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On the Placement of Retrieval Practice During a Lecture: How Does Lecture Quizzing Affect Memory, Attention, and Test Anxiety?

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ON THE PLACEMENT OF RETRIEVAL PRACTICE DURING A LECTURE: HOW DOES LECTURE QUIZZING AFFECT MEMORY, ATTENTION, AND TEST ANXIETY?

by

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Abstract

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Although lectures are a common method of teaching within higher education, critics argue that this traditional style of teaching encourages a passive approach to learning where students are not actively involved during the learning process. Prior research conducted in classroom settings suggests that clicker quizzes may encourage more student involvement and increase exam scores (Roschelle, Penuel, & Abrahamson, 2004). While the use of clicker quizzes during a lecture seems promising to promote more active learning, perhaps the greatest benefit of quizzing during a lecture is that it provides students with an opportunity to practice retrieval of what they learn, which may improve long-term retention (e.g., McDaniel, Roediger, & McDermott, 2007). The current study examined the effects of inserting quizzes during various segments of a lecture. A pre-recorded lecture was divided into three segments of equal lengths. Participants were randomly assigned to one of the following experimental conditions: (1) – quizzing after each segment; (2) quizzing only after the first segment; (3) quizzing only after the last segment; (4) no quizzing during the lecture. After a one-week retention interval, participants completed a final cumulative test. The results indicated that the interspersed condition significantly outperformed the beginning, end, and no quizzing conditions on the final test. This was especially the case among those with high test anxiety. Results also indicated that the interspersed condition reported significantly less episodes of mind wandering relative to the other conditions, and participants in the interspersed condition recorded significantly more notes.

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Introduction

The lecture is perhaps the most common pedagogical tool used to deliver instruction within higher education. According to the National Center for Education Statistics (NCES), about 83% of college and university faculty use lectures as the primary teaching method in most of their classes (Chen, 2002). The popularity of lectures as a teaching method is perhaps due to their usefulness as mass communication. Lectures may be a convenient way to disseminate content in a timely manner for large groups of students. They may also be more effective than having students independently read the course assigned textbook, according to some research (e.g., Costin, 1972). While there are some benefits of lectures, this so-called "chalk-and-talk" style of teaching has received some criticism. Critics claim that the lecture style of teaching is outdated and may promote a passive approach to learning where the job of the student is to simply listen and take notes (Exley & Dennick, 2009; Felder & Silverman, 1988). Furthermore, critics argue that lectures may encourage students to simply memorize and regurgitate facts, rather than form a strong knowledge base of the subject matter (Costin, 1972; McKeachie, 1986). It has been argued that the lecture style of teaching makes it difficult for students to engage in application, analysis, and synthesis of concepts, which are all important processes to build a durable and connected mental model (Costin, 1972; McKeachie, 1986; Trees & Jackson, 2007)

The criticism of lectures combined with technological advances in the classroom has led to considerable interest among educational researchers in investigating the multi-faceted processes that influence learning from lectures. In fact, there has been a growing body of research dedicated to understanding how different lecture environments affect attention and engagement (e.g., Wilson & Korn, 2007), note-taking skills (e.g., Kiewra, 1989), cooperation and collaboration (e.g., Lambiotte, Skaggs, & Dansereau, 1993), and class attendance (Credé, Roch, & Kieszczynka, 2010). More recently, researchers have started to investigate the effectiveness of using flipped classrooms instead of traditional lecture-based classrooms (Kim, Kim, Khera, & Getman, 2014). Flipped classrooms take a student-centered or blended approach to learning where pre-recorded video lectures are posted online prior to in-class sessions, and class time is then devoted to interactive activities like discussions, debates, and problem solving (Kim et al., 2014). While these classrooms activities may be a promising alternative to combat the passive learning approach associated with traditional lecture teaching, experimental research has not been done, as of yet, to support their effect on learning outcomes (Goodwin & Miller, 2013).

The rapid proliferation of educational technologies has helped to facilitate more engagement in classrooms. For example, many instructors deliver a spoken lecture in conjunction with a visual aid using software such as Microsoft PowerPoint which makes it relatively easy to insert different forms of media (e.g., YouTube videos and animations) that can attract students' attention during instruction. The use of multimedia in the classroom has drawn interest by researchers, and the literature suggests that there are many cognitive mechanisms that influence learning with multimedia (see Mayer, 2002 for review). For example, verbal redundancy occurs when learners are simultaneously presented with text and speech, most commonly through a live or pre-recorded lecture and accompanying PowerPoint slides. In this case, the learner must coordinate between reading the slides and listening to the lecture, which can reduce the cognitive resources available for learning (Mayer, 2002, 2014).

Besides the use of presentation software, instructors are increasingly relying on audience response systems (or clickers) to promote more involvement from students during lectures. There has been some research indicating that the use clickers in the classroom is associated with a number of positive outcomes such as increased engagement, improved exam performance, and overall class enjoyment (Roschelle, Penuel, & Abrahamson, 2004). One main advantage of using clickers in the classroom is that it provides students with "low-stakes" quizzing that can aid the learning process. There is a large body of empirical work that provides evidence on the many benefits of quizzing and/or practice testing (see Roediger & Karpicke, 2006 for a review). While there have been many laboratory studies to support the use of quizzing rather than passive reading or re-studying (Karpicke & Blunt, 2011; Karpicke & Roediger, 2007, 2008; Roediger & Butler, 2011; Roediger & Karpicke, 2006), there is minimal evidence to support the use of quizzing in more educational contexts like lectures. Szpunar, Khan, and Schacter (2013) provided some support for this idea by showing that intermittent quizzes throughout a lecture can reduce mind wandering and enhance retention. Still, it is unclear whether frequent quizzing throughout a lecture can improve other lecture related behaviors besides mind wandering; thus, more research is needed.

The primary aim of this dissertation is to investigate the mechanisms that provide a benefit of quizzing throughout a lecture. To date there has been little research to address how interspersed quizzing throughout a lecture interacts with other cognitive processes such as subsequent learning episodes and attention. Thus, a more general goal of this dissertation is to explore how the placement of quizzing throughout a lecture differentially affects learning and retention. It is hypothesized that interspersed quizzing throughout a lecture will influence many lecture relevant behaviors including attention, note-taking, and test anxiety. This hypothesis was formulated after considering findings from previous work which is explicated in the following sections.

Learning during a Lecture

Although the lecture method of teaching has been subjected to criticism, some university instructors have voiced support for this pedagogical method. Those in favor of lectures claim that this style of teaching is an important component of learning because it provides students with an opportunity to develop background information and basic ideas that are necessary to obtain before independent learning can be efficient outside the classroom (Fry, Ketteridge, & Marshall, 2008). Cashin (1985) also suggested that there are many benefits to the lecture style of teaching. For example, lectures provide instructors with the opportunity to cover material that may not be explicated in the course textbook (e.g., current research). In addition, lectures are a good way to convey interest about a subject matter which can often be noticed by the speaker's tone (Cashin, 1985). Perhaps an enthusiastic speaker may stimulate interest about a particular topic which could ultimately add value to the students' learning experience. Furthermore, when done effectively, lectures can be a good way to transmit new information, explain and clarify ambiguous concepts, and address misconceptions (Steinert & Snell, 1999).

There are specific behaviors that students engage in throughout a lecture which collectively contribute to the learning process. During a lecture students must simultaneously listen/attend to the lecture information, comprehend or interpret the lecture information, and take notes. While these behaviors may individually contribute to information processing, they are not mutually exclusive but rather interdependent. For example, lecture comprehension is often influenced by listening skills and attention (Hansen & Jensen, 1994). Students must pay considerable attention to the speaker, while also ignoring both internal and external classroom distractions (Farley, Risko, & Kingstone, 2013). This may impact the type of notes a student records during the lecture. If a student struggles with lecture comprehension, this may interfere with purposeful note-taking (Kiewra, 1987). Specifically, the student may take fewer notes, vague notes, or verbatim notes.

The relationship between attention and learning during a lecture has drawn some interest among researchers partly because attention plays a vital role in academic performance (e.g., Exeter et al., 2010; Farley et al., 2013; Wilson & Korn, 2007). During a typical lecture class students must divide their attention between the auditory material and visually presented material while also taking notes. Many researchers conclude that attention is best during the first 10-15 minutes of a lecture (Wilson & Korn, 2007); however, some researchers assert that many other factors play an important role, such as course difficulty and the instructor who is teaching the course (Johnstone & Percival, 1976; Wilson & Korn, 2007).

