details of carbon reactions	Added bulleted review sections between main ideas presented in multimedia module, Emphasized that ATP and NADPH are both examples of energy sources in introduction and summary slides, Added subtitles explaining most complex portions of photosynthesis	Increased labeling of structures, All labels formatted with bold text	Moved labels closer to structures	Labels to structures appeared right as words spoken, Speed of information presented slowed and resulted in overall length of multimedia module gaining 1 minute and 45 seconds

Table 5: Content edits made to the multimedia module organized by Mayer's (2001, 2009) principles of multimedia learning.

Collectively, feedback received from students and instructors was used to edit and improve upon the multimedia module before it was released to the next set of BIOL 198 students during the Summer 2012 semester.

Research Iteration 2

The second research iteration took place during the summer semester of 2012. Only one course section was offered and was assigned to the experimental treatment. While no comparisons could be made to a control group for the summer semester, eliminating the ability to provide data in regards to the first research question, results were used to compare male and female performances on tests. This allowed for data and results to be collected and quantitatively analyzed in regards to the second research question. In addition, qualitative data were collected and analyzed in regards to the third research question.

No pre-semester test was administered in the summer. Results for this iteration begin with the pre-module 5 test as shown in figure 24.

Summer 2012				
TREATMENT	N	Mean	Std. Deviation	Std. Error Mean
Score Female	46	4.6522	2.20320	.32484
Score Male	22	5.4545	1.89554	.40413

Figure 24: Pre-module 5 test descriptive statistics for the Summer 2012 BIOL 198 section.

Due to the low number of males enrolled in and volunteering to participate in the study (n=22), the distribution of scores was assessed for normality. The histogram, shown in figure 25, reveals that pre-module 5 scores were distributed normally about the mean.

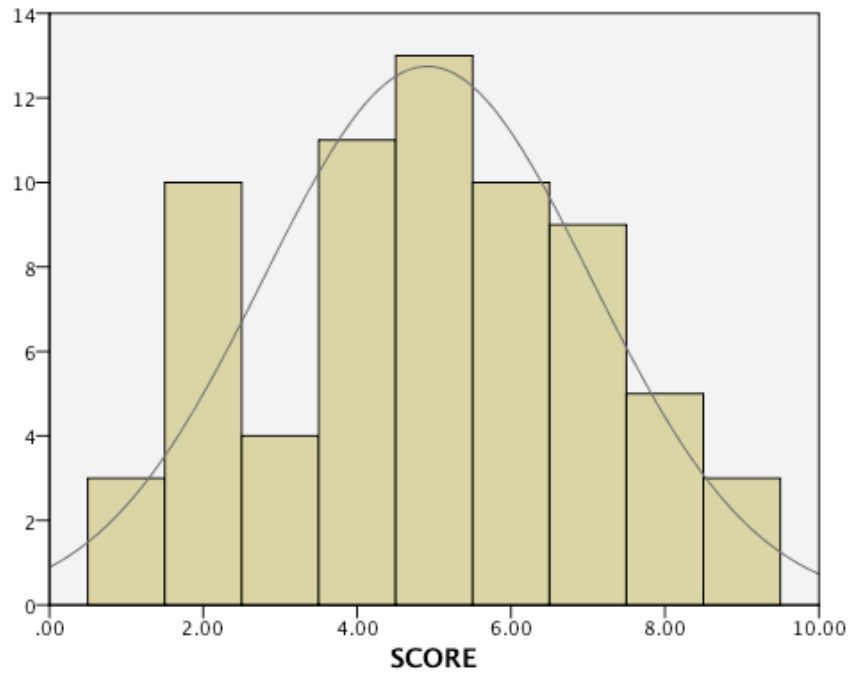


Figure 25: Pre-module 5 test histogram checking for normality of score distributions.

A one-way ANOVA was performed to assess if any differences existed between the performance of males and females on the pre-module 5 test. Results, shown in figure 26, indicate that there was no statistically significant difference between the means of this test.

Summer 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.581	1	9.581	2.152	.147
Within Groups	293.889	66	4.453		
Total	303.471	67			

Figure 26: Results from a one-way ANOVA indicate that pre-module 5 test means were not statistically significantly different between males and females.

Quantitative analyses supporting the second research question include results of the post-module 5 test. Due to a disproportionate number of female participants (n=36) versus male participants (n=13), results were stratified by gender. Results of descriptive statistics are shown in figure 27.

Summer 2012

GENDER		N	Mean	Std. Deviation	Std. Error Mean
Score	Female	36	6.6389	2.00218	.33370
	Male	13	6.0000	2.41523	.66986

Figure 27: Post-module 5 test descriptive statistics from the Summer 2012 section.

Due to the number of male participants being less than 30, the distribution of scores from the post-module 5 test was assessed for normality. The results are illustrated in the histogram shown in figure 28.

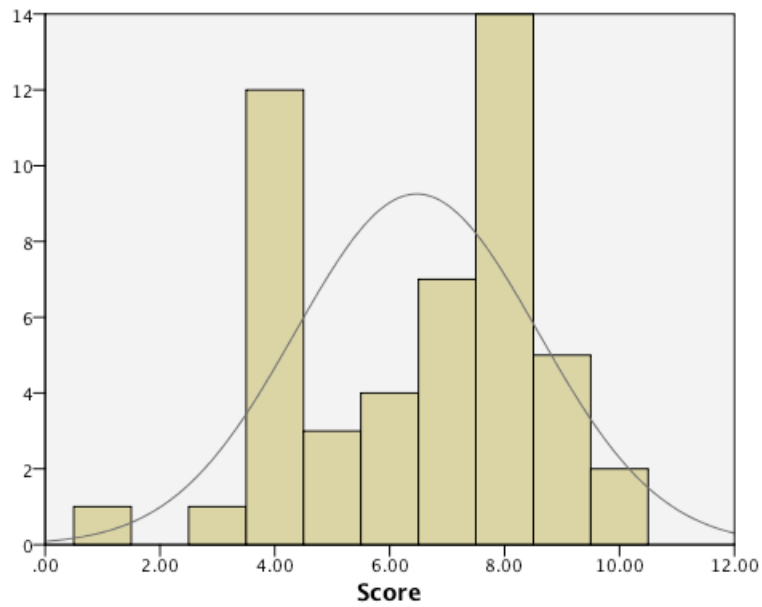


Figure 28: Post-module 5 test histogram checking for normality of score distributions.

Given the bimodal distribution of scores a nonparametric test was used to analyze the shape and distributions between genders. Results are shown in figure 29.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Score is the same across categories of GENDER.	Independent-Samples Mann-Whitney U Test	.555	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 29: Results of Mann-Whitney test for distribution of nonparametric data.

The null hypothesis, which stated that the distributions were equal, was maintained. With this information a Kolmogorov-Smirnov test was performed to evaluate the difference between post-module 5 test scores by gender. Results, shown in figure 30, suggest that females gained a better understanding of photosynthesis compared to their male counterparts.

Kolmogorov-Smirnov Test, Summer 2012

			Score	GENDER
N			49	49
Normal Parameters ^{a,b}	Mean		6.4694	1.2653
	Std. Deviation		2.11248	.44607
Most Extreme Differences	Absolute		.194	.459
	Positive		.165	.459
	Negative		-.194	-.276
Kolmogorov-Smirnov Z			1.359	3.211
Asymp. Sig. (2-tailed)			.050	.000
	Sig.		.046 ^c	.000 ^c
Monte Carlo Sig. (2-tailed)	99% Confidence Interval	Lower Bound	.040	.000
		Upper Bound	.051	.000

Figure 30: Results of Kolmogorov-Smirnov test supporting that there was a statistically significant difference in post-module 5 means by gender.

The third research question entailed the use of qualitative methods for gaining feedback regarding the content and specific features of the multimedia module. This information was attained from students, graduate teaching assistants, and faculty instructors directly involved with the BIOL 198 course during the Summer 2012 semester. Feedback was condensed into two groups, students and instructors, and assessed for emerging themes. These themes, again categorized as either being related to format or content, were compared to Mayer's (2001, 2009) principles of multimedia learning. Collectively this information was used to improve the

multimedia for the next research iteration. Figures 31 and 32 illustrate the emerging themes garnered from students and instructors.

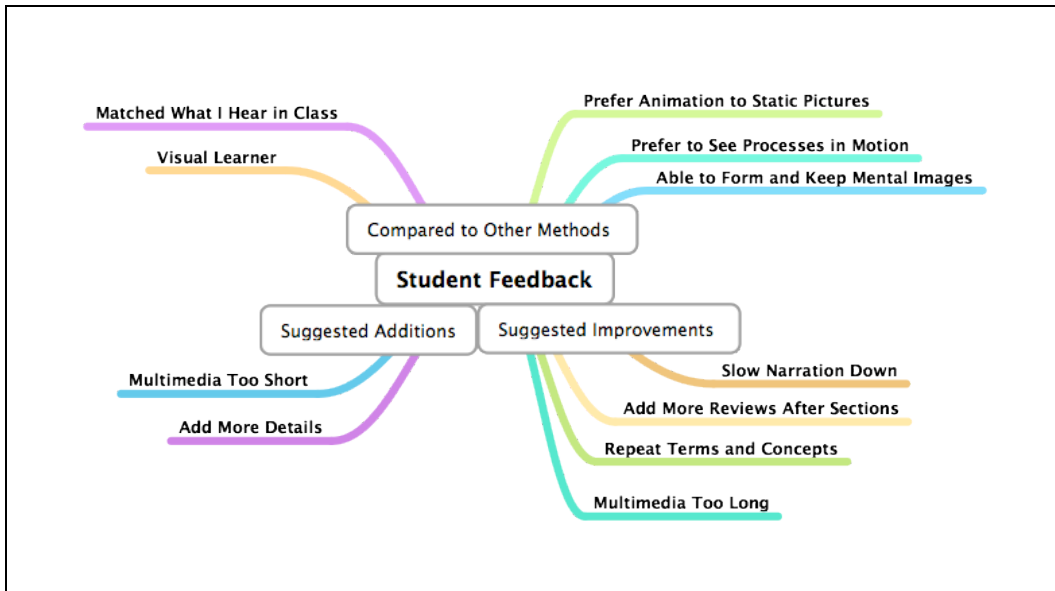


Figure 31: Emerging themes about format and design from students regarding their use of the multimedia module for learning concepts related to photosynthesis.

