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Use of Multimedia in an Introductory College Biology Course to Improve Comprehension of Complex Material

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Many students who have the ability to succeed in science, technology, engineering and math (STEM) disciplines are often alienated by the traditional instructional methods encountered within introductory courses; as a result, attrition from STEM fields is highest after completion of these courses. This is especially true for females. The present study examined the use of teacher-designed multimedia within an introductory biology course. A mixed-methods approach was used to assess the relationship between the use of multimedia and the amount of information students comprehended when learning photosynthesis in a real class setting. Also, the relationship between the use of multimedia and learning gains of females was examined. It was determined that multimedia significantly increased learning gains of female students compared to the use of static pictures and text. In addition, preliminary indications are that multimedia had the greatest value for second-tier students with lower prior knowledge levels, and this was often females.

Introduction

The number of students pursuing and completing (STEM) degrees will likely fall short of the projected need for scientists within the United States over the next twenty-five years; this could cause a serious decline in technological and biomedical advancements as well as threaten the security of the U.S. economy (Seymour, 1992; Astin, Parrott, Korn & Sax, 1997; Freeman, 2005; Lowell, Salzman, Henderson, 2009; Volenec, Barbarick, Pierzynski, & Bergfeld, 2012). 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, where over sixty percent of college students are female, relying on this conventional pool of students to pursue and complete STEM degrees will no longer suffice if future vacancies in science fields are to be filled (NSF, 2010; Falkenheim & Burrelli, 2012; Gates & Mirkin, 2012; Tan, Barton, Kang, & O'Neill, 2013). To reverse this trend, steps must be taken to recruit and retain more students in STEM fields; this includes the development of instructional methods that accommodate a wider variety of learning styles.

The recruitment of students into STEM fields begins early as experiences in secondary - and even primary - educational settings significantly impact students' attitudes towards science. Positive attitudes foster higher degrees of intrinsic motivation and greater achievement of content mastery, negative attitudes can damage students' abilities to succeed as a strong relationship exists between attitude towards and achievement in science (Osborne, Simon, & Collins, 2003; George, 2006; Desy, Peterson, & Brockman, 2009). And while progress has been made in recruiting STEM majors, the retention of students within these majors after completion of introductory STEM courses at the collegiate level continues to be a challenge. In fact, a student's experience within introductory science courses represents the single most influential factor regarding their decision to leave STEM disciplines (Seymour & Hewitt, 1997; Koenig, Schen, Edwards, Bao, 2012; Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012). Sixty percent of students who enter college with the goal of majoring in a STEM discipline graduate in a non-STEM field (Gates & Mirkin, 2012). Factors contributing to a student's negative experiences within these courses are varied but generally relate to lack of preparation, lack of confidence, and a competitive classroom atmosphere. In addition, the mis-match between instructional methods used and learning styles of many students, exacerbated by the fact that most introductory courses are taught in large lecture halls where the instructor appears inaccessible and content delivery is impersonal, greatly contributes to these negative experiences.

The relationship between classroom experience, attitude towards, and performance within introductory STEM courses is even stronger for second-tier students compared to top-tier students (Felder, 1993; Fassinger, 1995; Seymour & Hewitt, 1997; Weaver & Qi, 2005; Laird, 2008; Mayer, 2009; Rocca, 2010). The term “top-tier” refers to students who are successful regardless of their major, instructional method used, or academic environment encountered; they are confident and curriculum proof. Top-tier students generally have a broad knowledge base and high-prior knowledge levels, good study skills, and the capacity to extract large amounts of information from a variety of instructional formats (Felder, 1993; Kalyuga, 2005; Mayer, 2009). Second-tier students, often referred to as the other 98 percent, have the initial intention of and ability to succeed in STEM courses, but do not tend to thrive in the academic climate encountered in most introductory STEM courses (Trefil, 2008). To be clear, second-tier does not mean second-rate, but rather refers to students who possess a different learning style than what is often encountered within STEM courses (Tobias, 1990). Second-tier students tend to be deductive learners, prefer to have a concrete idea or concept presented first before examples are given or abstraction is required, and prefer information that is highly organized and linearly structured (Felder, 1993; Mayer, 2009). Additionally, second-tier students generally identify as visual learners, fail to thrive in competitive environments, are easily intimidated by others who appear to possess strong science skills, and are often considered to be low-prior knowledge learners regarding scientific concepts. As a result, second-tier students have to work harder to incorporate new information presented in class into something that is familiar and useful to them (Felder, 1993; Kalyuga, 2005; Mayer, 2009). For them, the amount of information that must be simultaneously received, processed, and organized is much larger than it is for top-tier students.