Laboratory experiments dedicated to understanding the role of attention in educational contexts are typically discussed within a mind wandering theoretical framework (Lindquist & McLean, 2011; Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012; Smallwood, Fishman, & Schooler, 2007; Smallwood & Schooler, 2006). Mind wandering is usually defined as a state of decoupled attention (i.e., attention becomes divided between internal and external information) or a shift of attention from a task to unrelated concerns (Smallwood & Schooler, 2006). Findings from prior work on mind wandering indicate that students report (via mind-wandering probes) frequent mind wandering during lectures (Farley et al., 2013; Lindquist & McLean, 2011; Risko et al., 2012). Lindquist and McLean (2011) found that moments of mind wandering were more likely to be reported at the end of a lecture (44%) rather than at the beginning (25%), and they also concluded that mind wandering was negatively associated with note-taking and retention.

The rapid proliferation of technological devices that are suitable for classroom use has created a challenge for educators. Today's classrooms are commonly occupied by students using laptops, smartphones, and tablets. Although these devices are useful to support task-relevant behaviors such as note-taking, the integration of technology in the classroom has also allowed students to engage in computer mediated non-lecture related activities (e.g., emailing, surfing the web, etc.) which can adversely affect attention (Brown & Petitto, 2003; Risko, Buchanan, Medimorec, & Kingstone, 2013). For example, Risko et al. (2013) found that having participants complete a computer mediated non-lecture activity (i.e., responding to a series of emails) led to significant reductions of attention which consequently led to poor performance on a retention test, as indicated by a mediation analysis.

Findings from Risko et al. (2013) suggest that there is a need for educational researchers to develop an attention aware classroom (Risko et al., 2012) that "would enable instructors to maximize each student's opportunity to learn by implementing evidence-based practices that optimize student attention" (p. 275). Some researchers have started to develop interventions that would encourage a more attention aware classroom (e.g., Bunce, Flens, & Neiles, 2010; Burke & Ray, 2008; Szpunar & Schacter, 2015). For instance, Bunce et al. (2010) had students self-report moments of distraction (e.g., texting, web surfing, etc.) throughout a 50-min lecture while also incorporating different instructional methods such as quizzing and demonstrations. The results indicated that moments of distraction during lectures were reduced following quizzes and demonstrations; however, it is important to note that these instructional methods were not experimentally manipulated.

Although past research suggests that attention is an important component of learning from lectures, being able to interpret and understand what's being presented during a lecture also plays an integral role in the learning process. A student's ability to successfully interpret the lecture material may be contingent on how well the instructor organizes the lecture (Bjork, 1979; deWinstanley & Bjork, 2002). According to Bjork (1979) a lecture's organizational structure should be clear, and important ideas should be presented in multiple contexts. By presenting new information in an organized manner, the student will be able to easily integrate it with prior knowledge (deWinstanley & Bjork, 2002). Ultimately, an organized mental model combined with variable encoding can produce more durable learning (Maki & Hasher, 1975; Young & Bellezza, 1982). For instructors, one strategy that may help to promote more organization could be to lecture in conjunction with a visual aid that includes graphical representations such as concept maps. Finally, Etkina (2000) posited that having students generate questions following a lecture could give students the opportunity to reflect on their knowledge and identify any gaps or misconceptions, which could ultimately help with knowledge organization.

Besides being able to effectively interpret and understand lecture information, prior research has provided some evidence that a large part of learning from lectures involves note-taking (see Kiewra, 1987 for review). Although students' motivation to take notes during class time often varies, Di Vesta and Gray (1972) proposed that the act of recording notes has two important functions. First, the encoding function asserts that the process of recording notes, even in the absence of review, can facilitate learning (Kiewra, 1989). This facilitative effect may occur because note-taking often promotes more elaborative processing of specific ideas and greater organization of the lecture material (Kiewra, 1989). Second, the storage function of note-taking implies that the act of recording notes allows students to redistribute lecture material to an external device (e.g., paper) which will then make that information explicitly available for future reference instead of having to rely on memory (Kiewra et al., 1991).

The encoding function of note-taking is usually measured by comparing the performance of students who listen to the lecture but do not take notes with those who listen and record notes. There has been mixed results to support the encoding function. Some studies do not find support for note-taking's encoding function because speaking rates are too fast and/or the lecture information is too dense (Cook & Mayer, 1983; Einstein, Morris, & Smith, 1985). When the material is dense or fast paced, students have to allocate more attentional resources to processing the material, which ultimately affects their note-taking behavior. Conversely, the storage function of note-taking is usually tested by comparing the performance of students who review their notes with those who are not allowed to review their notes. Unlike studies examining the encoding function of note-taking, findings from research investigating the storage function of note-taking consistently demonstrate a clear advantage for the review of notes (Carrier, 1983). Carter and Van Matre (1975) suggested that the benefit of note-taking may primarily derive from the opportunity to review notes rather than the act of note-taking itself. It could be that stored notes available for review scaffold additional learning of the lecture material.

The implications from research on student note-taking suggest that being able to take effective notes is a valuable skill to help supplement the learning process. However, it is often the case that note-taking is not necessarily a skill that students have when entering college or learn throughout their educational career (van der Meer, 2012). When taking notes during a lecture students have to pay attention to the instructor, interpret the material, identify what is important to write down in their notes, and coordinate the physical writing or typing of their notes. Note-taking is further complicated by the fact that people typically speak at a faster rate than which they are capable of writing or typing, making it difficult to remember what the instructor said and write the associated information down before the instructor moves on to the next topic. A student in a lecture class may elect to reduce their cognitive “burden” during instruction and devote all working memory resources to production and simply write everything that the instructor is saying without worrying about comprehension during class. This would not be an ideal experience for the student because class-time would be devoted to transcription rather than learning. Conversely, a student might take no notes if they devote all their working memory resources to comprehension, resulting in a less than ideal situation where they have no stored record of their understanding.

Past research on note-taking has provided some evidence that students often struggle with extracting the main ideas from a lecture (Austin, Lee, & Carr, 2004; Baker & Lombardi, 1985; Foos, Mora, & Tkacz, 1994). To potentially alleviate this problem some instructors choose to lecture in conjunction with a PowerPoint presentation, where they can provide lecture handouts to students in order to supplement note-taking (Marsh & Sink, 2009). Findings from experiment one of Marsh and Sink (2009) suggest that test performance is greatly influenced by the opportunity to review lecture notes rather than whether or not the handouts are available during the lecture (i.e., their findings suggest that when a delayed posttest is given, it doesn’t matter whether students had access to the handouts during the lecture; what matters is whether students have an opportunity to review notes before the test). Besides investigating the effects of providing access to lecture handouts, there has been minimal research to propose possible interventions that may help support student note-taking. Findings from Szpunar et al. (2013) revealed that frequent quizzing throughout a lecture induced more note-taking; however, it was unclear how note-taking behaviors changed (or differed) throughout the duration of the lecture.

Using Clickers in the Classroom

As previously mentioned in the introduction, the lecture method of teaching has received some criticism primarily because it is believed that this style of teaching promotes passivity, with learners performing little active processing that often leads to weak and shallow knowledge (Revell & Wainwright, 2009). While some instructors may agree that other pedagogical techniques might be better than lectures for encouraging students to become more actively involved in classroom learning, few have the time or resources to use more effective teaching methods (Schwartz, 1989; Steinert & Snell, 1999). Steinert and Snell (1999) state that interactive lecturing via small discussions can facilitate more active involvement with the course content, teacher, and/or classmates; however, this is not always feasible for instructors to implement in courses with a large student enrollment.

Fortunately, the advancement of classroom technologies has made it somewhat easier for instructors to make lectures more interactive and engaging. With the recent emergence of audience response systems (i.e., clickers), many instructors have implemented the use of clickers during lectures in order to promote more student involvement (Caldwell, 2007). Clickers are used to quickly collect and analyze student responses to questions asked during class. When using clickers during a lecture, the instructor usually allocates a fixed time for receipt of answers, and students respond using their voting devices. Once all responses are received, the software generates a chart showing the number of students who answered correctly and incorrectly.