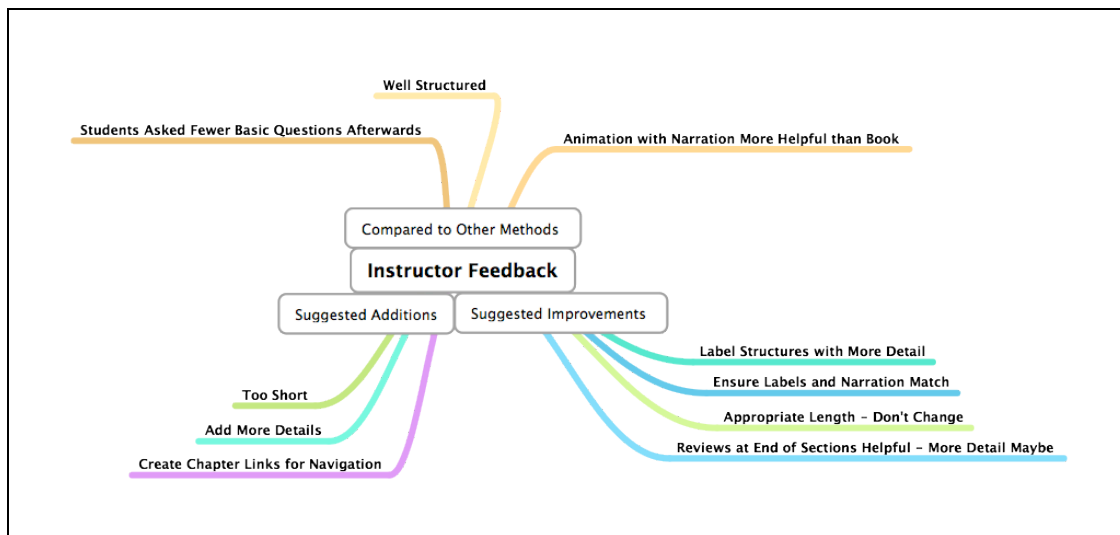


Figure 32: Emerging themes regarding format and design from instructors regarding their views of using multimedia as a tool for teaching photosynthesis.

Emerging themes from students and instructors were then compared to Mayer’s (2001, 2009) principles for multimedia learning. Results are shown in table 6.

	Coherence	Signaling	Redundancy	Spatial Contiguity	Temporal Contiguity
Student Comments	Add more content, Make narration less formal	Introduction and reviews at end of sections helpful, Add more reviews at end of each section	Visual + audio beneficial, Prefer to see processes in motion	N/A	Verbally repeat what is shown in animation
Instructor Comments	Well structured for this level of learning, Wonder if these graphics will confuse students as they are different than textbook	Reviews at end of each section helpful, Create links at very end leading back to each section	Visual + audio beneficial, Visualization of processes important for understanding	Add more details to labels	Ensure labels match narration exactly

Table 6: Emerging themes from students and instructors organized by Mayer’s (2001, 2009) principles of multimedia learning.

Feedback from instructors regarding inaccuracies or confusing concepts found within the multimedia was also compiled. These corrections, and applications to Mayer’s (2001, 2009) principles of multimedia learning, are detailed in table 7.

	Coherence	Signaling	Redundancy	Spatial Contiguity	Temporal Contiguity
Edits	Clarified process of photolysis, Continued to clarify details of carbon cycle	N/A	Fixed discrepancy between visual labeled “electron transfer chain” and verbalization of “electron transport chain”	N/A	Followed the movement of carbon atoms as described verbally during the carbon cycle

Table 7: Resulting edits made to the multimedia module organized by Mayer’s (2001) principles of multimedia learning.

Collectively, feedback received from students and instructors was used to edit and improve upon the multimedia module before it was released to the next set of BIOL 198 students during the Fall 2012 semester. Overall the amount of comments related to format, design, and content became fewer in number and more consistent in theme compared to the first iteration. This reflects the benefit of using a design-based research process.

Research Iteration 3

The third iteration of the design-based research process took place during the Fall 2012 semester. After assessing descriptive statistics on pre-semester test scores for all eight sections of BIOL 198 offered, four sections were selected to participate. These four sections performed similarly on the pre-semester test and again fit the requirements of NEGD. Selected sections include TU 730, TU 930, WF 1130, and WF 130. Sections labeled TU 1130, WF 730, and WF 930 were not included as their means represented outliers. In addition, the section labeled TU 130 was not chosen to participate as it was reserved for pre-med majors and did not contain the

same student body composition as other sections. Descriptive statistics for the pre-semester exam are shown in figure 33.

Fall 2012

	TU730	TU930	TU1130	TU130	WF730	WF930	WF1130	WF130
N	70	71	74	71	72	69	73	71
Minimum	4.00	3.00	4.00	2.00	4.00	1.00	2.00	4.00
Maximum	14.00	14.00	13.00	13.00	14.00	13.00	15.00	14.00
Mean	8.22	8.248	7.803	8.274	8.471	7.955	8.04	8.181
Std. Deviation	2.10864	2.54773	2.18443	2.48075	2.06350	2.38959	2.50927	2.24711

Figure 33: Descriptive statistics from the Fall 2012 pre-semester test given to all course sections of BIOL 198.

The TU 730 and WF 1130 course sections were randomly assigned to receive the experimental treatment and the TU 930 and WF 130 course sections were randomly assigned to receive the control treatment.

Approximately one week before the beginning of the photosynthesis module another test, the pre-module 5 test, was administered to the four participating course sections. The purpose of this test was to assess if any differences existed amongst the participating course sections specifically regarding their pre-existing knowledge of photosynthesis. Because this test occurred approximately 2 months after the pre-semester exam had been given, the number of students enrolled in each section had changed. In addition, only students who chose to be part of the voluntary study completed the pre-module 5 test. Figure 34 shows the results of the pre-module 5 test.

Fall 2012

	TU730(EXP)	TU930(CON)	WF1130(EXP)	WF130(CON)
N	58	63	66	60
Minimum	1.00	1.00	.00	.00
Maximum	8.00	9.00	9.00	10.00
Mean	4.3966	5.0000	4.9242	5.6667
Std. Deviation	1.75659	1.80501	1.83396	2.06395

Figure 34: Descriptive statistics from the pre-module 5 test.

In addition to the descriptive statistics, a one-way ANOVA was performed to assess if the differences between the pre-module 5 test means were significantly different amongst the participating course sections before the treatment was administered. The results, shown in figure 35, reveal that pre-module 5 test score means between sections were statistically significantly different.

Fall 2012

SCORE	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	25.911	1	25.911	7.296	.007
Within Groups	870.089	245	3.551		
Total	896.000	246			

Figure 35: Pre-module 5 one-way ANOVA results.

Results of the one-way ANOVA indicating that the means of the pre-module 5 test were statistically significantly different were unexpected. Participating sections were believed to be relatively equivalent at the start of the semester when sections were chosen and randomly assigned to a treatment. A one-way ANOVA performed on the pre-semester test results of participating sections, shown in figure 36, revealed a more homogenous set of course sections at the beginning of the semester when assignment to treatment groups was performed:

Fall 2012

SCORE	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.202	1	5.202	.934	.335
Within Groups	1576.040	283	5.569		
Total	1581.242	284			

Figure 36: Pre-semester test one-way ANOVA results.

Implications of this discrepancy between participating course sections on the pre-module 5 test, especially in regards to the requirements for NEGD, are discussed in the following chapter.

Quantitative analyses supporting the first research question include results from the post-module 5 test and the daily online quiz. Figures and a brief description of each analysis are discussed in turn.

Results from the post-module 5 test consist of descriptive statistics and ANOVAs. Because participation in the study was voluntary, the number of participants was lower than the number enrolled in each section as well as the number of students taking the pre-module 5 test. Figures 37 and 38 illustrate the means and standard deviations of the post-module 5 test for each participating course section.

Fall 2012

	TU730EXP	TU930CONT	WF1130EXP	WF130CONT
N	56	59	55	39
Minimum	2.00	2.00	1.00	2.00
Maximum	10.00	10.00	10.00	10.00
Mean	6.8393	6.1017	6.3273	6.5385
Std. Deviation	1.97048	2.15515	2.45745	1.71443

Figure 37: Descriptive statistics for the post-module 5 test.

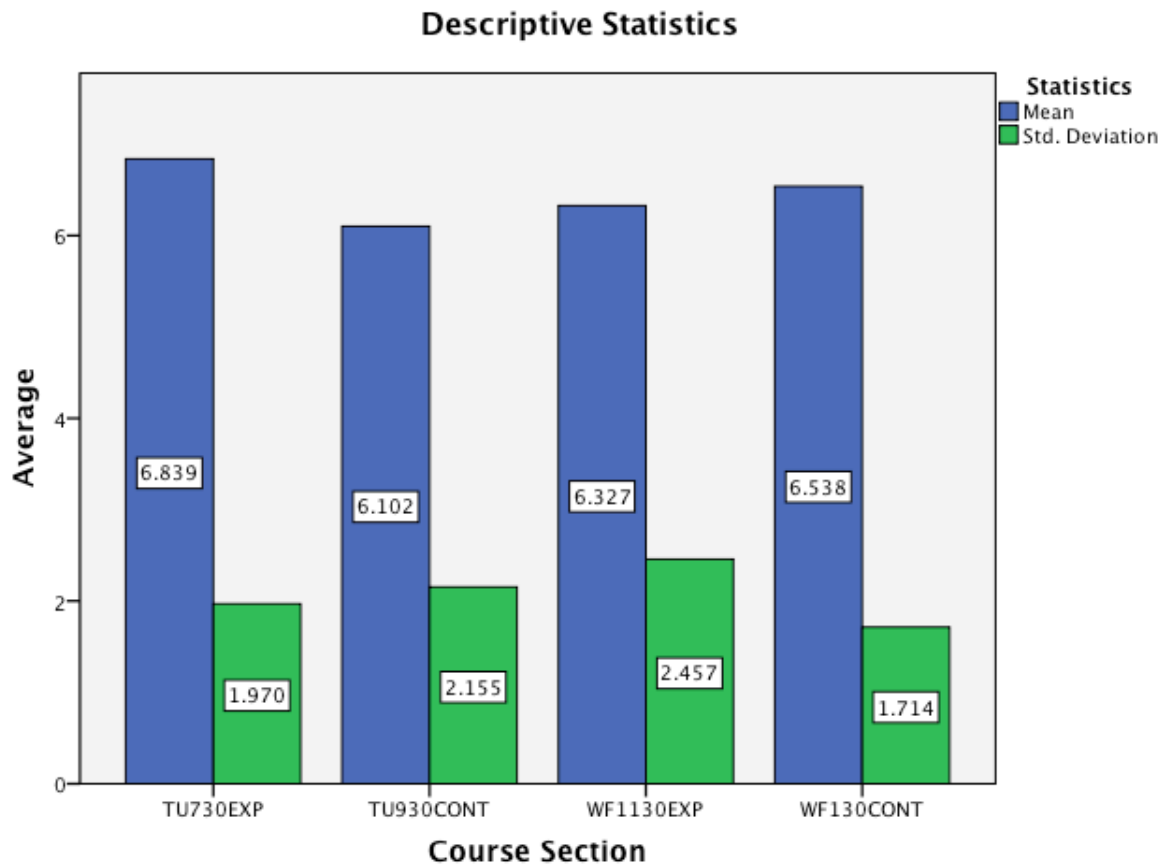


Figure 38: Descriptive statistics for the post-module 5 test.