Experiences within introductory STEM courses also vary by gender; males are more likely to exhibit the traits of top-tier students and females more likely to exhibit those of second-tier students. Males often have more confidence, motivation, and a positive self-perception in regards to their abilities to succeed within STEM courses (Desy, Peterson, Brockman, 2009; Bryant, Kastrup, Udo, Hislop, Shefner & Mallow, 2013). Much of this stems from social cues that males receive early in their education. Compared to females, males are seen as being naturally more capable in math and science and consistently receive more attention, praise, critical feedback, and support for assertiveness (Seymour, 1995; Chang, 2002). In addition, the instructional methods used in most introductory STEM courses align closely with the learning preferences of males. Together, these factors contribute to more positive classroom experiences for males, in turn contributing to their academic success, and making them more likely to perform as top-tier students.

By comparison, classroom experiences tend to be more negative for females due to a lack of self-confidence, increased levels of anxiety, inability to see relevancy of course material to their daily lives, and lower-prior knowledge levels (Astin & Astin, 1992; Chang, 2002; Papastergiou, 2008; Gates & Mirkin, 2012; Bryant et al., 2013; Tan, Barton, Kang, & O'Neill, 2013). These traits are manifestations stemming from a variety of experiences such as early exposure to traditional gender roles, differential societal expectations for males and females, and the hidden curriculum girls are exposed to before ever attending college, which suggests that science and science-related careers are not for females. Many of these experiences occur in the social milieu, beyond school, and are difficult to study empirically. However, some of these negative experiences occur within science classrooms at all levels and represent areas where educational research stands to make improvements.

Unknowingly, instructors often contribute to females' negative classroom experiences. For example, instructors frequently attribute a female's success in STEM subjects to effort and her failure to a lack of ability. The reverse is often true for males; their success is attributed to natural ability while failure is attributed to lack of effort (Seymour, 1995). In addition, many STEM instructors report having lowered expectations for female students (Chang, 2002). Also, the academic climate encountered is often discouraging as the instructional methods used are exceedingly competitive and fail to accommodate more than a few learning styles (Chang, 2002; Tindal & Hamil, 2003; Kulteral-Konak et al., 2011; Wilson & Kittleson, 2013). Compared to other disciplines, STEM faculty rely more on hierarchical and authoritarian approaches, use instructor-centered lecture styles which encourage inductive reasoning, and are less likely to be interested in a student's personal development (Astin & Astin, 1992; Rosser, 1995; Kulteral-Konak et al., 2011; Wilson & Kittleson, 2013). This instructional style often presents an invisible barrier, generally favoring only one or two learning styles, but not the ones females usually prefer (Tindal & Hamil, 2003; Kulteral-Konak et al., 2011).

Collectively, these factors lead to discouraging experiences for females, especially those who most closely resemble second-tier learners. Regardless of intent or ability, the number of obstacles that must be overcome to succeed within STEM disciplines is far greater. Thus, the development of instructional methods that accommodate and support a wider variety of learning styles is imperative. The number of females within the second-tier is substantial - enough to prevent the shortfall of American scientists and engineers that has been forecast to occur within the next few decades – if they are not lost from the pipeline (Felder, 1993; Freeman, 2005; Falkenheim & Burrelli, 2012; Volenec, Barbarick, Pierzynski, & Bergfield, 2012; Gates & Mirkin, 2012).