One main advantage of using clickers during lecture instruction is that it provides each student with the opportunity to assess his or her individual performance relative to the rest of the class, and the instructor can ascertain general understanding (Caldwell, 2007; Wood, 2004). This suggests that clickers can be a valuable tool to deliver a preliminary diagnostic assessment before administering a formal examination. Still, it must be noted that although clickers can help provide insight into the nature of misconceptions, this usually depends on the instructor creating a carefully designed question. With a well-designed question, the instructor can explain why the answers are correct or incorrect and resolve any misunderstandings via informative feedback.

There has been some research dedicated to exploring the uses, outcomes, and benefits of using clickers in educational settings (for reviews see Caldwell, 2007; Fies & Marshall, 2006; Judson & Sawada, 2002; Roschelle et al., 2004; Simpson & Oliver, 2007). The reviews on clicker use in the classroom converge on the finding that clickers generally help to improve exam scores. The frequency of clicker use during classroom instruction has also been associated with increases in attendance (Caldwell, 2007). However, Trees and Jackson (2007) indicated that the effects of clicker use on attendance are often mediated by the students' grade level and whether students receive points for responding to clicker questions (i.e., clicker points are less likely to motivate attendance for upperclassmen).

Although the use of clicker technologies seems promising, the experimental research is limited on their effectiveness when implemented in college lecture-based courses. Mayer et al. (2009) provides some empirical evidence suggesting that clickers can help improve academic performance. The authors found that students scored significantly higher on course exams when they were in the class where clickers were used to answer a few questions (i.e., 2-4 questions) per lecture compared to a class with in-class questions without clickers and a class with no in-class questions. While implications from this work provide some experimental support regarding the use of educational technologies in college classrooms, prior reviews of the literature conclude that similar work is oftentimes not systematic enough to permit reliable conclusions (Caldwell, 2007; Roschelle et al., 2004). It could be the case that other pedagogical techniques co-associated with clickers may be responsible for producing positive learning outcomes rather than clickers themselves.

The Importance of Retrieval Practice

One advantage of using clickers in the classroom is that it's a convenient way to implement the instructional method of practice testing. In many large lecture courses, exams are usually administered two or three times in a given semester. Perhaps this infrequency of testing indicates that tests are primarily used as a mechanism of assessment; however, research suggests that there may be additional benefits of testing besides assessing student performance. Prior studies have indicated that taking a test following study produces better retention of the material compared to re-reading or re-studying (e.g., Carpenter, Pashler, & Vul, 2006; Karpicke & Roediger, 2007; McDaniel et al., 2007; Roediger & Karpicke, 2006). This enhanced learning following a test is known as the testing effect. In the literature, this effect has also been referred to as test-enhanced learning (e.g., Roediger & Karpicke, 2006) or retrieval practice (e.g., Roediger & Butler, 2011). These effects appear to be independent of grading and appear to be due to the cognitive processing that occurs when a student answers a test item.

Empirical findings on the effects of retrieval practice are quite robust, and the memorial advantage of retrieval practice has been demonstrated across a wide range of disciplines including foreign languages (e.g., Karpicke & Roediger, 2008; Pavlik Jr, 2007), art history (e.g., Butler & Roediger, 2007), biology (e.g., Wooldridge, Bugg, McDaniel, & Liu, 2014), psychology (e.g., Kang, McDermott, & Roediger, 2007) and statistics (e.g., Maass, Pavlik Jr, & Hua, 2015). Studies on the testing effect have demonstrated that the long-term benefit of retrieval practice is still upheld even when participants in the comparison re-study group are given additional study time (Karpicke & Roediger, 2008). This particular finding suggests that the retention of information is perhaps more crucially determined by the type of practice involved, instead of the duration of practice (i.e., the quality of practice seems more important than the quantity of practice).

Furthermore, recent work suggests that frequent testing can lower test anxiety (Agarwal, D'Antonio, Roediger, McDermott, & McDaniel, 2014; Szpunar et al., 2013), providing additional support for testing beyond just a simple memory advantage. Individuals who suffer from test anxiety often experience fear or worry before, during, and after taking an exam (Cassady & Johnson, 2002). It is believed that test anxiety can impede memory performance by blocking encoding and/or rehearsal and disrupt subsequent retrieval during test taking (Cassady & Johnson, 2002; DeCaro, Thomas, Albert, & Beilock, 2011; Nyroos, Schéle, & Wiklund-Hornqvist, 2016). Moreover, high levels of text anxiety has been associated with less motivation to perform academic tasks, regardless of social and educational functions of the school (Nyroos et al., 2016).

Interestingly, findings from Agarwal et al. (2014) imply that retrieval practice during classroom instruction may help to reduce test anxiety among students. In a survey of 1,408 middle school and high school students, Agarwal et al. (2014) found that 72% of students reported that retrieval practice made them less nervous for tests and exams. In addition, Szpunar et al. (2013) found that participants who received intermittent quizzing during a lecture felt less anxious about the upcoming final test. Taken together, it appears that test-enhanced learning could reduce test anxiety. This may ultimately help alleviate the widely expressed concern that excessive testing often creates stress and worry among students.

Earlier studies on the testing effect have usually been conducted using word lists (Tulving, 1967; Wheeler, Ewers, & Buonanno, 2003) or picture lists (Wheeler & Roediger,

1992) as the experimental materials. Furthermore, the vast majority of this prior work has been conducted using college-aged students. There has been a recent push to investigate the testing effect using more complex and educationally relevant materials for all types of students (Karpicke & Aue, 2015; Karpicke, Blunt, & Smith, 2016). For example, Karpicke et al. (2016) found that practicing retrieval, instead of re-studying, enhanced performance on final free recall and recognition tests in elementary school students, regardless of reading comprehension level or processing speed. This finding suggests that the act of practicing retrieval can also be a powerful way to enhance learning for children and not just adults.

The effects of retrieval practice have also been demonstrated across a variety of test types (Agarwal, Karpicke, Kang, Roediger, & McDermott, 2008; Carpenter & DeLosh, 2006; Hinze & Wiley, 2011; Kang et al., 2007; Smith & Karpicke, 2014). Evidence from past work suggests that the effects of retrieval practice may also depend on the type of test that is initially given. For example, in the first experiment of Carpenter and DeLosh (2006) the authors found that initial tests of free recall led to significantly better final test performance that initial tests of recognition. This finding of the effects of test format supports the idea that the type of processing required during initial testing likely plays an important role in the long-term memory benefits of retrieval practice. In addition, prior research has also indicated that feedback plays a critical role in contributing to the benefit of retrieval practice (e.g., Butler, Karpicke, & Roediger, 2007; Kang et al., 2007). If students provide incorrect responses on an initial test and do not receive corrective feedback, they may continue to provide incorrect responses on later tests, which could potentially lead to errors or misconceptions in their mental model (Roediger & Marsh, 2005).

Few studies have investigated the benefits of retrieval practice during spoken lectures (Butler & Roediger, 2007; McDaniel et al., 2007; Szpunar et al., 2013). Butler and Roediger

(2007) conducted an experiment that implemented testing after participants watched a pre-recorded art history lecture. The participants received a short-answer test, a multiple-choice test, or re-study of facts following the lecture. After a 30-day retention interval, participants who received an initial short-answer test performed significantly better on a final test than those who took an initial multiple choice test or re-studied the material; however, it must be noted that the final test was in short-answer format which could lead to an effect of transfer-appropriate processing (Morris, Bransford, & Franks, 1977). Finally, Szpunar et al. (2013) reported two experiments where participants watched a 21-min statistics video lecture. The lecture was divided in four segments of equal lengths. Immediately following each lecture segment, all participants completed math problems for one minute. After the 1-min math session, participants were either given brief quizzes on each segment (i.e., tested group), no quizzes on each segment (i.e., non-tested group), or re-studied the material on each segment (re-study group). The results revealed that participants in the tested-group took significantly more notes, and retained significantly more information on the fourth lecture segment than the other two groups. In addition, the tested-group reported fewer incidences of mind-wandering compared to the non-tested and re-study groups.