Results from a one-way ANOVA, shown in figure 39, indicate that post-module 5 test score means were not statistically significantly different between the four participating course sections suggesting that the use of multimedia for learning complex and abstract concepts is not beneficial. However, when comparing the TU 730 section with the TU 930 section as shown in figure 40, the difference in means between the two sections on the post-module 5 test is statistically significantly different which does perhaps suggest a benefit provided by multimedia.

Fall 2012

SCORE	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.004	1	5.004	1.111	.293
Within Groups	932.498	207	4.505		
Total	937.502	208			

Figure 39: One-way ANOVA results for the post-module 5 test comparing mean scores for all four sections.

Fall 2012

EXPSCORE730 vs CON930	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.181	1	17.181	4.117	.045
Within Groups	471.515	113	4.173		
Total	488.696	114			

Figure 40: One-way ANOVA results for the post-module 5 test comparing mean scores for the TU 730 experimental section and the TU 930 control section.

Results from the daily online quiz regarding the experimental groups only included students who had been verified by K-State Online as having viewed the multimedia. Because the daily online quiz is part of the normal coursework required of all BIOL 198 students and applies to their final grade, it was imperative to only record and analyze scores for those who had chosen to participate in the research study. A disparity exists between the numbers of participants in the experimental and control sections due the inability to verify if students in the control sections had voluntarily read the control narration, had been given additional learning materials, or had

been told to participate. As a result, the scores from all students in the control sections were used in the data analysis. Results of descriptive statistics for the daily online quiz are shown in figures 41 and 42.

Fall 2012

	TU730EXP	TU930CONT	WF1130EXP	WF130CONT
N	52	72	47	70
Minimum	.00	.00	.00	.00
Maximum	1.00	1.00	1.00	1.00
Mean	.6346	.4792	.4947	.4679
Std. Deviation	.30301	.29891	.32340	.30669

Figure 41: Descriptive statistic results for the daily online quiz.

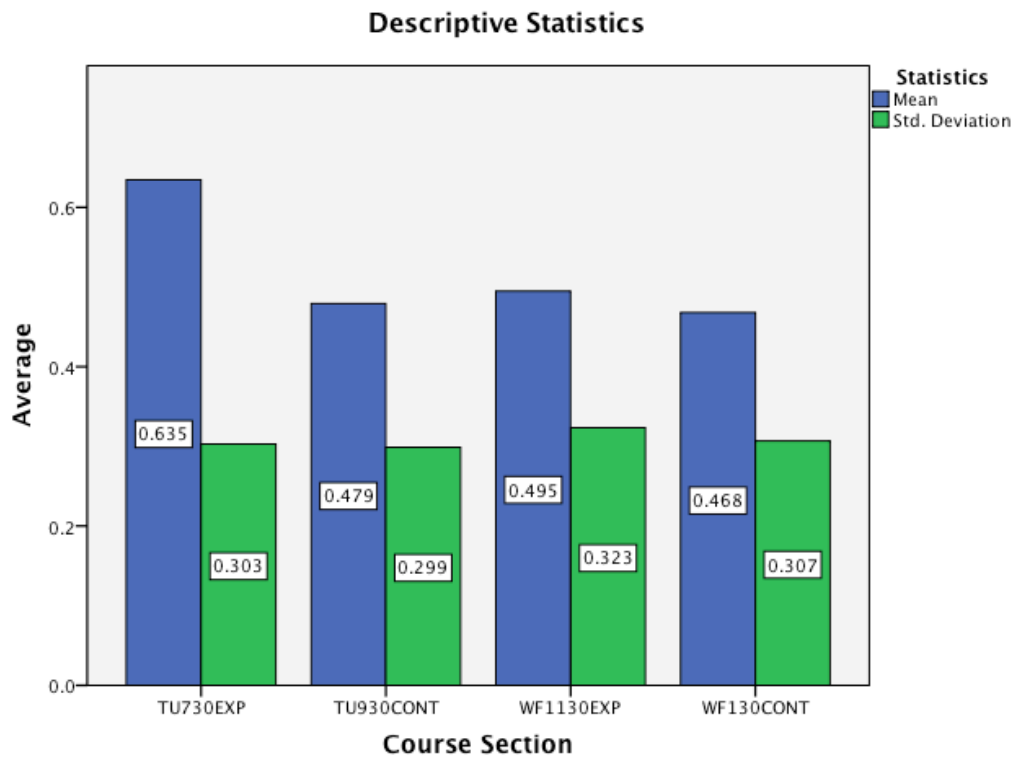


Figure 42: Descriptive statistic results for the daily online quiz.

In addition to descriptive statistics, a one-way ANOVA was performed to assess if the daily quiz score means were significantly different between treatments. Results, shown in figure 43, indicate that a statistically significant difference exists between the daily online quiz score means between treatments. This suggests that the use of multimedia for improving student comprehension when learning complex and abstract concepts is beneficial. Due to the disparity in the number of participants between treatments, daily quiz scores were stratified by treatment.

Fall 2012

SCORE	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.366	1	.366	3.953	.048
Within Groups	21.681	234	.093		
Total	22.047	235			

Figure 43: Results from a one-way ANOVA performed between the four participating sections on the daily online quiz.

Due to validity threats suffered during the Fall 2012 semester, results of the quiz were further broken down by comparing the TU 730 and TU 1130 experimental sections to the TU 930 control section as the WF 130 section suffered serious confounds. Because sample sizes were larger due to the combination of experimental sections, data was stratified by treatment. Results, shown in figures 44 and 45, indicate that the use of multimedia is beneficial for students learning complex and abstract concepts and agree with the results from the daily online quiz.

Fall 2012

TREATMENT		Statistic	Bootstrap ^a				
			Bias	Std. Error	95% Confidence Interval		
					Lower	Upper	
SCORE	N	99					
	Multimedia	Mean	.5707	-.0009	.0322	.5076	.6338
		Std. Deviation	.31550	-.00222	.01466	.28429	.34116
		Std. Error Mean	.03171				
		N	72				
	Text	Mean	.4792	.0001	.0337	.4132	.5451
	Std. Deviation	.29891	-.00250	.01882	.25828	.33343	
	Std. Error Mean	.03523					

a. Unless otherwise noted, bootstrap results are based on 1000 stratified bootstrap samples

Figure 44: Results of descriptive statistics performed on daily online quiz scores between the combined scores of the TU 730 and TU 1130 experimental sections and the TU 930 control section.

Bootstrap for Independent Samples Test, Fall 2012

SCORE	Mean Difference	Bootstrap ^a				
		Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
					Lower	Upper
Equal variances assumed	.09154	-.00106	.04491	.036	.00474	.17581
Equal variances not assumed	.09154	-.00106	.04491	.038	.00474	.17581

a. Unless otherwise noted, bootstrap results are based on 1000 stratified bootstrap samples

Figure 45: Results from a t-test performed on daily online quiz scores between the combined scores of the TU 730 and TU 1130 experimental sections and the TU 930 control section

Quantitative analyses supporting the second research question yielded interesting, yet unexpected results. Data highlighting gender differences from the pre-module 5 test, post-module 5 test, and daily online quiz for students in experimental sections are presented. Results lend support for the use of multimedia for males, however, as opposed to females. The reasons

and significance of this, which center on the benefit multimedia can provide to students with lower-prior knowledge levels, are discussed in the following chapter.

Analysis of scores by gender on the daily online quiz yielded statistically significant results. Daily online quiz scores were not compared between gender and treatments due to confounds discussed in the following chapter. The only verifiable daily quiz score results that could be used to answer the second research question came from course sections assigned to use the multimedia as use could be verified via K-State Online. The descriptive statistics and one-way ANOVA are shown in figures 46 and 47 respectively.

Fall 2012

GENDER		N	Mean	Std. Deviation	Std. Error Mean
Score	Female	55	.5045	.2945	.0397
	Male	44	.6534	.3244	.0489

Figure 46: Daily online quiz descriptive statistics results by gender for participants in the experimental treatment groups.

Fall 2012

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.542	1	.542	5.703	.019
Within Groups	9.213	97	.095		
Total	9.755	98			

Figure 47: One-way ANOVA results for daily online quiz by gender for participants in the experimental treatment groups.

The differences between male and female student performance on the pre-module 5 and post-module 5 test, while not statistically significant as determined by a one-way ANOVA, are included in figures 48 and 49. They illustrate the gains made by students having lower-prior knowledge after using multimedia. The significance of this is discussed in the following chapter.

Fall 2012

GENDER		N	Mean	Std. Deviation	Std. Error Mean
Score	Female	71	4.9014	1.85284	.21989
	Male	53	4.3774	1.72344	.23673

Figure 48: Pre-module 5 test descriptive statistics by gender for participants in the experimental treatment groups.

Fall 2012

GENDER		N	Mean	Std. Deviation	Std. Error Mean
Score	Female	58	6.3966	2.40569	.31588
	Male	53	6.7925	2.02255	.27782

Figure 49: Post-module 5 test descriptive statistics by gender for participants in the experimental treatment groups.

Results supporting the third research question were attained via qualitative research methods where feedback was solicited from students enrolled in the fall BIOL 198 section and who had used the multimedia module for learning about the process of photosynthesis. Questions asked of students were different compared to previous research iterations and were more concerned with social validity issues as opposed to their opinions about certain multimedia features. The third research iteration represented the last iteration of the study. Gaining student feedback about certain features that were confusing or that could be improved upon was not the goal although some students did note features they liked or that could be improved. The amount of information received during this iteration was much greater than in previous iterations. It is believed that this is a result of changing the way in which feedback was gathered and the phrasing of the questions. For example, the researcher relied exclusively on embedded questions within the daily online quiz and softened to the wording to pull more personal preference statements from students.

Figure 50 illustrates emerging themes from student feedback regarding the use of multimedia for learning complex and abstract topics such as photosynthesis.

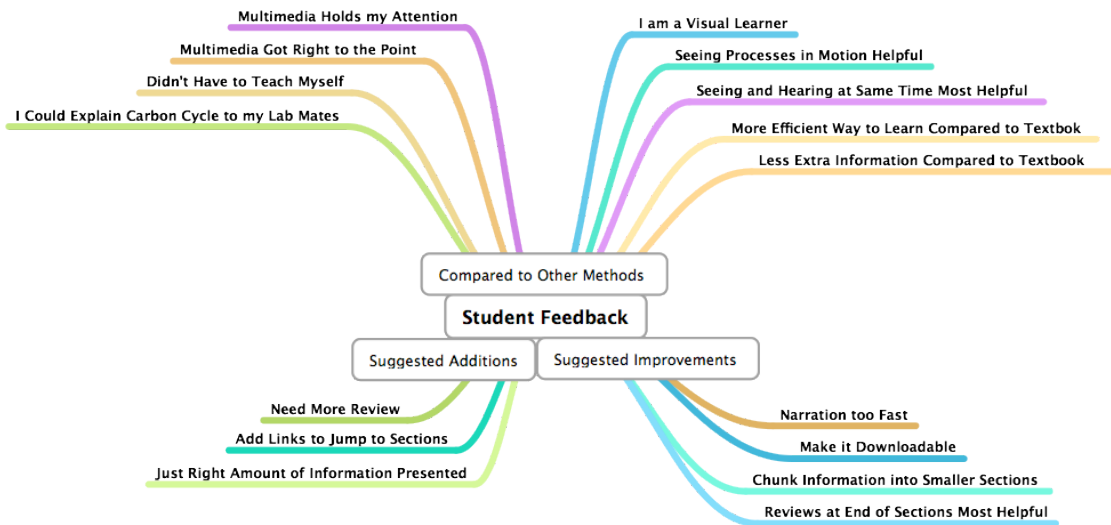


Figure 50: Emerging themes related to format and design from students regarding their use of the multimedia module for learning concepts related to photosynthesis.