Background

A potential tool, which facilitates the preferred learning styles of second-tier students, especially females, within introductory STEM courses is multimedia. Defined as a presentation that uses both pictures and a spoken narration (Mayer, 2009), multimedia provides a platform for presenting complex scientific concepts in a concrete, less competitive manner, possibly reducing the instructional mismatches that are known to contribute to attrition from STEM disciplines. However, little information exists regarding the use of multimedia for increasing the learning gains of students in biology courses, especially at the introductory level where attrition rates are the highest. In addition, very little information regarding the design and development of multimedia for the express purpose of increasing learning gains of females within introductory courses exists.

Previous studies examining the use of multimedia, if performed in a college classroom and not an educational laboratory, were conducted in senior-level chemistry or physics courses where students were much less likely to switch majors (Stelzer, 2009; Stelzer, 2010), or relied on commercially produced multimedia that was not designed for a targeted audience (McClean, 2005). This study is unique in that the design and development of the multimedia was done solely for use in an introductory STEM course by one of the course instructors and targeted a particular group of students.

This study compared the use of instructor-designed multimedia to instructor-designed text with static pictures for increasing the amount of information all students comprehended when learning about the process of photosynthesis. Additionally, the value of multimedia for second-tier students, particularly females, was investigated.

Methods

The use of multimedia to improve student-learning gains within an introductory STEM course was examined in a large, mixed-majors biology course at a mid-western university during four academic semesters in 2012 and 2013 using a mixed-methods approach. Student enrollment was extremely diverse; almost every major, academic year, and preparation level were represented.

The topic of photosynthesis was selected as the focus for multimedia development. A pre-semester exam, given the first day of class to all students in this course, revealed that out of sixteen topics tested, students struggled the most with photosynthesis. This has been a consistent trend within the course for ten years. Figure 1 reveals the results of the pre-semester exam corresponding to the four academic semesters of this study.

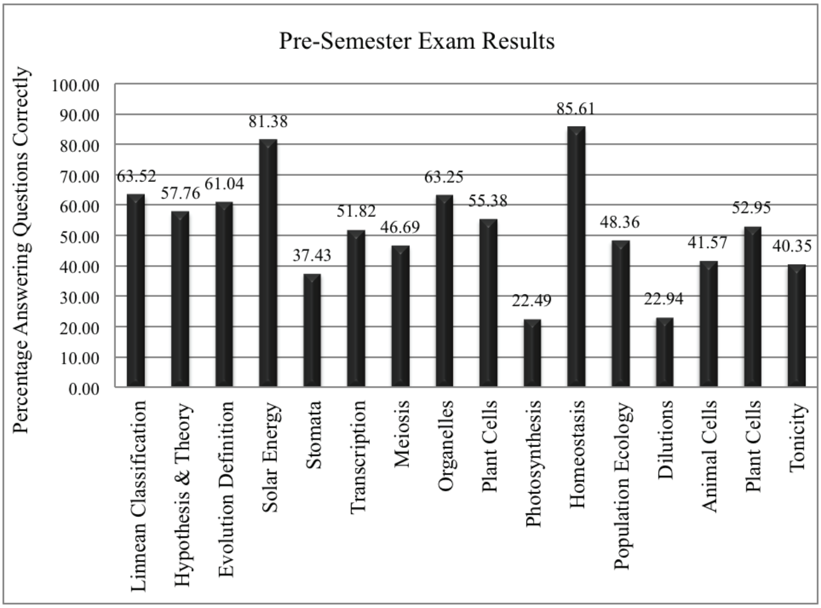

Figure 1. Results of the pre-semester exam given the first day of class. Bars represent mean percentage of all students answering questions correctly during the four semesters corresponding to the study. Students consistently scored the lowest on questions related to photosynthesis.