While there is a wealth of research to support the practical implications of testing, there appear to be three main theoretical accounts of the mechanisms behind the testing effect thus far (see Karpicke, Lehman, & Aue, 2014 for a review). First, according to the theory of transfer-appropriate processing (Morris et al., 1977), memory performance is best when the processes engaged during initial learning (or encoding) overlap with the processes required for retrieval. Compared to the processes engaged during study, the processes engaged when taking an initial test provide a stronger match with the processes necessary to complete a final test. Second, another explanation suggests that retrieval of information from memory leads to elaboration of memory traces and formation of multiple retrieval routes (Carpenter, 2009; Roediger & Butler, 2011). This suggests that retrieval practice may allow for more durable memory traces, which makes it more likely that the information will be successfully retrieved again in the future. Specifically, practicing retrieval after some study period may promote encoding of additional features or the creation of alternate routes to access the memory trace, whereas re-studying the material may not (Butler, 2010). Perhaps the more retrieval routes there are, the greater the likelihood of successfully accessing the memory trace after a delay.

Finally, Bjork's (1994, 1999) desirable difficulties/retrieval effort hypothesis has also been used to explain the advantage of retrieval practice. A general tenet of this account implies that difficult but successful retrieval of information is better for memory than easier and successful retrieval of information (i.e., a more difficult initial test can sometimes lead to better final recall than a less difficult initial test; see Pyc & Rawson, 2009). According to Karpicke and Roediger (2007), retrieval practice is a technique that makes initial learning slower compared to repeated study, which often promotes rapid initial learning. This slower and more effortful learning ultimately enhances long-term retention.

There is another benefit of retrieval practice that has received some attention in the literature. Prior research has indicated that retrieval practice can enhance future learning episodes or subsequent encoding (Arnold & McDermott, 2013a, 2013b; Grimaldi & Karpicke, 2012; Kornell, Hays, & Bjork, 2009; McDermott, Agarwal, D'Antonio, Roediger, & McDaniel, 2014), which is called test-potentiated learning. Kornell et al. (2009) suggest that unsuccessful retrieval may drive the enhancement of subsequent encoding or restudy (i.e., there is enhanced encoding following a failed generation attempt). One theoretical reason for why initial testing can enhance future learning has been framed within a metacognitive theory. Specifically, it is suggested that initial testing changes metacognitive knowledge, which as a result changes the strategies individuals use during the next learning episode (Pyc & Rawson, 2012). deWinstanley and Bjork (2002) noted that when practicing retrieval during a lecture, students may become more aware of their knowledge and may spend more time studying outside a lecture depending on whether they knew the answers to questions asked during class, suggesting some support for test-potentiation.

The Current Study

The goal of the current study is to investigate the benefits of quizzing throughout a lecture. There is some preliminary evidence that interspersing periods of lecture instruction with quizzing can encourage note-taking and enhance attention by reducing mind wandering (Szpunar et al., 2013). However, these previous findings have not addressed how specific lecture behaviors (or cognitive processes) change as a function of when the quiz is administered during lecture instruction. Furthermore, there is minimal evidence to explain how the placement of quizzes at specific time points within a lecture may affect long-term retention. Thus, a more specific aim of this study is to examine how the placement of quizzes within a pre-recorded lecture influences memory and retention for lecture information.

Prior research on the effects of testing (or quizzing) during a lecture has only focused on one placement of testing within a single study. Specifically, one line of research has focused on the effects of giving a pre-lecture quiz at the beginning of class compared to a no quiz condition (Leeming, 2002; Narloch, Garbin, & Turnage, 2006). Another line of research has investigated the effects of administering a quiz after a lecture compared to a re-study condition (Butler & Roediger, 2007) or interspersed quiz condition (Weinstein, Nunes, & Karpicke, 2016). There has been no empirical work, as of yet, comparing different placements of lecture quizzing within a single study. Thus, the current work fills a void in the literature by allowing for such an important comparison to be made.

Although quizzes can be administered at different time points during instruction, Weinstein et al. (2016) notes that in typical classroom settings, quizzing is usually employed at the end of class. There has been some empirical support suggesting that intermittent quizzing during instruction may be better than quizzing only at the end of instruction (e.g., Weinstein et al., 2016); however, it is not clear whether the advantage of intermittent quizzing is upheld when compared to quizzing only at the beginning of instruction. More specifically, the design of these past studies (e.g., Szpunar et al., 2013) did not determine whether interspersed quizzing can have a test potentiating learning effect.

A general hypothesis of the current study is that intermittent quizzing will support a number of important mechanisms and behaviors that influence lecture processing. The study will address the following questions to pursue the above stated broader objectives and hypotheses:

1. How does quizzing during a lecture affect final test performance? In support of the testing effect, it is predicted that the interspersed quizzing condition will significantly outperform the other conditions on the final test (i.e., more quizzing during a lecture will result in better posttest performance).
2. Does quizzing only near the beginning of a lecture have a test-potentiated learning effect? If so, does this effect last throughout the entire duration of the lecture? It is predicted that quizzing participants only at the beginning of a lecture (i.e., after the first lecture segment) will enhance future learning episodes. More specifically, the prediction is that

quizzing only at the beginning of a lecture (i.e., during segment one) will promote encoding of segment two material. In turn, participants should perform just as well as the interspersed condition on final test items pertaining to segment two even though they were not previously tested on segment two material.

3. Does quizzing during a lecture promote note-taking? If so, how does note-taking change as a function of when the quiz is given? It is predicted that quizzing participants during segment one will significantly increase note-taking during the subsequent learning episode (i.e., segment two). Perhaps giving a quiz at the beginning of instruction causes participants to expect further quizzing. Consequently, they may alter their subsequent encoding strategies by taking more notes. It is also predicted that quizzing participants after each segment will gradually induce more note-taking, whereas no quizzing will gradually reduce the number of notes students record throughout the lecture segments. These predictions imply that quizzing will support attention by promoting task-relevant behaviors and reduce task-irrelevant behaviors such as mind wandering.
4. Is there a relationship between test anxiety and quizzing during a lecture? More specifically, how does the level of test anxiety affect posttest performance as a function of when the quiz is given? It is predicted that intermittent quizzing will lower (final) test anxiety, and quizzing only at the end of a lecture will induce anxiety about the final upcoming test. It is also predicted that the benefits of quizzing after each lecture segment will be greater for participants with high rather than low cognitive test anxiety. Specifically, quizzing after each segment will help participants with high test anxiety encode and organize the lecture material which as a result may thwart excessive worrying

about the upcoming final test, which is a common characteristic of individual with high test anxiety (Cassady & Johnson, 2002).

By directly comparing different placements of quizzes during lecture instruction, this work will provide insight into how retention for lecture information differs depending on when a quiz is given during lecture instruction. Implications from the current work may help instructors decide when is the best time to administer a quiz during a lecture in order for students to receive the maximum benefit of retrieval practice.

Chapter 2

Method

Participants

A total of 110 individuals from Amazon Mechanical Turk (MTurk) provided data for this experiment. All of the participants self-selected this study from a list of available tasks on MTurk. In order to participate in the experiment, the participant had to be located in the United States or Canada and had to have previously completed 50 HITs with at least 95% of those HITs being approved by the requester. Participants had to certify that they are 18 years of age or older (an MTurk requirement), a native English speaker, and had no significant hearing impairments. Because the experiment was conducted in two sessions, participants were paid $2.50 for completing the first session and $2.50 for completing the second session. Although 110 individuals participated in the experiment, a total of 15 participants did not return to complete the second session, and four participants reported having computer issues (n = 91).

Mechanical Turk workers are, on average, 36 years old (median = 33, range: 18 - 81) and 65% female (Paolacci, Chandler, & Ipeirotis, 2010). The participants used in data analyses had an average age of 35 years (SD = 1.56) and was 56% female (n = 51).

Design

The experiment used a between-subjects design with four experimental conditions. As shown in Figure 1, a 33-min pre-recorded lecture was divided into three segments of equal lengths; thus, each lecture segment was approximately 11 min each. The placement of quizzing across each lecture segment was manipulated, leading to four experimental conditions: quizzing after each lecture segment (interspersed condition); quizzing only after the first lecture segment (beginning condition); quizzing only after the last segment (end condition); no quizzing during the lecture (no quizzing condition). Finally, after a one-week retention interval, all participants were given a final test.