Confounds Suffered during Fall 2012 Iteration

The Fall 2012 semester resulted in unexpected complications. Because the first two iterations had gone smoothly, it was assumed that the third and final iteration would as well, especially as many unknowns regarding the study had been addressed in previous semesters. However, the third iteration of research was conducted under different conditions due to the lack of support from instructors as well as others associated with the course. It is believed that the change in attitude towards the study and the negative atmosphere in which the study was conducted, resulted in fewer significant findings during the third iteration of research.

Of specific concern are internal threats to validity involving history and selection. Some sections selected to serve as control groups received additional or supplemental material to increase their understanding of photosynthesis. This most likely impacted the results of the post-module 5 test and daily online quiz. In addition, some instructors of the control section removed the control narration from K-State Online where its use could be tracked and instead posted it elsewhere and distributed a few copies during class. While this was most likely not done intentionally to harm the results as some apologized afterwards stating they were just trying to help, the impact on the study remained the same.

In addition, during the administration of the pre-module 5 test and post-module 5 test where students were asked to volunteer for the study and fill out the exam during class, the instructor of one control section kept making announcements to students using a microphone. While the researcher asked the instructor to refrain and wait until the end of the exam, the distraction this presented to students represents a notable confound. This same instructor then changed all student grades on the daily online quiz to 100%, erasing the researcher's ability to analyze score differences between this control group and experimental groups.

Despite these confounds, the data from this semester still indicate a positive relationship between the use of multimedia for increasing the amount of information students comprehend about complex and abstract concepts. This perhaps reaffirms the use of this method; it continues to help students even when conditions are poor.

Chapter 5 - Discussion and Conclusion

Overview

The overall purpose of this study was to examine the use of multimedia within a college biology course in an effort to assess its value for increasing student comprehension and retention when learning complex and abstract scientific concepts. Because a large discrepancy exists between the current number of students pursuing and completing STEM degrees and the number of scientists that will be required in the future (AAAS, 1990; Annetta et al., 2010), novel teaching methods are needed to recruit and retain more students in the sciences. This is especially true of females where their participation within the STEM fields is generally much lower.

The low number of females within the sciences is a result of many causes; however, one large contributing factor includes the discouraging experiences females accumulate while enrolled in science courses. Unlike some factors related to social pressures and norms, such as those associated with hidden curriculums, classroom experiences can be improved upon via research grounded in educational theories and tested in real classroom settings. As described in this study, the learning preferences of females can be quite different from males. These differences need to be considered when designing effective curriculum for STEM courses.

This study set out to investigate three areas regarding the design and development of a novel teaching approach, which entailed the use of multimedia in STEM courses, in an effort to increase the amount of information comprehended and retained by students when learning complex and abstract concepts. The overarching question addressed the value of multimedia as a learning tool within an introductory STEM course. For a deeper understanding, two additional questions were investigated which concerned the benefits females gain from the use of

multimedia and which multimedia features were believed to be the most helpful. Specifically, three research questions were investigated:

1. Does the use of multimedia affect the amount of information students comprehend and retain when learning complex and abstract scientific concepts?
2. Is there a relationship between the use of multimedia, gender, and learning outcomes?
3. Which features do students and instructors believe are most helpful regarding the effectiveness of multimedia instruction?

Using a design-based research approach, several versions of the multimedia were produced and tested over the course of three academic semesters. The overall relationship between the use of multimedia and the amount of information comprehended and retained by students was measured using quantitative techniques. The relationship between the use of multimedia and gender was also examined using quantitative techniques. Information regarding student and faculty beliefs about the use of multimedia as a whole for learning complex and abstract concepts as well as preferences regarding certain multimedia features was collected using qualitative techniques.

Summary and Discussion of Results

Data and results from each of the three academic semesters comprising this study are discussed individually. Because the multimedia module was edited and revised after quantitative and qualitative analyses were performed, the multimedia used each semester was truly different. Presenting the results of each rendition is important for understanding the evolution of the multimedia in this study.

In regards to the first research question, results from all three semesters support the use of multimedia for improving the learning gains of students enrolled in BIOL 198. Students within course sections using the multimedia module as a tool for learning about photosynthesis

consistently scored higher on tests related to comprehension and retention compared to those using the control media. Results from the post-module 5 test, daily online quiz, and unit exam are discussed.

Course sections containing students who had viewed the multimedia module had higher mean scores on the post-module 5 test compared to course sections containing students who had used the control media. The differences in these mean scores were statistically significant with a p-value of 0.016 for the Spring 2012 semester and 0.045 for the Fall 2012 semester. Because only one course section was offered during the summer, comparisons on the post-module 5 test between treatments was not possible.

Daily online quiz scores for students in course sections using the multimedia module were also consistently higher compared to course sections assigned to use the control media. The daily online quiz is part of the required course work for all students enrolled in BIOL 198. Points received are applied to students' final semester grades. The differences between the mean scores of the daily online quiz between treatments were statistically significant with a p-value of 0.004 for the Spring 2012 semester and 0.048 for the Fall 2012 semester. No comparisons exist for the Summer 2012 semester as only one course section was offered.

Unit exam scores for students in course sections using the multimedia module were also higher compared to students in course sections using the control media. Results from the Spring 2012 semester indicate that the difference in the means of the unit exam scores between treatments was statistically significant with a p-value of 0.024. No comparisons regarding unit exam score differences between treatments exist for the Summer 2012 semester due to only having one section nor the Fall 2012 semester due to the inability to insert questions in the exam as had been done previously.

Both the post-module 5 test and daily online quiz represented opportunities to measure the amount of information comprehended by students due to the fact that both were taken within a short amount of time after viewing the multimedia module. Tests that measure the amount comprehended and recalled in the short-term are generally known to test a student's ability to recognize and reproduce presented material. According to Mayer (2001, 2009), these tests measure the quantity of learning that occurred as a result of exposure to a certain learning method. Improving the ability to comprehend and recall information is one of two major goals of multimedia learning according to Mayer (2001, 2009).

The second goal of multimedia learning relates to the ability to reconstruct a mental representation from the presented material after a longer amount of time has passed between the use of a certain learning method and the taking of an exam (Mayer, 2001, 2009). The unit exam, taken two weeks after the viewing of the multimedia module, represented a sufficient way to measure this. Because the multimedia module could not be downloaded to students' computers and was removed from K-State Online after the administration of the post-module 5 test, it is assumed that the difference in mean scores on the unit exam between treatments is the result of the use of the multimedia module.

In regards to the second research question, results from the Spring 2012 and Summer 2012 semesters provided consistent evidence that female students benefit more from the use of multimedia than their male counterparts. This was especially noted for tests measuring comprehension. Statistically significant results were found for the post-module 5 test while encouraging results were found for the daily online quiz. Results from the Fall 2012 semester were mixed and indicated that the amount learned from the use of the multimedia module was tied to the amount of prior knowledge possessed, not gender. This finding aligns with findings

by Rouet et al. (2008) who found that the prior knowledge level of a student correlated with the learning gains derived from the use of multimedia when learning complex processes. Rouet et al. (2008) also found the amount of knowledge gained by these lower prior knowledge learners when using multimedia exceeded the amount of knowledge gained by the use of static pictures.

During the Spring 2012 semester, female students using the multimedia module scored higher on the post-module 5 test as opposed to female students using the control media. This difference was statistically significant with a p-value of 0.042. When the post-module 5 test scores for male students between treatments were compared, no statistically significant difference was found. Results from the daily online quiz, which did indicate that female students using the multimedia module scored higher than female students using the control media, were not statistically significant with a p-value of 0.153. Similar results were found when analyzing the results of the unit exam. Again, female students using the multimedia module scored higher on the exam compared to female students using the control media, but the results were not statistically significant with a p-value of 0.146. Daily online quiz the unit exam scores for male students, compared by treatment, were not statistically significant.

The Summer 2012 semester provided a different opportunity to measure the value of multimedia between genders. With only one course section offered, all students had the opportunity to use the multimedia module. When post-module 5 test results were analyzed, it was revealed that female students scored higher on the post-module 5 test than male students. The difference between post-module 5 test scores by gender was statistically significant with a p-value of 0.046. Results from the daily online quiz were also analyzed and while female students using multimedia scored higher than their male counterparts, the results were not statistically significant as the p-value was 0.521. In regards to the unit exam scores, there was no statistically

significant difference between the performance of female and male students as the p-value was 0.401

The Fall 2012 semester provided interesting yet unexpected results in regards to the value of multimedia for female and male students. The only consistency noted for the use of multimedia in relation to gender concerned the amount of prior knowledge possessed by students. In previous course sections, pre-module 5 scores were lower for female students than male students and the benefit derived from the use of multimedia was greater for female students as denoted by higher scores on the post-module 5 test. However in the Fall 2012 course sections, male students demonstrated a lower-prior knowledge level on the pre-module 5 test compared to female students and the benefit derived from the use of multimedia was greater for male students as denoted by higher scores on the post-module 5 test.

Results from the Fall 2012 daily online quiz also support the trend noted for the post-module 5 test scores between genders. Male students using the multimedia module received higher scores on the daily online quiz than female students using the multimedia module. The difference in scores between genders was statistically significant with a p-value of 0.019.

While the results for these three semesters do not fully support the second research question exactly as asked, they do highlight the potential benefit multimedia can provide to students if their prior knowledge level is a concern. Due to social pressures and hidden curriculums many females face during high school, it is feasible that their ability to build an adequate knowledge base within STEM disciplines is hindered compared to their male counterparts. As a result, females are more likely to possess a lower-prior knowledge level compared to their male counterparts. It is possible that the use of multimedia as part of the overall curriculum within introductory STEM courses could elevate the base knowledge level of

female students to a degree that would allow them to extract more meaning out of the content presented.

The third research question was qualitative in nature. Feedback attained from students and instructors in regards to the use of multimedia as a teaching and learning tool, as well as the features they believed to be most useful, was assessed for emerging themes and provided invaluable insight. This information served as the basis for the redesign of the multimedia module over the three iterations comprising the design-based research process.

Feedback attained from the Spring 2012 semester resulted in copious amounts of data from both students and instructors. Because the multimedia used during this semester represented the first attempt at creating and using such a module, the amount of changes required were numerous as predicted. In addition, feedback from instructors highlighted several content areas in need of clarification and correction.