After analyzing the cumulative results of the pre-semester exam, entire course sections falling within one standard deviation of the overall mean were randomly assigned to different media groups for learning about the process of photosynthesis. As the photosynthesis module approached, approximately ten weeks into a sixteen-week semester, another pre-test was administered which focused specifically on the process of photosynthesis. This pre-test consisted of ten multiple-choice questions, and was given in-class. Results of the pre-test were used to verify that the level of students' background knowledge regarding the details of photosynthesis was similar between experimental and control groups, and served as a baseline or starting point for subsequent assessment of learning gains. The pre-semester exam (Fig. 1) was not used further in the analyses of results.

Students within course sections chosen for the study received directions regarding access to their assigned media, which was available online. Students were instructed to use the media while completing an online daily quiz about photosynthesis; this quiz was a normal part of the course. Twenty-four hours after using the assigned media to complete the quiz, participants were tested in-class using a multiple-choice post-test that was identical to the pre-test but with questions re-ordered. Two weeks later, participants took a unit exam that included questions on the topic of photosynthesis as covered in class. The media could not be accessed or used in any way during the post-test or unit exam. Results from the unit exam were not included due to variation in test questions between semesters. All students had equal access to class materials on photosynthesis, and the media replaced a required component of the course (textbook chapters on photosynthesis). Participation in the study was completely voluntary.

Instructional media used during the study included: 1. A document consisting of text and static images ("Text"), which was used as the control and was similar to what students encounter in traditional textbooks and 2. A multimedia presentation ("Multimedia"), which was used as the experimental media. The text was identical to the spoken narration used within the multimedia; the static images for the text document were derived from screen shots from the multimedia. A sample of the text document is shown in Figure 2. The document was delivered online to participants via a learning management system where access of the document by students could be monitored and recorded. The text material provided the same information as that contained within the multimedia, but in a format similar to a traditional textbook and without animation or narration.

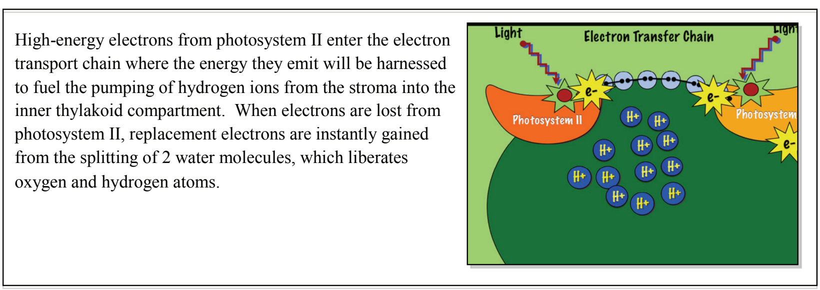
High-energy electrons from photosystem II enter the electron transport chain where the energy they emit will be harnessed to fuel the pumping of hydrogen ions from the stroma into the inner thylakoid compartment. When electrons are lost from photosystem II, replacement electrons are instantly gained from the splitting of 2 water molecules, which liberates oxygen and hydrogen atoms.

Figure 2. Representative image from the "Text" instructional media. This document contained text and images that were identical to the spoken narration and animated visuals used in the multimedia presentation.

The multimedia presentation consisted of a spoken narration with corresponding animations illustrating the process of photosynthesis (Fig. 3), and was designed using Richard Mayer's "Principles for Multimedia Learning" (2009). These principles provide guidance in multimedia instructional design by describing best practices for the development of visual aids with narrations and include:

Table 1

Richard Mayer's Principles of Multimedia Learning. These principles were used in the design and development of the multimedia.

Coherence	Exclude unnecessary words, pictures, sounds, music, and symbols from a multimedia presentation.
Signaling	Highlight organization of the multimedia presentation using verbal or pictorial cues and signal end of one segment or beginning of another.
Redundancy	Present graphics and a spoken narration simultaneously.
Spatial Contiguity	Place graphics and corresponding labels as close as possible.
Temporal Contiguity	Spoken words and presentation of graphics should occur simultaneously.
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.

The multimedia had a running time of eleven minutes and was 23 MB in size. It was produced using Apple's Final Cut Pro Suite (version 7.0.3), exported as a QuickTime file (version 10.1), and was delivered online to participants via a learning management system where access of the multimedia by students could be monitored and recorded.