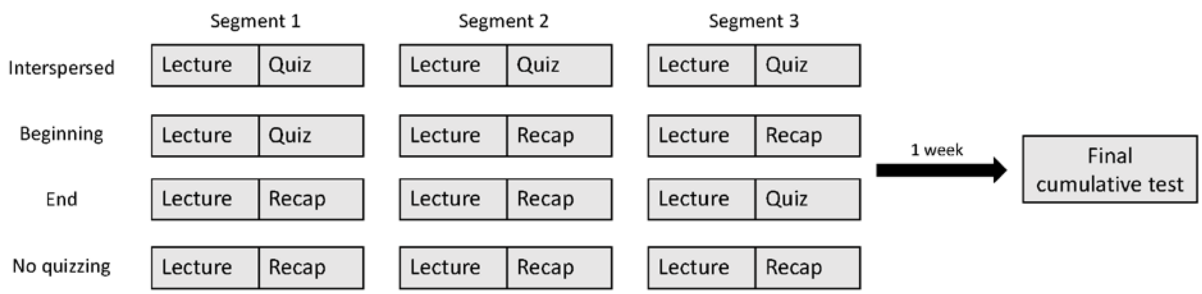

Figure 1. Schematic of experimental design.

Materials

Lecture. In the current study participants watched a 33-min pre-recorded lecture. Using a pre-recoded lecture allowed us to some degree control the stimulus. In addition, given the rapid rise of web-based learning, using a pre-recorded lecture allowed us to mimic online learning environments such as massive open online courses (MOOCs) and Khan Academy, which is an online educational company that provides freely available short video lectures across various disciplines. These online platforms typically include large repositories of pre-recorded lectures that are accessible to enrolled students (i.e., MOOCs) or the general public.

The lecture used in the current work was recorded using Microsoft PowerPoint by the first author. The spoken narration was supplemented by a Microsoft PowerPoint presentation, and each slide within the presentation contained no more than two bulleted points with one relevant picture on each slide. This was strategically done after considering past research which suggests that incorporating lecture slides with an abundant amount of text can inhibit schema organization and adversely affect note-taking (e.g., Cooper, 2009; Tufte, 2003).

The topic discussed in the lecture was inspired by a video lecture posted on Khan Academy titled "An Introduction to Light." The lecture included content about wave-particle duality, visible light behaviors (e.g., reflection, refraction, and diffraction), and the electromagnetic spectrum. The lecture was divided into three segments of 11 minutes each; thus, each lecture segment covered one topic (i.e., segment one covered wave-particle duality, segment two covered visible light behaviors, and segment three covered the electromagnetic spectrum)

Quizzes. A total of eleven multiple choice quiz questions were created for each segment. Those eleven questions (for each segment) were split into two groups of roughly equal difficulty. More specifically, six questions were used during the lecture quizzing, and the remaining five questions for each segment were used as the unseen items on the final cumulative test. Thus, the final cumulative test administered one week following the lecture contained a total of 33 questions, where a total of 18 questions were previously seen and a total of 15 questions were unseen. For all multiple choice questions three plausible incorrect responses were developed to serve as alternative options/lures. Some of the alternative options were created using common misconceptions in participants' free recall responses from a previous study using the same experimental materials. Finally, three of the quiz items for each segment could be answered directly from the bulleted points shown in the slide presentation (e.g., for the quiz item "What are massless particles that carry small amounts of energy?" participants saw the bullet point "Photons are massless particles that carry small amounts of energy" within the slide presentation). The remaining three quiz items were not shown as bulleted points in the slide presentation, but they were spoken by the narrator (i.e., for the quiz item "How do you calculate the velocity of a wave?" the narrator stated that "in order to calculate the velocity of a wave, you multiply the frequency and wavelength"). Finally, all questions on the quizzes and final test were surface level questions, meaning that participants were not required to make inferences beyond what was discussed in lecture.

Mind Wandering Probes. Participants were instructed to report mind wandering by responding to three thought probes. Before beginning the lecture, a standard description of mind wandering was given to the participants, similar to previous research conducted by Smallwood and Schooler (2006). More specifically, they were provided with the following information about mind wandering: "Mind wandering (or zoning out) would be instances where you are thinking about anything else besides the task (e.g., what you ate for dinner last night, what you will be doing this weekend). Sometimes when you are reading or watching a video you may suddenly realize that you are not thinking about what it is that you are reading, hearing, or watching." The mind wandering probe was displayed as a pop-up speech bubble initiated by the YouTube annotation feature. The speech bubble stated the following question: "Are you mind wandering?" Participants were instructed to indicate whether they were or were not mind wandering by selecting "yes" or "no" within 10 seconds of the onset of the speech bubble. A mind wandering probe appeared within each lecture segment and was spaced approximately 10 minutes apart (i.e., the mind wandering probes appeared after 10 minutes and 30 seconds for segment one, after nine minutes and 30 seconds for segment two, and after eight minutes and 30 seconds for segment three). The probes were strategically placed at a point where the narrator paused (i.e., not in the middle of a sentence) so as to not interfere with verbalizations of the lecture content.

Cognitive Test Anxiety. To assess test anxiety, the Cognitive Test Anxiety Scale – Short Form (CTA-SF) was used (Cassady & Finch, 2014), which is designed to measure the cognitive processes that contribute to text anxiety in learners. The CTA-SF is a modification of the original Cognitive Test Anxiety Scale (CTAS) developed by Cassady and Johnson (2002). It has a total of 17 items that are common to the original 24-item CTAS (e.g., "I lose sleep over worrying about examinations;" "During tests, I find myself thinking of the consequences of failing."). Results from a factor analyses conducted by Cassady and Finch (2014) revealed that the 17-item single factor solution was comparable to the overall fit statistics of the two-factor solution for the full CTAS; the fit for the single factor model was slightly better than that of the two factor model. Overall scale reliability for the reduced single-factor 17-item scale revealed a strong internal consistency value of .96. Finally, participant responses to the CTA-SF are completed using a 4-point Likert-type scale using the following response options: 1 – "Not typical of me," 2 – "Somewhat typical of Me," 3 – "Quite typical of me," 4 – "Very typical of me." The score range obtainable by any respondent on the CTA-SF falls between 17 and 68. (See Appendix E for full CTA-SF scale)

Procedure

The study HIT was posted on MTurk, along with a brief description of the task, requirements for participating, and the approximate duration for session 1 (45 – 55 min) and session 2 (20 – 30 min) of the experiment. Participants who elected to participate were redirected to Qualtrics through MTurk. From this point on, all experimental materials were delivered via Qualtrics.

Session 1 began with the informed consent document. Participants were instructed to read the document carefully and click a checkbox to give consent. After obtaining consent, participants were instructed to complete a 10-item multiple choice pretest on general physical science knowledge. The pretest items were obtained from a bank of College Level Examination

Program (CLEP) physical science practice questions (Callihan & Callihan, 2013). The participants were not timed during the pretest; however, approximately 90% of the participants (n = 82) completed the pretest within 15 min.

Following the pretest, participants were randomly assigned to one of the four experimental conditions. The participants first saw a screen warning them that they were about to watch a video and to remove any distractions or take any necessary breaks so that they could focus on watching the video. The participants were also told that they may be quizzed at various points throughout the lecture. At the bottom of each lecture segment, there was a text box where participants had the option to take notes (i.e., participants were not required to take notes, but they were told that note-taking could benefit their learning). Controls were removed from the video lecture in order to prevent pausing, stopping the video, or skipping ahead. While the participants were watching the video lecture, a mind wandering probe appeared within each lecture segment. The probes were spaced approximately 10 min apart. When the mind wandering probe appeared on the screen, participants were instructed to indicate whether they were or were not mind wandering by selecting "yes" or "no" within 10 s of the onset of the probe. If the participant did not respond to the probe within 10 s, they were considered to be mind wandering.

Upon completion of each lecture segment, participants were given a six-item multiple-choice quiz or a structured recap depending on which condition they were randomly assigned to. All quizzing sessions were untimed, and participants were given corrective feedback (i.e., for an incorrect response, the participant saw their chosen response along with the correct answer). For the structured review, the quiz questions were presented as factual statements. For example, the question "the idea that light consists of waves and particles describes which of the following theories?" was presented as "the theory of wave-particle duality is the idea that light consists of waves and particles." During the recap, the factual statements were presented as bulleted points and the narrator of the lecture verbally read each statement.