It was unexpected to discover that both students and instructors suggested adding more content and details to the multimedia module. The version used during the Spring 2012 semester was approximately ten minutes in length and was feared to be too long to hold attention. In addition, there was concern that the file size, which was 15.2 MB, would cause some to experience technical difficulties. Neither of these concerns were voiced by students nor instructors.

Feedback received from students and instructors was aligned with Mayer's (2001, 2009) principles of multimedia learning which provided the necessary framework for deciding which changes would be the most beneficial for the next iteration of multimedia produced. Many comments received, while valuable, fell outside of the focus of multimedia learning as detailed

by Mayer (2001, 2009). Consequently they were not considered when designing the next iteration of multimedia.

Feedback received from students and instructors during the Summer 2012 semester was less voluminous and more focused on a smaller variety of categories. Part of this is due to the fact that there were simply fewer students and instructors involved with the course. However, it is believed that the other part of this stems from the changes and improvements made from the first iteration of research. While both students and instructors continued to recommend the slowing of the narration, feedback regarding other changes such as the creation of section reviews and additional labeling received unsolicited and overwhelming amounts of positive feedback. It was interesting to note that these changes, which were most recommended by students and instructors during the Spring 2012 semester, were the very ones most heralded by students and instructors during the Summer 2012 semester. What is more, the instructors involved with the course during the summer were not involved with the course during the spring and only one student enrolled in the summer section had been enrolled in the course during the spring.

Comments about the length of the multimedia module became more dichotomous. Compared to the Spring 2012 version, this version had increased by almost two minutes to arrive at an overall running time of eleven minutes and fifty-four seconds. Some students and instructors commented that the length was too long and they began to lose focus while others continued to recommend the addition of more content and details. The size of the multimedia module, which had increased to 22.2 MB, did not seem to be a problem for most. However, unlike the spring semester, several students did comment on the inability to open the file when

using a rural Internet connection or the frustration they experienced while waiting for the multimedia to buffer during playback.

Feedback from both groups, as well as content clarification and corrections suggested by instructors, were again aligned with Mayer's (2001, 2009) principles of multimedia learning. Collectively these were used to edit and improve the multimedia module once more for its final release in the Fall 2012 semester.

Qualitative information from the Fall 2012 semester was only attained from students. While emerging themes continued to include the need to again slow the narration and add even more reviews while chunking the information into smaller portions, comments regarding the overall length of the multimedia indicated that an acceptable balance had been struck between content and running time. Interestingly, the length of the multimedia had not changed. In fact it remained at eleven minutes and fifty-four seconds. However, more time was devoted to the introduction and review of sections and less to details within each section. In addition, the file size remained at 22.2 MB. Only one student commented on difficulties with buffering during playback.

Collectively, feedback received from both students and instructors over the course of the three semesters aligned well in regards to the overall value of using multimedia as a learning tool and specific features believed to be the most helpful. When analyzing feedback concerning the value of multimedia as a learning tool, five main themes emerged. These include: ability to hold attention, value of seeing complex molecular processes in motion, importance of being able to hear and see processes at the same time, majority of students identifying as visual learners, and the ability to form more accurate mental images which can be used on subsequent quizzes and exams. This conclusion is congruent with many other studies evaluating the benefit of using

words and pictures as opposed to text alone. Multiple studies have indicated that in the majority of cases students learn better from words and pictures than simply just words (Levie & Lentz 1982; Levin, Anglin, & Carney, 1987; Mayer, 2001; Schnotz, 2008).

When analyzing feedback from both students and instructors regarding specific features of the multimedia, less alignment between the comments of the two groups was noticed. However, reviewing the data multiple times allowed two main themes to emerge: the need to slow the speed at which information is presented and the value of providing section reviews between main ideas presented in the multimedia module.

At the outset of the study I was concerned with the possibility that the feedback received from students who appeared to support the use of multimedia would simply highlight their disdain for the textbook and reading in general, as opposed to critically evaluating the multimedia module. I was concerned that comments would simply pit one learning method against the other. Fortunately, this was not the case. The overwhelming majority of students who shared positive comments about the use of multimedia as well as specific features they liked, also described how it fell short in comparison to reading. Most of these comparisons were centered upon the inability to write notes or highlight details in the multimedia module. However, because students were not directly asked how the multimedia compared to other learning methods the verbiage used in their descriptions did not form a concise category. As a result, the comments were placed with the category of “compared to other methods”.

Internal Threats to Validity During Fall 2012 Semester

Throughout the results and discussion portions describing the Fall 2012 semester, comments were made alluding to potential internal threats to validity. Although approval was granted from the department head regarding the use of BIOL 198 course sections before the

study had begun and he was fully aware that the study would stretch over the course of three academic semesters, the third iteration was met with a noticeable degree of pushback. Upon the first inkling of this pushback I again consulted the department head to ensure I still had his approval, which I did. The email he sent in regards to this can be found in the Appendix.

During the spring and summer semesters, which entailed the BIOL 198 course being led by two different teaching coordinators, instructors had been excited to participate. Many asked if they could help and if they could see the results of their course section's data after it was collected. The teaching coordinators even invited me to present the multimedia module at a faculty meeting to describe the study (which I did not, due to confounds that could have been produced for future iterations) but did discuss with the faculty the overall use of multimedia for teaching and provided a short snippet of the multimedia I had produced. It was a very collegial atmosphere.

During the fall semester, a different teaching coordinator was selected to oversee the BIOL 198 course. As a courtesy, approval was sought from him before the Fall 2012 semester began. No issues were indicated. However, when the study began he informed me that it was too invasive and took too much time. Instructors of course sections chosen to participate at the beginning of the semester, as determined by the pre-semester test results, were alerted that they did not have to participate in the study. After speaking with the instructors individually and gaining their approval, the study continued but was met with much greater amounts of animosity. Several complained to the teaching coordinator that I was undermining their relationship with students. As a result, I was not allowed to execute all parts of the study as planned. For example, I was not given the opportunity to conduct instructor focus groups nor was I allowed to submit questions for the unit exam. In addition, when collecting daily online quiz grades I

noticed that the instructors of one course section assigned to the control treatment had manually changed all student grades to 100%. Instructors of the other course section assigned to the control media had told the students to read their textbook and not to read the text document I had provided. In addition, links were sent to students regarding several animations about photosynthesis that could be found on You-Tube and the course coordinator encouraged them to watch these videos before taking the unit exam.

Conclusions and Relation to Present State of Knowledge in the Field

This study began as an investigation regarding fairly simple questions about the use of multimedia for improving the amount of information comprehended and retained by students learning complex and abstract science concepts. Motives for this study were born out of real need as well as calls by many previous investigators in this field to further research in this area. According to Schnotz (2008), “we need a better understanding of how people learn from multimedia. We need to know under which conditions multimedia learning is effective and why. In other words: We need further theory driven empirical research on learning from multimedia” (p. 40).

The first question investigated during this research project set out to answer the simple question of “does multimedia work?” The premier placement of this question related to the numerous inconsistencies within the literature. While previous studies had attempted to answer the very same question, the end results were often the same with the authors stating that results are inconclusive (Huang & Aloï, 1991; Large, et al, 1994; Flagg & Kosinski, 1996; Sanger et al., 2001; Schoenfeld-Tacher, Jones, & Persichitte, 2001; Tsui & Treagust, 2004; Education Week, 2007; Rosen, 2011; Merkt et al., 2011).

Part of the inconclusiveness of these studies stemmed from the fact that the net cast was too broad. The majority of studies used commercially available software and employed this software using a one-shot case methodology. Many of these studies neglected to consider the background of students and the thoughts of teachers asked to use it. In addition, many of these studies were conducted in educational labs using paid volunteers. As stated by Rouet et al. (2008), it is imperative to “focus on the differential effects of a particular environment, learner characteristics, and the broader learning context” (p. 12). Another contributing factor regarding the inconclusiveness of studies in this field center upon many promising ideas being formulated and described in abstracts and even presented at conferences, yet not carried through in a manner that yielded empirical data. The majority of these studies, while not necessarily worthy of repeating, did provide insight on how to design and conduct a more effective study in order to generate data related to “does it work?” Many of the abstract presentations observed at the most recent Association for Educational Communications and Technology conference held in Louisville, Kentucky, October 31-Nov 4, 2012, highlighted this.

Of the studies undertaken in the past that did produce empirical evidence indicating a positive relationship between the use of multimedia and an increase in the amount students comprehend and retain had a different set of characteristics. Most of these studies were developed in partnership with educators, educational theories such as constructivism were used, and the methodology employed required true treatment groups and often required multiple iterations of testing (Cuban, 1986; Paivio, 1991; Mayer, 2001; Simon, 2001; Ashburn, Krockover, Eichinger, Pae, Witham, Islam, Cross, & Robinson, 2002; Yarden & Yarden, 2009). Furthermore, they were conducted in real classrooms with all of the messiness that comes with teaching and learning. And finally, the multimedia targeted a very specific academic level and

subject. According to Schnotz, (2008), multimedia learning is most effective when its content is adapted to the “level of a learner’s cognitive system” (p. 18). This statement agrees with similar statements made by Sweller (1999) and Mayer (2001, 2009).

Valuable lessons attained from all of these afore mentioned studies set the stage for this research project. As a result, data generated in regards to the first research question, “does it work”, appear to favor the use of multimedia and agree with Mayer’s (2001, 2009) Cognitive Theory of Multimedia Learning. Supporting evidence for this conclusion comes from the results of three separate academic semesters where research was conducted in real classrooms, using a student population with extremely diverse backgrounds, and a host of instructors who were not always enthusiastic about having to do “one more thing”. Simply put, it was a realistic setting. The evidence supporting the effectiveness of multimedia to improve both comprehension and retention of these students is a testament to the potential it might have in other introductory biology courses and perhaps for other introductory STEM courses in general.

The reasons I believe this specific form of learning helps this particular level of student is centered upon the idea that their lack of background information in relation to complex and abstract scientific concepts was considered when designing the multimedia. According to Gadamer’s phenomenological perspective on learning, if a learner lacks an appropriate background or prior knowledge, the receipt of additional and more complex information will not result in additional learning; just supplying educational materials is not enough (Linge, 1976). Gadamer suggests that a learner’s current knowledge level or a “knower’s boundness” must be assessed and considered when designing “objects” intended to foster learning otherwise the information presented will not amount to anything beyond random facts (Linge, 1976, pg. xii).

In addition, complex and abstract concepts such as photosynthesis are not tangible and cannot be experienced in every day life. They are simply out of reach for many students and contribute to the inability of students to go beyond rote memorization when trying to learn this type of material. They do not see the relevancy of this material to their daily lives and, as a result, are unable to connect this material with what they already know. This is consistent with the ideas of Ricoeur who posited that if facts lack context or a place to reside in the mind of the learner they are unable to truly be comprehended. As stated by Ricoeur, “understanding is not concerned with simply grasping a fact” (as cited by Thompson, 1981, p. 56). If information lacks context and relevancy, it becomes exceedingly difficult to create real and lasting meaning from it.