This study employed a nonequivalent control group design as entire course sections assigned to use the different forms of media had natural variations due to the fact they were actual courses in which students had enrolled for credit. Experimental and control groups consisted of naturally assembled collectives, which were as similar as availability permitted (Cambell & Stanley, 1964). Quantitative statistical analyses were performed on the pre-test scores, online daily quiz scores, and post-test scores of whole course sections assigned to use the different media. Analyses included measures of central tendency and independent sample t-tests. Measures of central tendency were used to ensure that none of the participating course sections represented outliers in regards to the knowledge level students had pertaining to photosynthesis. Independent sample t-tests were used to measure mean score differences between pre and post-tests by media used and by gender. In addition, independent samples t-tests were used to measure mean score differences on the online daily quiz by type of media used and by gender. The level of significance was set at $p < .05$.

To gain a deeper understanding of the relationship between media and student learning preferences, qualitative research methods were used including student focus groups and social validity questions. Focus groups were conducted outside of class using volunteers from course sections participating in the study. Discussions centered upon students' learning styles and their opinions about learning new material from multimedia versus text. Social validity questions, which were embedded in the online quiz, also explored students' opinions about learning from multimedia versus text. Students were asked to compare the use of multimedia with text when learning complex and abstract material in the course, and then were invited to freely describe their experiences with either format via open-ended questions. Information gathered from both the student focus groups and social validity questions were transcribed into one document. Data were coded for emerging themes.

Results

Participation, while completely voluntary, was high. Ninety percent of students in course sections assigned to the experimental treatment participated (333/370), while eighty-four percent of students in course sections assigned to the control treatment participated (249/296). The discrepancy in the number of students between the experimental and control treatments reflects the fact that only one course section was offered during the Summer 2012 semester. Students choosing not to participate were excluded from statistical analyses.

Quantitative and qualitative results from this study provided insight into the value of multimedia for students learning complex scientific concepts in a real course settings. Students in course sections who used Multimedia had significantly higher mean post-test scores than students in course sections that used Text (Fig. 4). There was no significant difference between the pretest scores of students in the experimental or control groups at the start of the study (Fig. 4).

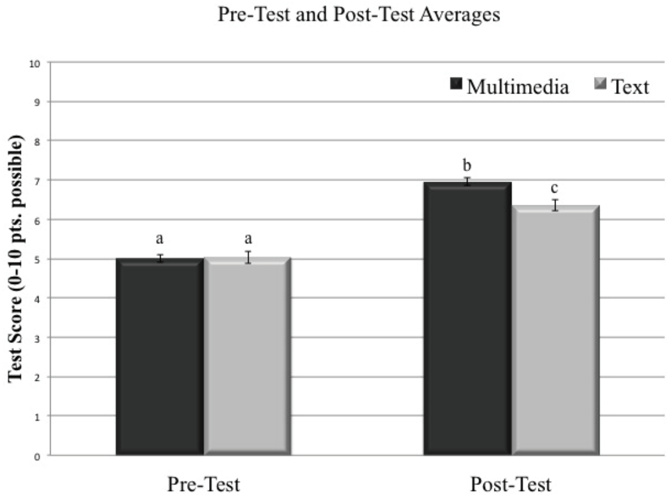

Figure 4. Pre-test and post-test results from Text versus Multimedia. Students were given a pre-test over photosynthesis, then provided access to experimental materials (Text or Multimedia) online for two weeks, then tested for their understanding of photosynthesis with a post-test. Data are shown as mean + SEM. Bars with different superscripts are different ($p < .05$).

The value of multimedia specifically for females was also assessed. The post-test mean scores of females using Multimedia were significantly higher than those of females who used Text (Fig. 5). In contrast, the post-test mean score for males using Multimedia, while higher than males using Text, was not significantly different (Fig. 6). The pre-test mean scores were not significantly different between males and females indicating that neither group possessed more background knowledge about the process of photosynthesis (Figs. 5 and 6). However as shown in figs. 5 and 6, females demonstrated significant improvement when using Multimedia compared to Text, while males did not.