After completing all three segments of the lecture, the participants were instructed to complete a brief demographic survey which provided basic descriptive information (i.e., age and sex). Following the demographic survey participants were instructed to complete the CTA-SF. Finally, on the last screen of the first session, participants were reminded that they would receive a link to complete the second session in exactly one week. On the day of the final test, the participants were sent a private message via MTurk to courteously remind them to participate.

During session 2 (one-week later) participants were instructed to complete a final cumulative test. They were told that the questions on the test covered all concepts (or ideas) presented during the lecture. The final test was untimed and the participants did not receive feedback. After completing the final test, all participants were debriefed.

Chapter 3

Results

Scoring

Final Cumulative Test. Qualtrics survey software scored all responses on the final cumulative test. One point was given for every correct response. The total number of correct responses was then divided by the total number of possible correct responses (n = 33) to derive a proportion score for each participant.

Mind Wandering. For the mind wandering probes, participants received a score of zero for a "no" response and a score of one for a "yes" response. Thus, higher scores reflected higher levels of mind wandering. Participants received a mind wandering score for each segment as well as a total mind wandering score.

CTA-SF. Participants' responses to each item on the 4-point Likert type CTA-SF scale were scored as follows: 1 – "Not typical of me," 2 – "Somewhat typical of Me," 3 – "Quite typical of me," 4 – "Very typical of me." No item required reverse-scoring, and higher scores indicated higher levels of cognitive test anxiety. The score range obtainable by any respondent on the CTA-SF falls between 17 and 68. The lowest score recorded in the sample was 17 (n = 8) and the highest score recorded was 68 (n = 1); there were no outliers in the distribution of scores.

Note-taking. Participants were encouraged, but not required to take notes during the lecture; approximately 78% of the participants took notes. Participants were given the following instructions for note-taking: "Although you are not required to take notes in this experiment, research suggests that taking organized notes can help you learn and remember information better. If you decide to take notes, you are encouraged to write in complete sentences or phrases with bullet markers."

Note-taking was operationalized as any fact recorded by the participant (in the provided text box) while watching the lecture. One point was awarded for each fact recorded by the participant, and credit was given only if the participant recorded a phrase and/or complete sentence relevant to the topic being discussed in the lecture. Facts that were not mentioned in the lecture but recorded by the participant were not counted. All participants received a note-taking score for each segment by summing the total number of notes recorded within the segment. The scores were also aggregated across the lecture segments in order to produce an overall (or total) note-taking score for each participant.

Finally, prior to conducting any analyses, the data was screened in SPSS 23 to address any issues of missingness, normality, and outliers, following recommendations by (Pallant, 2013) and (Tabachnick & Fidell, 2007).

How does the placement of quizzing during a lecture affect final test performance for items previously seen (i.e., shown on the quiz or recap) and items not seen (i.e., not shown on the quiz or recap)?

A mixed ANCOVA was performed to examine if there was a benefit of condition for the type of items on the final cumulative test (i.e., previously seen vs. unseen). Participants' pretest scores was the covariate. The between-subjects variable was quizzing condition and the within-subjects variable was scores on previously seen items (i.e., items shown on the quiz or recap) and unseen items (i.e., items not shown on the quiz or recap).

The results indicated that pretest score was a significant covariate, $F(1, 86) = 25.43$, $p < .001$, $\eta_p^2 = .23$. There was no significant effect of item-type, $F(1, 86) = 2.79$, $p = .10$, and no significant interaction between quizzing condition and item-type, $F(3, 86) = 1.51$, $p = .22$. There was, however, a significant main effect of quizzing condition, $F(3, 86) = 3.01$, $p = .04$, η_p^2

= .10.   Pairwise comparisons revealed that the interspersed condition performed significantly better than the beginning (*p* = .005), end (*p* = .040), and no quizzing conditions (*p* = .034) on the final test. These results can be seen in Figure 2.

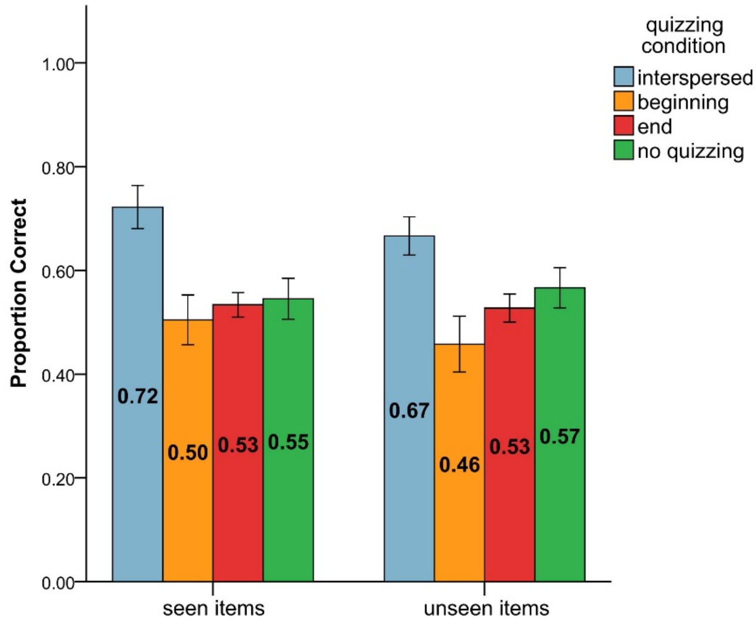

Figure 2. Proportion correct for previously seen items (i.e., quizzed or recap items) and unseen items (i.e., items not quizzed or shown in recap) on the final cumulative test as a function of quizzing condition. Error bars represent one standard error of the mean.

A mixed ANCOVA was performed to examine final test performance for items that were previously seen on the quiz or shown in the recap across the lecture segments.   Once again, the covariate was the participants' pretest scores. Quizzing condition served as the between-subjects variable, and participants' seen items scores for segment 1, segment 2, and segment 3 served as the within-subjects (or repeated measures) variable.

The results revealed that pretest score was a significant covariate, $F(1, 86) = 15.63$, $p <$ .001, η_p^2 = .15. There was a significant effect of quizzing condition, $F(3, 86) = 3.56$, $p = .02$,

η_p^2 = .11, and segment, $F(2, 172) = 3.80$, p = .02, η_p^2 = .04. In addition, the interaction between segment and quizzing condition was significant, $F(6, 172) = 2.22$, $p = .04$, η_p^2 = .07.

Follow-up tests of simple effects revealed a significant simple effect of quizzing condition within segment one, $F(3, 86) = 2.74$, $p = .05$, η_p^2 = .09, within segment two, $F(3, 86) = 2.95$, $p = .04$, η_p^2 = .09, and within segment three, $F(3, 86) = 3.31$, $p = .02$, η_p^2 = .10. Pairwise comparisons showed that the interspersed condition performed significantly better than the beginning condition ($p = .019$) and end condition ($p = .010$) on final test items that were previously seen during segment one. In addition, the interspersed condition performed significantly better than the end condition ($p = .009$) and no quizzing condition ($p = .015$) on final test items that were previously seen during segment two. Finally, the interspersed condition performed significantly better than the beginning ($p = .020$) and no quizzing conditions ($p = .037$) on final test items that were previously seen during segment three. Similarly, for segment three, the end condition performed significantly better than the beginning ($p = .022$) and no quizzing conditions ($p = .052$) on previously seen items. These results can be seen in Figure 3 below.