As opposed to traditional learning methods, I believe that the use of multimedia can alleviate many of the issues described by Ricoeur and Gadamer in regards to neglecting a learner’s past experiences. First and foremost, multimedia can be designed by educators who know their students’ backgrounds and knowledge levels better than anyone. As a result, multimedia can be tailored to facilitate certain levels of learners. In doing so, multimedia can increase basic vocabulary, connect vocabulary to concepts, build smaller concepts into larger ideas, and eventually ideas into mental models. This, I believe, is what specifically enabled the multimedia used in this study to improve students’ comprehension above and beyond the text used as a control. This also agrees with the fundamentals of constructivism as described by Vygotsky. According to Vygotsky, language is the foundation from which all ideas spring. Improving a learner’s vocabulary and ability to relate vocabulary to larger concepts improves their overall ability to comprehend ideas (in Miller, 2011). It allows the abstract to become

concrete. According to Gadamer, “former concretizations mediate the text to us” (as cited by Linge, 1976, p. xvi).

In reference to these powerful statements, I believe one of the greatest contributions provided by the multimedia used in this study was that it allowed the abstract to become more concrete. This set learners up for success as concrete ideas could be further developed into mental models. Mental models that are a student’s own aids in retention; the model is based on their past experiences and knowledge and does not require rote memorization in order to be retained. It was constructed out of their efforts to compare their unknown to the known, or what they thought was correct to what is actually correct. The ability to compare and contrast what was previously known to what needs to be understood as highlighted by guided instruction is invaluable for learning and helps one move away from rote memorization and towards comprehension. As discovered during this study, many students commented that the use of multimedia allowed difficult processes to be visualized and manipulated in their heads suggesting that they were able to form their own mental models. Thus, the findings of this study support the use of multimedia as an effective learning tool in relation to the ideas of Gadamer, Ricouer, and Vygotsky and the learning theories of constructivism, hermeneutics, and phenomenology.

Could other learning techniques accomplish the same thing? Of course. As mentioned several times during this document, multimedia is not the only option for teaching the digital natives inhabiting our classrooms nor is it the end-all-be-all in regards to educational technology. It is simply a tool, but one very worthy of consideration. According to Schnotz, (2008), “multimedia does not guarantee effective learning” (p. 40). As Mayer (2001, 2009) often stated, poorly designed multimedia results in little to no learning gains and the results of this study agree

with this. As the multimedia improved through multiple research iterations, so did student feedback regarding its effectiveness. This attests to the fact that the better the multimedia design, the more students will benefit when learning complex and abstract concepts.

The second question investigated during this study entailed the use of multimedia for increasing the learning gains of female students enrolled in an introductory biology course. Simply stated, this question set out to investigate “for whom does it work?” Given the concerns regarding not just the overall lack of STEM graduates now and in the future for meeting the demands of the United States but also the lack of diversity in STEM (Rosser, 1995; Andrade et al., 2002; Banks, 2011; Kulteral-Konak et al., 2011), this was a reasonable question. It was also a question that again did not have a lot of evidence supporting it either way. While a few studies had examined the value of multimedia for increasing female student participation within the STEM fields, the majority of these had been conducted with high school students (Schoenfeld-Tacher et al., 2001; Papastergiou, 2008). Of those conducted at the collegiate level, many were performed in physics departments (Dori & Belcher, 2005; Stelzer et al., 2008; Chen et al., 2010). Very little, if any, information existed regarding the use of multimedia for improving the learning gains of females within an introductory college biology course.

Evidence in regards to this specific question indicates that there is a possible relationship between the use of multimedia and an increase in learning gains of female students. However, the results were not as strong as those attained for the first question. Part of this was due to the fact that having to compare learning gains by gender resulted in smaller numbers to analyze within each sample during the study. However, procedures such as stratification and bootstrapping helped alleviate these statistical issues. Another factor perhaps influencing the findings relates to the amount of prior knowledge students possessed. Because student

identification was anonymous it was not possible to track performance on an individual basis, only averages for an entire course section and by gender could be attained. When discussing the lower prior knowledge of students in this study, the point of reference is the pre-module 5 test score. At times, male students indicated a lower-prior knowledge level than their female counterparts. As a result, they seemed to benefit more from the use of multimedia. When female students indicated a lower-prior knowledge level compared to their male counterparts, they appeared to benefit more from the use of multimedia. This was especially true during the Fall 2012 iteration where it was discovered that male participants made much greater improvements in their understanding of photosynthesis compared to their female counterparts. It was also discovered that the males in this semester had a lower-prior knowledge level.

While these results were not expected, they were not at all discouraging. The idea of lower-prior knowledge learners benefitting more from the use of multimedia aligns well with other studies investigating the use of scaffolding devices. Work performed by Kirschner, Sweller, and Clark (2006) indicated that individuals who were new to a field or a concept benefit tremendously from demonstrations of how to use and apply a concept as it provides a framework or reference point for future learning. In addition, this finding agrees with the learning theories of constructivism, hermeneutics, and phenomenology.

Comparing the prior knowledge level to amount of learning gains made through the use of multimedia as opposed to a text document containing static pictures is actually quite promising as in the majority of STEM courses, it has been found that female students are the ones with lower-prior knowledge levels (Astin & Astin, 1992; Seymour, 1995; Papastergiou, 2008). Much of this is due to their conformity to social norms and exposure to hidden curriculums, which can start at a very early age (Tobias, 1990; Chang, 2002; Farrell, 2002;

Hallstrom & Gyberg, 2009; Kulteral-Konak et al., 2011). Some of it is also due to the mismatch between what they perceive science and scientists to represent and their personal goals (Seymour, 1995; Papastergiou, 2008; Hallstrom & Gyberg, 2009; Barker, Cohoon, and Thompson, 2010). Whatever the cause, the result is the same: females are more likely to avoid STEM disciplines or switch majors outside of the STEM disciplines after their first year (Tobias, 1990; Andrade, 2002; National Center for Women and Information Technology, 2009). At a time when the United States needs more, not less, graduates in the STEM fields and at a time when the majority of college students are female, multimedia provides a viable option to help make the science disciplines more welcoming for all students.

Many female students leaving STEM disciplines cite mismatches between the pedagogy used within their introductory courses and their preferred learning methods (Felder & Silverman, 1988; Astin & Astin, 1992; Rosser, 1995; Lachenmeyer, 1997; Kulteral-Konak et al. 2011; Lin, 2011). Overwhelmingly the majority of females surveyed in this study, as well as those in other studies, identified as visual learners. However, the majority of teaching methods employed in the STEM disciplines are not visually based (Philbin et al., 1995; Kulteral-Konak et al., 2011). Making small pedagogical changes could yield big results. The production of empirical data, verifying anecdotal evidence discussed by educators for years, is a step in the right direction.

Female students also cite the need for instructors to make complex and abstract concepts more concrete as well as emphasize connections between concepts (Philbin et al., Lachenmeyer, 1997; 1995; Kulteral-Konak et al., 2011). Many prefer to have a more human connection with their instructor and prefer to know the person “behind the voice”. Multimedia represents one way that these learning preferences can easily be facilitated.

The third and final research area investigated during this study concerned the production of guidelines for other educators to use should they desire to produce multimedia for their own students. This was actually the basis for the undertaking of this entire research project. Born out of need while looking for these exact guidelines and finding none, I set out to improve this area of the literature and to hopefully make a useful contribution to the field for others who might also be seeking the same information. Outside of Mayer's (2001, 2009) principles for multimedia learning, Paivio's (1986, 2006) dual-coding theory, and Sweller's (1988) cognitive load theory, all of which emphasized the general benefit of presenting information using narration and visuals simultaneously, little empirical evidence existed for the use of multimedia specifically within STEM courses at the collegiate level.

In regards to the production of actual guidelines for building multimedia from the ground up, very few studies within the literature could be found. A few studies had examined the use of 3-D graphics or the creation of Flash-based animations, but none got to the root of the problem and provided first-timers with such details as acceptable running lengths, file size, file format, how to distribute the end product to students, the amount of detail to include, and is it really any better than a textbook? Furthermore, few studies existed regarding the use of multimedia in real biology classrooms. Of those found, most appeared to simply review commercially available software. If students seemed to like it, as determined again by a one-shot case study, then the multimedia was deemed "a good buy" or "an appropriate choice". But if students complained or showed little to no improvement, it was deemed "too expensive" or "not user friendly". None of these studies answered my question of how to build it from the ground up, given what little extra time and resources exist for educators at any level.

The third research question, which can simply be posed as “why does it work”, truly yielded the most gratifying results. Finally some answers were provided to a question I began asking four years ago. As a result of this study, it was determined that: students prefer to see complex processes in motion; they prefer to watch a process unfold as it is being described to them by someone they know; they do try to create meaning for themselves when reading the textbook but oftentimes feel they arrive at the wrong conclusions due to their overall lack of understanding; they like small chunks of information presented at a relatively slow pace; and they prefer to have ample review in between the main ideas. They do not mind if the presentation is a little long or a little dry. They do not need exciting graphics or 3-D animations. In fact, many indicated that simple is best for learning “hard stuff”. While they prefer small file sizes that play on any Internet-ready device they will go the extra mile and find a computer that is capable of playing the multimedia. In short, they will meet the educator half way. This is all that can be asked of them and is all Gadamer said would be possible when teaching individual unique beings foreign material that has, for the most part, escaped them in their past.

In conclusion, the lessons learned from the multiple iterations of research and the feedback received, both quantitative and qualitative, provided a good start to answering the three research questions originally posed. In agreement with Mayer’s (2001, 2009) Cognitive Theory of Multimedia Learning, Paivio’s (1986, 2006) Dual Coding Theory, and Baddely’s (1986) Working Memory Theory, the results from the first research question support the use of multimedia for increasing the amount of information students are able to comprehend and retain.

In agreement with the fundamentals of constructivism, phenomenology, and hermeneutics, results from the second research question support the idea that it is critical to have a thorough understanding of students’ current knowledge level before designing curriculum.

This is congruent with findings by Ainsworth (2008) who highlighted the need to move away from a positivistic approach and towards assessing the value of multimedia from a phenomenological and hermeneutical perspective. According to Ainsworth, (2008), it is critical to take into account the background of the learner and how they interact with multimedia before drawing conclusions about the effectiveness of the multimedia. As detailed throughout the multiple iterations of this research project, the lower the prior knowledge level of a student, the more beneficial was the use of multimedia. This agrees with findings from previous researchers who discovered that low-prior knowledge learners benefit the most from the use of pictures (Ainsworth, 2008; Mayer & Sims, 1994; Snow & Yalow, 1984). Relating back to the question regarding the use of multimedia for helping female students, this is encouraging as females typically encounter more roadblocks as science students. However, this finding is potentially important for any student who may not have been able to fully attain the prior preparation needed to succeed in college science courses and certainly opens up exciting possibilities for future studies.