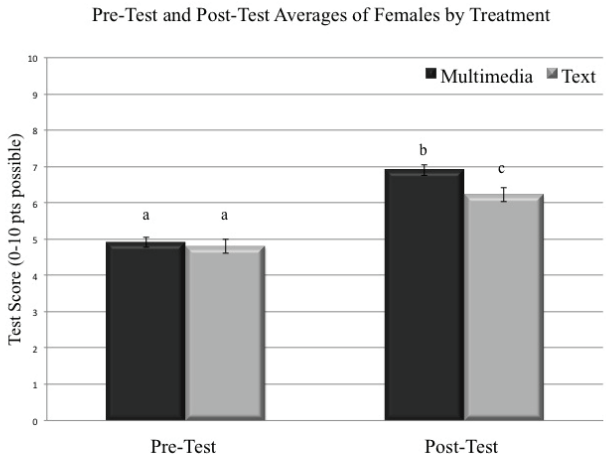

Figure 5. Pre-test and post-test results from females using Multimedia or Text. Data are shown as mean + SEM. Bars with different superscripts are different ($p < .05$).

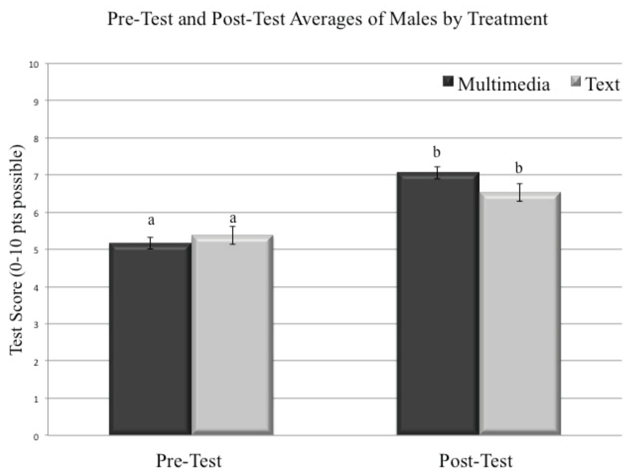

Figure 6. Pre-test and post-test results from males using Multimedia or Text. Data are shown as mean + SEM. Bars with different superscripts are different ($p < .05$).

Although it was not statistically testable, it appeared from each of the four semesters that the gender group starting with the lowest prior knowledge level, and thus more likely to reside in the second-tier, gained the most from viewing Multimedia (Fig. 7). During three out of the four semesters representing this study, females exhibited a lower-prior knowledge level in relation to the process of photosynthesis and consequently made greater learning gains when using Multimedia. However, during the Fall 2013 semester males exhibited a lower-prior knowledge level in regards to the process of photosynthesis. This semester represented the only semester where males using Multimedia to learn about photosynthesis outscored females using Multimedia, supporting the idea that low-prior knowledge learners derive more benefit from the use of multimedia.