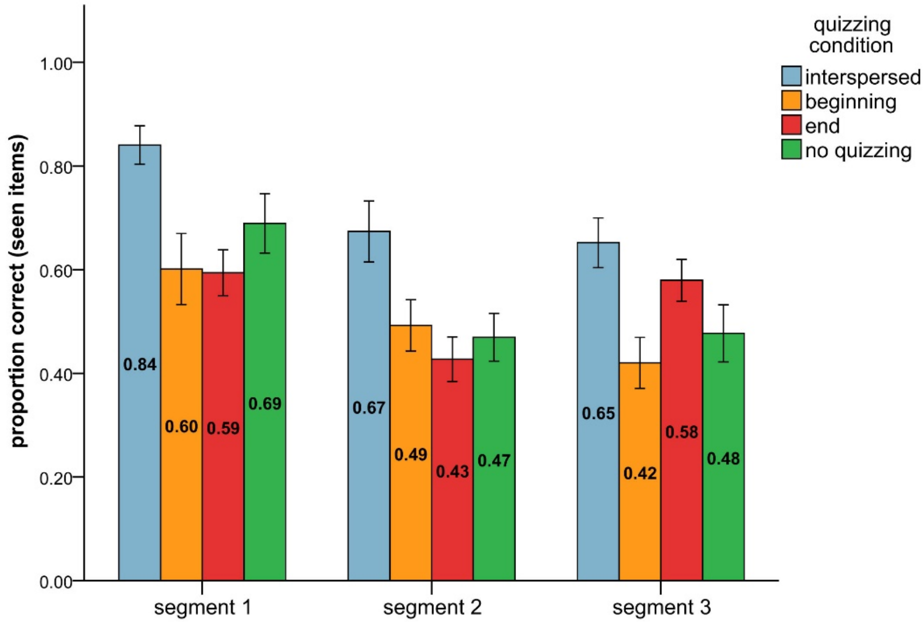

Figure 3. Proportion correct for seen items (i.e., quizzed or recap items) on the final cumulative test across the three lecture segments as a function of quizzing condition. Error bars represent one standard error of the mean.

A mixed ANCOVA was performed to examine final test performance for items that were not previously quizzed or not shown in the recap. In this analysis, the covariate was the participants' pretest scores. Quizzing condition served as the between-subjects variable, and participants' unseen items scores for segment one, segment two, and segment three served as the within-subjects (or repeated measures) variable.

The results revealed that pretest score was a significant covariate, $F(1, 86) = 26.68$, $p < .001$, $\eta_p^2 = .24$. There was no significant effect of quizzing condition, $F(3, 86) = 1.86$, $p = .14$, and there was no significant effect of segment $F(2, 172) = 1.82$, $p = .17$. Finally, the interaction between segment and quizzing condition was not significant, $F(6, 172) = 1.04$, $p = .40$. These results can be seen in Figure 4 below.

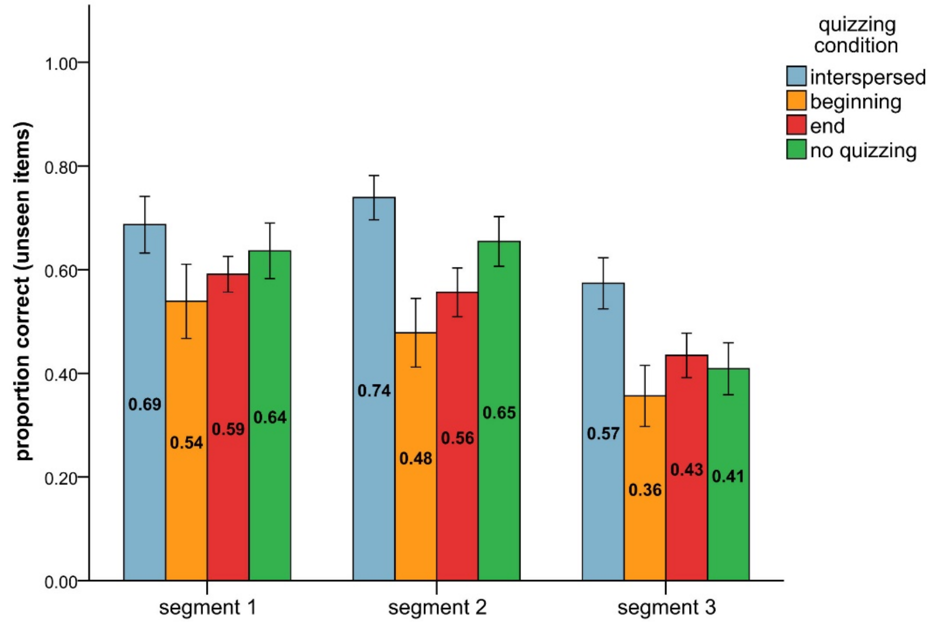

Figure 4. Proportion correct for unseen items (i.e., items not quizzed or shown in recap) on the final cumulative test across the three lecture segments as a function of quizzing condition. Error bars represent one standard error of the mean.

Lastly, a mixed ANCOVA was performed in order to examine if there was an advantage of interspersed quizzing for unseen items. In this analysis the non-interspersed quizzing conditions (i.e., the beginning, end, and no quizzing conditions) were aggregated and compared to the interspersed quizzing condition. Participants' unseen items scores for segment one, segment two, and segment three served as the within-subjects (or repeated measures) variable and the covariate was the participants' pretest scores.

The results revealed that pretest score was a significant covariate, $F(1, 88) = 29.40$, $p < .001$, $\eta_p^2 = .25$. There was a marginally significant effect of quizzing condition, $F(1, 88) = 3.54$, $p = .06$, $\eta_p^2 = .04$, indicating that the interspersed quizzing condition ($M = .57$, $SD = .24$) outperformed the aggregated beginning, end, and no quizzing conditions ($M = .40$, $SD = .24$) on unseen items on the final test. Finally, there was no significant effect of segment $F(2, 176) =$

1.36, p = .26, and the interaction between segment and quizzing condition was not significant, $F(2, 176) = 1.51$, p = .22.

Does quizzing only at the beginning of a lecture (i.e., only after segment one) have a test-potentiating effect?

An ANCOVA was performed in order to examine whether there was a transient effect of test potentiation. In this analysis, the interspersed and beginning conditions were compared on performance for segment two items. The results indicated that pretest score was a significant covariate, $F(1, 43) = 14.72$, $p < .001$, $\eta_p^2 = .26$. There was a significant effect of quizzing condition, $F(1, 43) = 4.19$, $p = .05$, $\eta_p^2 = .09$, indicating that interspersed condition significantly outperformed the beginning condition on segment two items. In addition, the interspersed and beginning conditions were compared on performance for segment three items. The results revealed that there was a significant effect of condition, $F(1, 43) = 5.13$, $p = .03$, $\eta_p^2 = .11$, indicating that the interspersed condition significantly outperformed the beginning condition on segment three items. Pretest score was also a significant covariate, $F(1, 43) = 12.00$, $p = .001$, $\eta_p^2 = .22$.

An ANCOVA was also performed to test whether potentiation alone had a benefit to later segment recall. This analysis compared non-quizzed sections after the initial quiz (i.e., the beginning condition) with non-quizzed sections with no initial quiz (i.e., the no quizzing condition) for segment two items. The results indicated that pretest score was a significant covariate, $F(1, 42) = 7.26$, $p = .01$, $\eta_p^2 = .15$, however there was no significant effect of quizzing condition, $F(1, 42) = .30$, $p = .59$. In addition, for segment three items, there was no significant difference between the interspersed and no quizzing conditions, $F(1, 42) = .02$, $p = .90$.

Finally, an ANCOVA was performed to examine whether those who were tested during segment one would outperform those who were not tested during segment one (i.e., the interspersed and beginning conditions was compared to the end and no quizzing conditions). Once again, pretest score was a significant covariate, $F(1, 88) = 24.95$, $p < .001$, $\eta_p^2 = .22$, however there was no significant effect of condition, $F(1, 88) = .02$, $p = .54$.

How does the placement of quizzing during a lecture affect mind wandering?

A mixed Analysis of Variance (ANOVA)[1] was performed in order to investigate differences in reported instances of mind wandering across the quizzing conditions and lecture segments. Quizzing condition was the between-subjects variable, and the three repeated measures were segment one mind wandering score, segment two mind wandering score, and segment three mind wandering score.

The results revealed a marginally significant effect of quizzing condition, $F(3, 87) = 2.56$, $p = .06$, $\eta_p^2 = .08$. There was a significant effect of segment mind wandering, $F(2, 174) = 8.95$, $p < .001$, $\eta_p^2 = .09$, and a significant interaction between quizzing condition and segment mind wandering, $F(6, 174) = 2.74$, $p = .01$, $\eta_p^2 = .09$.