Results produced from the third research question were unique in that they represent the work of many as both students and instructors contributed greatly to providing insight regarding the value of multimedia in a real classroom setting. This question also provided insight to a large missing piece in the literature – what do users of multimedia think about it as a learning tool and which features do they find most helpful. According to Tversky, Morrison, and Betrancourt (2002), despite a widespread belief that animation is a powerful instructional device, it is still an open question regarding which conditions and features of animated pictures really enhance comprehension and learning. Having so many different people involved in the improvement of this project was truly exceptional. The information they provided in regards to features they

found most helpful and also most distracting was unique. I fully believe that the contribution from this collective effort propelled the production of this multimedia module from mediocre to one of great value for students in this particular course. The speed at which potential improvements were pointed out and inaccuracies spotted was amazing. Simply put, none of us is as smart as all of us.

Recommendations for Future Studies

While results from this study are encouraging, additional investigations would be highly beneficial; many holes still exist within the literature. Furthermore, this study only investigated the use of multimedia within an introductory biology course at one university. Studies conducted in other STEM disciplines, especially within introductory courses, would be valuable.

Suggestions for future investigators include conducting research within real classrooms, taking strides to ensure participants are as similar as possible regarding their prior knowledge levels, and the development of true controls. The messiness that comes from actual students interacting in real learning environments truly tests the value of a proposed learning method, as well as its ability to endure. In addition, studies employing methodologies that are at least quasi-experimental in nature, if not truly experimental, are sorely needed. This begins with the careful selection and testing of participants to ensure that treatment groups are as equal as possible before the study commences.

The value of a true control against which to measure the effect of multimedia cannot be overstated. In relation to the use of robust controls, I would recommend future researchers invest in file-tracking software such as VideoClix. While expensive, this software provides a very effective and efficient way to monitor each student's use of a file. In addition, tracking

individual student progress as opposed to entire course sections would yield more information regarding the specific characteristics of learners most helped by multimedia.

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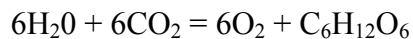
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Appendix A: Multimedia Narration and Screen Shots

Photosynthesis

Photosynthesis is a very important process as it provides food for almost every living thing on Earth. Yes, even humans and animals rely on photosynthesis as it allows solar radiation, which is the ultimate source of energy and comes from the sun, to be captured and converted into a usable form of energy for us non-photosynthesizing organisms.

So how do plants convert solar energy into a usable energy source like glucose? Consider this equation, showing the reactants and products of photosynthesis:



Remember, energy cannot be created nor destroyed, but it can change forms. This equation shows us how plants change solar energy, with the help of enzymes, into chemical energy, which is stored in the bonds of molecules like glucose.

The reactants needed for photosynthesis to occur come from the environment. Water is absorbed, via osmosis, through the plant's roots and it is distributed throughout the plant while carbon dioxide is obtained from the air and enters the plant through the stomata, which are usually located on the underside of leaves. With these reactants in place, and with the energy provided from the sun, the process of photosynthesis can begin.

Photosynthesis occurs in organelles called chloroplasts. The basic components of a chloroplast include the stroma and the thylakoids. The stroma is a fluid-filled matrix, which bathes the thylakoids and houses the carbon reactions. The thylakoids, which resemble discs and are collectively known as granum, have highly folded membranes. These membranes play a major role in photosynthesis as they are the sites of light reactions.

But what is it about these thylakoid membranes that allow them to capture light and kick-start photosynthesis? Well, these membranes contain chlorophyll which is a photosynthetic pigment meaning it is capable of absorbing light at specific wavelengths. Thus, chlorophyll and other photosynthetic pigments serve as “molecular bridges”, allowing energy from the visible light portion of the electromagnetic spectrum to be captured.

The visible light portion of the electromagnetic spectrum occurs in wavelengths ranging from 380 to 750 nanometers. However, chlorophyll a, which is the main photosynthetic pigment for most organisms, only absorbs light having a wavelength of 400 to 450 nanometers (which is seen as violet light) and 650-700 nanometers (seen as red light). Chlorophyll a cannot absorb green and yellow light occurring at wavelengths between 450 and 600 nanometers although other photosynthetic pigments certainly can. However, because chlorophyll a is the main photosynthetic pigment, the total amount of photosynthetic product ultimately produced increases if the plant is exposed to higher amounts of violet and red light.

So, how exactly does the absorption of specific wavelengths of light ultimately lead to the production of glucose? It all begins with the light reactions that occur within the thylakoid membrane. Remember, light harvesting pigments such as chlorophyll a exist in the thylakoid membrane, specifically within structures called photosystems. When light of a specific wavelength strikes a photosystem, something unique happens... the electrons contained within the chlorophyll are boosted to a higher energy status and leave the photosystem. Immediately they are ushered into a pathway, known as the electron transfer chain, where their energy will be used to drive the production of ATP. Let's discuss how this happens...

High-energy electrons from photosystem II enter the electron transport chain where the energy they emit will be harnessed to fuel the pumping of hydrogen ions from the stroma into the inner thylakoid compartment. When electrons are lost from photosystem II, replacement electrons are instantly gained from the splitting of 2 water molecules, which liberates oxygen and hydrogen atoms. The oxygen can easily diffuse out of the thylakoid – it is not useful for the plant and represents a byproduct of the light reactions. The hydrogen ions, however, are trapped within the thylakoid and contribute to an increasing hydrogen ion concentration that will ultimately be used to drive ATP production. Electrons gained from the splitting of these water molecules are instantly taken up by photosystem II, elevated to a high energy state due the receipt of sunlight, and, like previous electrons, are immediately ushered into the electron transport chain where their energy will be used to pump even more hydrogen ions into the thylakoid.

Once electrons have traversed the electron transport chain, their energy state becomes quite low. Luckily, photosystem I (so named because it was discovered first), is able to re-charge their energy status due to the sunlight it captures. These re-charged electrons enter another, yet

shorter, electron transport chain. While bouncing along this second chain, the electrons are pulled from the thylakoid membrane and their energy is used to create NADPH, which is a reduced co-enzyme.

The term reduced refers to any molecule that has just accepted electrons and, consequently, the energy associated with electrons. This allows for the temporary “storage” of electrons so that they can be used elsewhere to fuel energy-requiring reactions. In the case of photosynthesis, the energy contained within the NADPH will be used to fuel portions of the carbon reactions, which we’ll discuss in a minute.

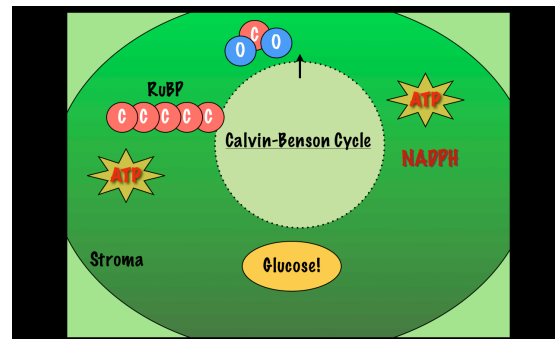
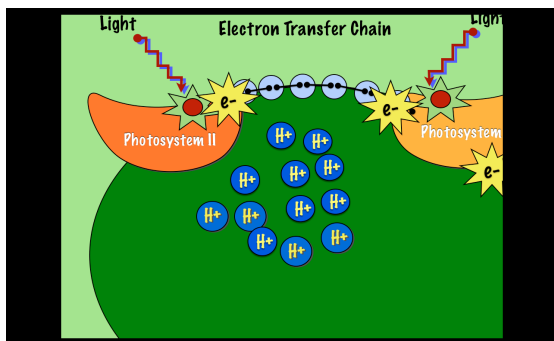
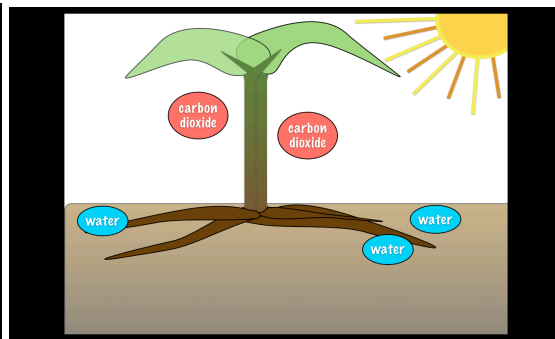
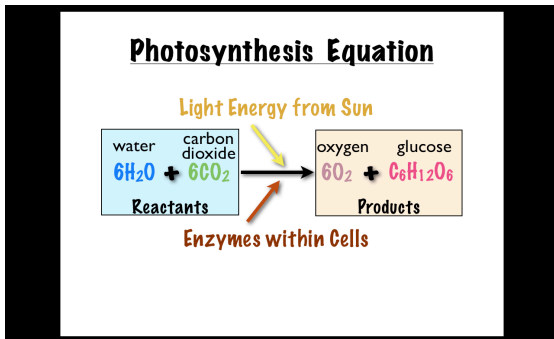
But for now, let’s return to the inner compartment of the thylakoid where the energy harnessed from electrons in the electron transport chain was used to create a large concentration of hydrogen ions. What purpose could these hydrogen ions possibly serve? Well, they drive the production of ATP! Because their concentration inside the thylakoid becomes so large, the gradient created propels them out through an ATP synthase molecule. ATP synthase uses the energy created by the flow of hydrogen ions to phosphorylate ADP, creating ATP.

So, with inputs of light and water, the light reactions of photosynthesis create NADPH and ATP, both of which are needed to fuel the carbon reactions. Thus, without the light reactions, the carbon reactions could not occur for very long.

Unlike light reactions, which occur in the thylakoid, carbon reactions occur in the stroma of chloroplasts. The outcome of these reactions is the production of glucose via the Calvin-Benson cycle, which is fueled by the NADPH and ATP previously created.

During the Calvin-Benson cycle, a process known as carbon fixation occurs which results in carbon atoms from carbon dioxide being extracted and incorporated into a molecule of glucose. This process must occur 6 times in order for one molecule of glucose to be produced. Each time this process begins when rubisco (RuBP), an enzyme containing 5 carbons, gains an additional carbon atom from a carbon dioxide molecule. Thus, a 6 carbon molecule is formed, although briefly, as it is unstable and quickly splits into 2 molecules of PGA, each having 3 carbons. At this point in the Calvin-Benson cycle, the energy from ATP and the reducing power of NADPH are used to convert the 2 PGA molecules into 2 molecules of PGAL, which also contain 3 carbon atoms each. After this process has occurred 6 times, resulting in 12 molecules of PGAL, the production of glucose can begin. Glucose contains 6 carbons (the chemical formula for glucose is $C_6H_{12}O_6$). These 6 carbons come from the joining of 2 PGAL molecules. But if one turn of

the Calvin-Benson cycle produces 2 molecules of PGAL, why must the cycle occur 6 times to produce one molecule of glucose? Because, rubisco must be regenerated if the cycle is to continue so the rest of the PGAL molecules are used for this regeneration. This insures that additional glucose molecules can be created during the carbon reactions of photosynthesis as long as there is a sufficient supply of carbon dioxide and energy in the form of NADPH and ATP.