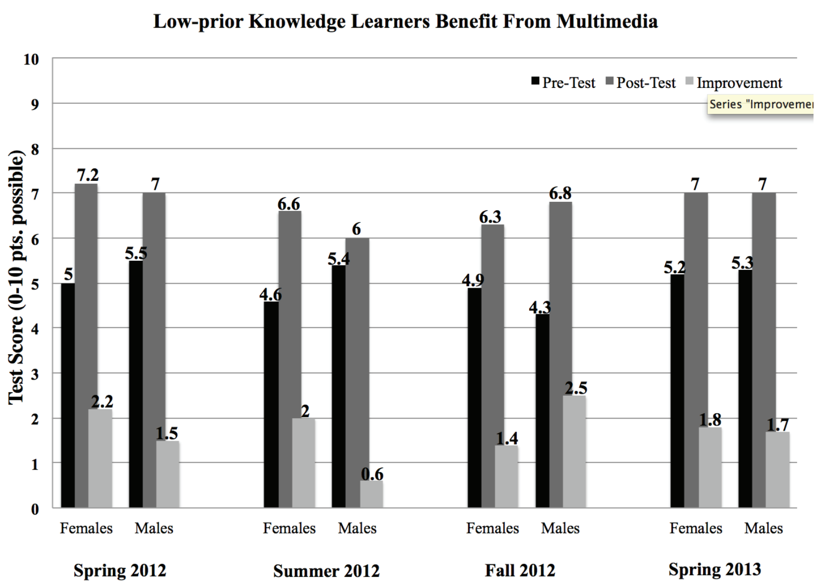

Figure 7. Student learning gains derived from differences between pre and post-test scores, when using Multimedia. Although not statistically testable, the gender group beginning with the lowest-prior knowledge level appeared to benefit more from the use of multimedia when learning about photosynthesis, perhaps indicating that multimedia is helpful for students who have lower background knowledge in STEM-related subjects and more likely to reside in the second-tier.

Qualitative results from this study reveal that students of both genders prefer the use of Multimedia compared to Text when learning complex information. After reviewing and coding student feedback collected from focus groups and social validity questions embedded within the online quiz, three central themes emerged: learning style, instructional format, and recall and comprehension (fig. 8). An overwhelming majority of students identified as visual learners and indicated that reading scientific material is an inefficient use of time because they cannot remember what they read nor do they feel as though they understood the meaning. Many indicated that trying to extract meaning from a text required them to “teach themselves” which made them uncomfortable and more likely to not to finish their reading assignment.

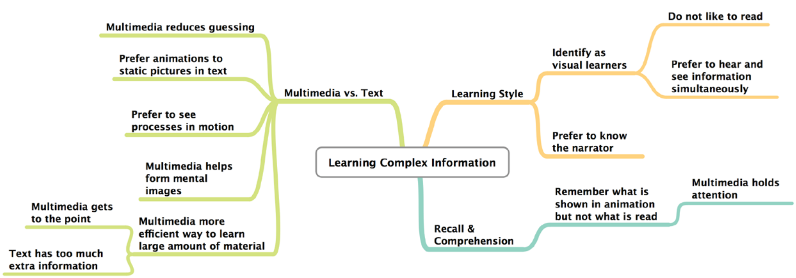

Figure 8. Emerging themes, coalesced from the four academic semesters comprising the study, reveal a preference for multimedia by all users.

Discussion

The work performed in this study supports the use of multimedia for improving the academic performance of second-tier students, especially females, within an introductory college biology course. It is believed that multimedia better accommodates the learning preferences of these students within introductory courses and might be of some benefit in other STEM disciplines. Second-tier students, especially females, identify as visual learners, prefer information that highlights concrete connections, appreciate self-paced learning in a non-competitive atmosphere, and prefer to have a connection with the instructor. Compared to top-tier students, these students often lack in-depth experience with scientific concepts, have less background knowledge, and have not had the opportunity to construct a rich population of mental schemas.

The importance of constructing mental schemas cannot be overemphasized. Schemas, defined as cognitive constructs that permit classification of smaller informational elements into larger elements for easier recall and use (Sweller, 2011), are critical for success within introductory STEM courses due to the amount and speed at which information is presented. Mental schemas represent the learner's interpretation of a concept and can be added to, rearranged, reorganized, and refined as new information is received. As schema construction improves, information can be processed more efficiently, recalled at a faster rate, and applied in novel ways. Mental schemas also allow more information to be stored in long-term memory, reducing the strain on short-term memory. According to Sweller (2011), "If nothing has changed in long-term memory, nothing has been learned." (p. 24).