Appendix B - Pre and Post Test Questions

1. The openings in leaves which allow gases to exchange from the atmosphere to the interior of the leaf are
 - a) monocots.
 - b) plasmodesmata.
 - c) stomata.
 - d) vacuoles.
2. A seed planted in a pot weighs 1 gram. After 6 months the plant that sprouted from that seed weighs 1000 grams. The **source** of the biomass (dry weight) that was gained by the plant is
 - a) CO₂
 - b) minerals from the soil
 - c) nitrogen from the air.
 - d) water.
3. The organelle known as the _____ is the source of ATP in **both** plant and animal cells. (Fill in the blank with the most appropriate choice from the list below).
 - a) chloroplast
 - b) lysosome
 - c) mitochondria
 - d) nucleus
4. Where do plants attain the carbon needed to make a glucose molecule?
 - a) from water
 - b) from the soil
 - c) from the CO₂ in the atmosphere
 - d) from the sun
5. What is the relationship between the light reactions and the carbon reactions during photosynthesis?
 - a) products from the light reactions fuel the carbon reactions
 - b) products from the carbon reactions fuel the light reactions
 - c) the glucose constructed during the light reactions is broken down during the carbon reactions
 - d) there is no relationship, the light and carbon reactions are independent of each other

6. Oxygen is a byproduct of photosynthesis. How is it produced?
- Oxygen is produced by photosystems I & II as a result of sunlight striking their surface.
 - Oxygen is absorbed from the soil and released via the stomata.
 - Oxygen is absorbed from the atmosphere and then released during photosynthesis.
 - Oxygen is produced from the splitting of a water molecule within the thylakoid
7. When sunlight strikes photosystems I & II which of the following occurs *immediately* as a result?
- glucose is produced
 - the electrons housed in the photosystem are boosted to a higher energy status
 - NADPH is created
 - oxygen is liberated
8. When electrons enter the electron transfer chain, which of the following occurs *immediately* as a result?
- ATP is produced
 - carbon dioxide is split into carbon and oxygen
 - photosystem I receives more sunlight
 - hydrogen ions are pumped into the inner compartment of the thylakoid
9. Which of the following fuels the ATP Synthase molecule?
- ADP
 - electrons
 - hydrogen ions (H⁺)
 - NADPH
10. In order to produce a maximal amount of glucose, where would a plant want its photosystems to be located?
- buried deep within the stroma
 - on the surface of the thylakoid receiving the most sunlight
 - on the underside of a leaf
 - none of the above as there is no relationship between placement of photosystems and production of glucose

Appendix C: Daily Online Quiz Questions

Module 5, Class 2 Quiz

Please help me to understand how you used and what you thought of the photosynthesis multimedia. Your opinion is important! Be honest, please. There are no wrong answers for questions 1-5. Questions 6-10, well, that's another matter.

1. Did you watch the photosynthesis multimedia module before or during your completion of this quiz?
 - A. Yes, I watched the photosynthesis multimedia module before taking this quiz.
 - B. Yes, I watched the photosynthesis multimedia module while I took this quiz.
 - C. Yes, I watched the photosynthesis multimedia module both before and during the taking of this quiz.
 - D. No, I only read the assigned textbook chapters and pre-lab reading portion of the lab manual.
 - E. Neither. I did not use the photosynthesis multimedia module or the textbook for the completion of my quiz.
 - F. Both the photosynthesis multimedia module and the textbook
2. If you used the photosynthesis multimedia module, how did you access it?
 - A. Via my personal computer (laptop or desktop)
 - B. Via a mobile device (smart phone, iPad, or other tablet device)
 - C. Via a campus computer in a computer lab
 - D. I tried to access it but had technical difficulties
3. If you used the photosynthesis multimedia module, what are your thoughts regarding its usefulness compared to learning the same material from a textbook?
 - A. Strongly prefer current textbook
 - B. Somewhat prefer current textbook
 - C. About the same
 - D. Somewhat prefer the multimedia module for learning about this topic
 - E. Strongly prefer the multimedia module for learning about this topic
4. Would you please explain your answer for question #3 so that I can understand your thoughts about learning information from multimedia as opposed to textbooks? Feel free to include anything you think would help me understand your opinion and learning preferences.

5. How often do you currently read your biology textbook?
- A. Two or more times per week
 - B. About once per week
 - C. About 1 to 3 times per month
 - D. Just to cram for exams
 - E. Never
6. Do you have any suggestions for improving the photosynthesis multimedia module?
7. How is oxygen produced during photosynthesis?
- A. The ATP Synthase molecule liberates oxygen while making ATP from ADP plus a free phosphate
 - B. When photosystem II loses its electrons it “steals” electrons from water molecules and this liberates hydrogen as well as oxygen
 - C. The reduction of NADP to NADPH produces oxygen as a byproduct and is known as an oxidation reaction
 - D. The breakdown of RuBP during the Calvin-Benson cycle produces oxygen
8. The majority of the PGAL molecules produced in the Calvin-Benson cycle are used to:
- A. regenerate RuBP
 - B. produce glucose
 - C. produce ATP
 - D. produce NADPH
9. By the time electrons bounce through the first electron transport chain and reach Photosystem I, their energy is:
- A. much lower than it was when they left Photosystem II
 - B. much higher due to the charge they receive from hydrogen ions
 - C. about the same as it was when they first left Photosystem II
 - D. much lower due to the production of NADPH
10. What is the relationship between the splitting of a water molecule within the thylakoid and the fueling of the ATP Synthase molecule?
- A. The oxygen within the water molecule is used to produce NADPH.
 - B. The splitting of a water molecule liberates oxygen and when it diffuses out of the thylakoid, it pulls hydrogen with it leaving more room for the ATP Synthase molecule to produce ATP.
 - C. When a water molecule splits, electrons are liberated and these are shuttled directly to the ATP Synthase molecule so that ATP can be produced.
 - D. When a water molecule is split, the liberated hydrogen ions are stuck in the thylakoid and contribute to the overall growing concentration of hydrogen ions.

11. The products of the light reactions are _____ while carbon reactions produce _____.

- A. PGA and PGAL, glucose and NADPH
- B. glucose and RuBP, carbon dioxide
- C. NADPH and ATP, glucose
- D. water and sunlight, NADPH and ATP

Appendix D: Unit Exam Questions

Where does a plant attain the reactants used in photosynthesis?

- A. Water: absorbed via the roots; CO₂: absorbed from the air via stomata
- B. Oxygen: absorbed from the air via stomata; Water: absorbed via the roots
- C. Glucose: attained during carbon reactions; Water: absorbed via the roots
- D. CO₂: absorbed via the roots; Oxygen: absorbed from the air via stomata
- E. Water: absorbed from moist air via stomata; CO₂: absorbed via the roots

How might a complete lack of water affect the rate at which ATP and NADPH are produced?

- A. It would increase ATP and NADPH production as more room would be available inside the thylakoid for light reactions to occur
- B. It would decrease ATP and NADPH production as fewer electrons and H⁺ would be available to fuel the light reactions of photosynthesis
- C. It would increase ATP and NADPH production as fewer H⁺ would bind to oxygen, leaving more H⁺ to fuel the light reactions of photosynthesis
- D. It would decrease NADPH production as the only source of electrons available to the electron transfer chain comes from the splitting of water; however, production of ATP would be unaffected
- E. The rate of ATP and NADPH production would be unaffected, water is not involved

To increase the total amount of photosynthetic product produced by a plant, exposure to which of the following wavelengths of the visible light spectrum would be most beneficial?

- A. About 400 nm (violet light)
- B. About 550 nm (green light)
- C. About 700 nm (red light)
- D. All of the above
- E. Only A and C

What would happen to the amount of glucose produced by a plant if it was completely deprived of all light for several days?

- A. The amount of glucose produced would be unaffected as it is produced during the carbon reactions and these reactions do not require light in order to occur.
- B. Glucose production would decrease somewhat, but would still occur as long as enough carbon dioxide was present to fuel the Calvin-Benson cycle.
- C. Without the light-reaction products of ATP and NADPH fueling the Calvin-Benson cycle, no glucose would be produced during this time.
- D. The production of glucose would be unaffected as long as the plant had produced and stored enough ATP and NADPH to sustain itself for an extended period of time.

E. Because glucose is the direct product of light reactions, it could not be produced without sufficient amounts of light.

Which of the following is specifically responsible for capturing sunlight, thus kick-starting the process of photosynthesis?

- A. The electron transfer chain
- B. Chlorophyll a
- C. Stroma
- D. Thylakoid
- E. Photosystems I and II

What is the significance of reduction reactions?

- A. These reactions allow the energy associated with liberated electrons to be captured and used elsewhere
- B. These reactions allow the energy associated with hydrogen ions to be stored and then used in subsequent reactions
- C. These reactions, which occur when a molecule such as glucose is combusted, liberate electrons and hydrogen ions
- D. Reduction reactions are important for allowing a large molecule to be methodically disassembled in a cell without the production of a lot heat
- E. Reduction reactions fuel oxidation reactions

Appendix E: Focus Groups Questions

Feedback on Animation

Please keep anonymous!

About you:

1. What role do you play in BIOL 198? Faculty member, GTA, or undergraduate practicum?
2. How long have you been associated with BIOL 198?
3. Were you responsible for providing the introductory lecture and wrap-up for Module 5, Class 2 (photosynthesis)?

Animation Questions: As you watch the photosynthesis animation, please answer the following questions

1. In regards to the visual portion of the animation, did you see any inaccuracies or anything that was unclear?
2. In regards to the narration that accompanied the animation, did you hear any inaccuracies or anything that was unclear?
3. In regards to the animation as a whole, what are your thoughts on the overall length?
4. Were any important details left out of the animation?
5. Were any details covered too deeply and thus unnecessary?
6. What are your thoughts on the value of multimedia in regards to helping students learn complex and abstract processes such as photosynthesis?
7. Have you ever created your own animations for students?

Appendix F: Focus Group Rubric

<i>Clear goals and objectives</i>	It is clear to the learner what is to be covered in the multimedia and what should be gained from its.
<i>Context meaningful to domain and learner</i>	The multimedia is situated in practice and will interest and engage a learner.
<i>Content clearly and multiply represented and multiply navigable</i>	The message in the multimedia is unambiguous. It supports learner preferences for different access pathways or channels. The learner is able to find relevant information while engaged in the media.
<i>Activities scaffolded</i>	The multimedia provides support for learner activities to allow working within existing competence while encountering meaningful chunks of knowledge.
<i>Support for transference and acquiring 'self-learning' skills</i>	The multimedia supports transference of skills beyond the learning environment and will facilitate the learner becoming able to self-improve.
<i>Support for collaborative learning</i>	The multimedia provides opportunities and support for learning through interaction with others through discussion or other collaborative activities.

Appendix G: Permission to Use & Discuss Results of Research

Ashley,

You may mention, recognize, describe, and discuss the Division of Biology in your dissertation, presentations, and publications. The Division is both your professional home and the research base for investigations and analyses in our Principles of Biology learning environment.

I look forward to reading the future publications.

Brian

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