The use of multimedia is believed to enhance schema construction for second-tier students, especially females, because it closely aligns with the learning preferences of these students. According to Mayer's Theory of Multimedia Learning (2009), multimedia allows the learner to build a coherent mental representation from presented material more efficiently due to the synchronized presentation of pictures and spoken narration. Known as dual-coding, the receipt of both visual and auditory information simultaneously has been shown in many studies to reduce the cognitive load for learners (Levie & Lentz, 1982; Levin, Anglin, & Carney, 1987; Sweller, 1988; Mayer, 2009; Sweller, 2011). Reducing cognitive load is critical for accurate schema construction.

However, simply adding pictures to a spoken narration does not guarantee increased learning gains. Poorly designed multimedia can actually result in negative learning gains; interestingly, top-tier students are most likely to be impacted (Chandler & Sweller, 1996; Schnotz, 2008). This makes the design of multimedia for use in large introductory courses challenging given the range of interests and aptitudes students possess.

To be effective, multimedia must be designed in accordance with current learning theories and must be focused on a particular learning environment, a specific group of students, and a targeted learning goal (Rouet, Lowe, & Schnotz, 2008). Previous studies examining the use of multimedia, but producing inconsistent results, lack some or all of these characteristics (Large, Beheshti, Breuleux, & Renaud, 1994; Tversky, Morrison, & Betrancourt, 2002; Hegarty, 2004; Yung, 2009; Lowe & Boucheix, 2011). By comparison, the present study was performed in a real classroom setting, complete with all of the messiness that comes with teaching and learning. The multimedia used was designed, developed, and refined to accomplish a targeted purpose for a specific group of students. In addition, a detailed and legitimate comparison was used as part of the pre-test/post-test experimental design. And finally, the multimedia focused on a complex topic that was hard to visualize due to the large amount of molecular processes involved. It also required a basic understanding of physics, biochemistry, and ecology; subjects that many second-tier students may not have experienced in as much depth.

These factors contributed greatly to the success of this study which provides evidence that multimedia can be an effective tool for use within an introductory biology course. All students exhibited learning gains after viewing a multimedia presentation as compared to a text document; however, when results were examined by gender, females had significantly greater learning gains when using multimedia. Because females often do not thrive in introductory courses using traditional instructional materials, multimedia appears to provide a valid means to improve learning and perhaps retention of females in STEM fields.

Several additional novel findings were uncovered when analyzing results from this study. The first potentially highlights the value of multimedia for second-tier students; the second indicates a potential benefit of using multimedia in real class settings, especially for assessment preparation. As indicated by a pre-test which specifically assessed students' prior knowledge on the process of photosynthesis, students who had the lowest mean scores appeared to benefit the most from the use of multimedia. Oftentimes, students possessing the lowest prior knowledge about photosynthesis were females; however, during one semester males indicated a lower-prior knowledge level and appeared to have benefitted more from the use of multimedia than females. This particular finding is highly encouraging as it perhaps indicates that the real value of using multimedia in STEM courses is not for top-tier students, but instead for the low to middle achievers. The value of using multimedia to prepare for quizzes and exams was also examined although not reported in the results section due to differences in the questions used amongst the four semesters. Although the data are preliminary, it appears that students who viewed Multimedia have increased scores on photosynthesis questions on quizzes and in-class unit examinations. Thus the use of multimedia in a "real class" appears to be a valid technique for enhancing understanding and retention of complex concepts. While both of these novel findings are encouraging, further controlled research needs to be performed in these areas to specifically examine the relationships.

In conclusion, the use of well-designed multimedia within an introductory biology course appears to be an effective tool for increasing student learning gains and self-confidence. This benefit is potentially greater for second-tier students, especially females, who are more likely to switch majors. Given the projected short fall of STEM graduates, developing and implement novel instructional techniques that are grounded in educational theory but tested in real classroom settings is critical.

While this study focused on the use of multimedia within an introductory biology course for improving the learning gains of females, it is believed that multimedia could be an effective tool for helping other students who reside in the second-tier. In addition, multimedia could prove to be a valuable tool within other introductory STEM courses where enrollments are large and student body diverse. Thus, further research is needed to investigate the relationship between the use of well-designed and targeted multimedia, learning styles of students, and STEM settings.

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