Follow up tests of simple effects revealed that there was no significant simple effect of quizzing condition for segment one, $F(3,87) = 1.42$, $p = .24$, indicating that attention levels were not significantly different across the quizzing conditions at the beginning of the lecture. There was, however, a significant simple effect of quizzing condition for self-reported instances of mind wandering for segment two, $F(3, 87) = 2.75$, $p = .05$, $\eta_p^2 = .09$, and segment three, $F(3, 87) = 3.50$, $p = .02$, $\eta_p^2 = .11$.

[1] An ANCOVA was originally performed with pre-test score as the covariate. The results indicated that pre-test score was not a significant covariate (p > .05), thus it was dropped from the model.

Pairwise comparisons showed that for segment two, the interspersed condition reported significantly less mind wandering than the end condition (*p* = .032). Similarly, the beginning condition reported significantly less mind wandering than the end condition (*p* = .015). For segment three, the interspersed condition reported significantly less mind wandering than the beginning condition (*p* = .003) and end condition (*p* = .035). The no quizzing condition also reported significantly less mind wandering than the beginning condition (*p* = .050). These results can be seen in Figure 5 below.

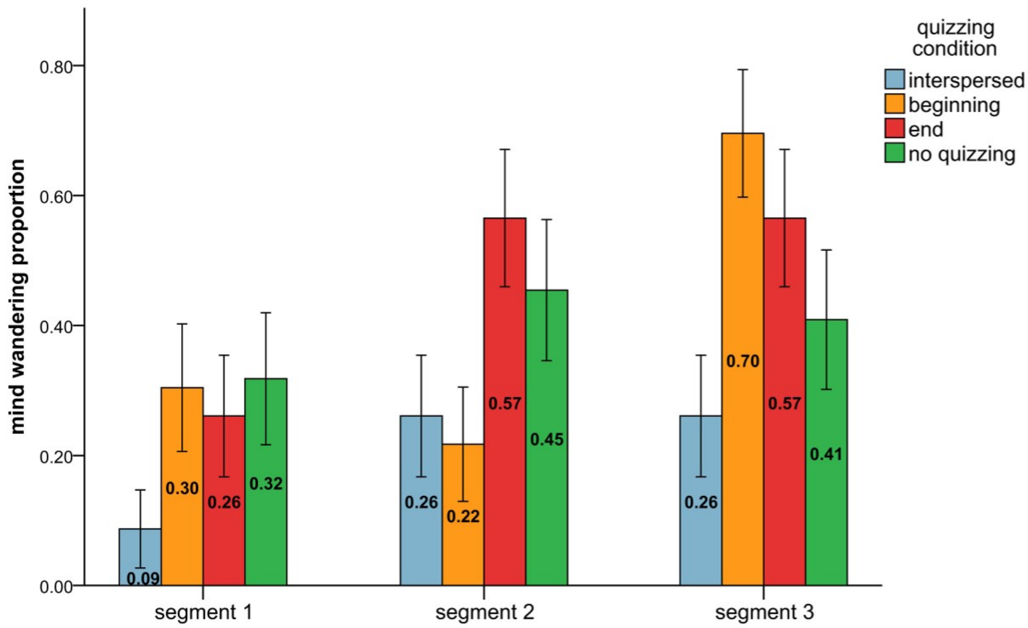

Figure 5. Self-reported mind wandering across the three lecture segments as a function of quizzing condition. Error bars represent one standard error of the mean.

Does quizzing during a lecture promote note-taking? If so, how does note-taking change as a function of when the quiz is given?

In order to determine whether there is a note-taking advantage across the quizzing conditions, a mixed ANOVA was performed using quizzing condition as the between-subjects variable and the number of notes recorded across the three segments as the repeated measures.

The results indicated that there was a significant effect of quizzing condition, $F(3, 67) = 3.09$, $p = .03$, $\eta_p^2 = .12$. There was a significant effect of segment note-taking, $F(2, 134) = 11.74$, $p < .001$, $\eta_p^2 = .15$, and a marginally significant interaction between quizzing condition and segment note-taking, $F(6, 134) = 2.01$, $p = .06$, $\eta_p^2 = .08$.

Follow-up tests revealed that there was no significant simple effect of quizzing condition for notes recorded during segment one, $F(3, 67) = 2.24$, $p = .09$, indicating that there were no significant differences in note-taking scores between the conditions at the beginning of the lecture. The results from simple effects testing did reveal, however, that there was significant simple effect of quizzing condition for notes recorded during segment two, $F(3, 67) = 3.15$, $p = .03$, $\eta_p^2 = .12$, and segment three, $F(3,67) = 3.15$, $p = .03$, $\eta_p^2 = .12$. The interspersed condition recorded significantly more notes than the end condition ($p = .011$) and no quizzing condition ($p = .010$) during segment two. In addition, the interspersed condition recorded significantly more notes than the beginning ($p = .045$), end ($p = .013$), and no quizzing conditions ($p = .008$) during segment three. These results can be seen in Figure 6 below.

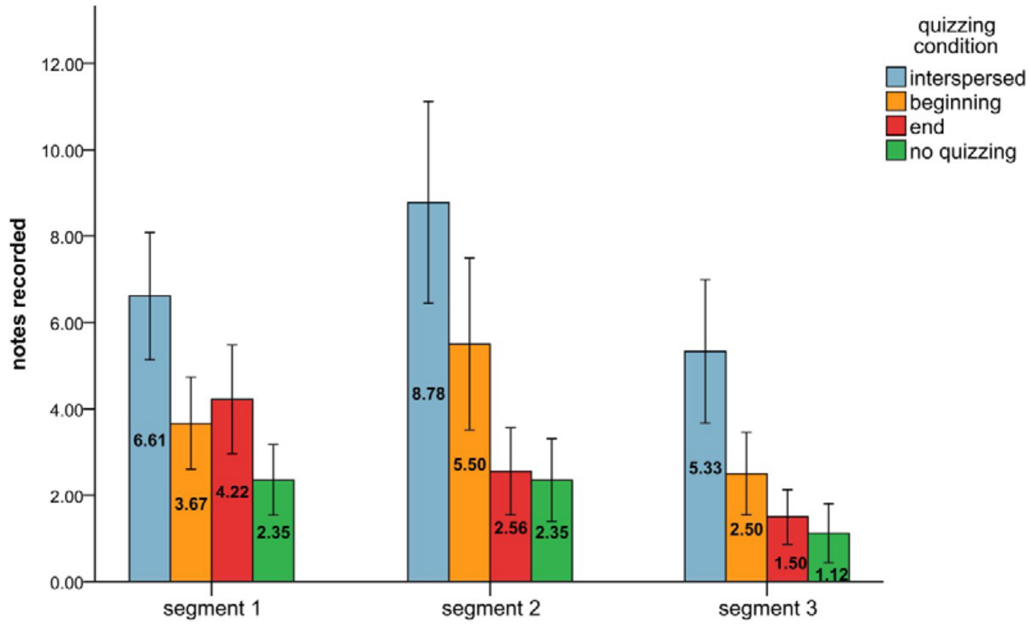

Figure 6. Note-taking across the three lecture segments as a function of quizzing condition. Error bars represent one standard error of the mean.

Is there a relationship between test anxiety and quizzing during a lecture? More specifically, how does the level of test anxiety affect posttest performance as a function of quizzing condition?

In order to examine the role of cognitive test anxiety on posttest performance, the median score on the CTA-SF (median = 30) was used to divide participants into two groups: low test anxiety (i.e., those with CTA scores equal to or below the median; n = 46) and high test anxiety (i.e., those with CTA scores above the median; n = 45).

After dividing the participants in low and high test anxiety groups, a two-way analysis of covariance (ANCOVA) was performed with pretest scores as the covariate and quizzing condition and test anxiety as between-subjects variables. Participants' overall final test score was the dependent variable. The results revealed that pretest score was a significant covariate, $F(1, 82) = 21.13$, $p < .001$, $\eta_p^2 = .25$. The main effect of quizzing condition remained significant after the median split, $F(3, 82) = 3.03$, $p = .03$, $\eta_p^2 = .10$. As reported in the earlier section (i.e., how does quizzing during a lecture affect final test performance?), the interspersed condition performed significantly better than the beginning ($p = .008$), end ($p = .032$), and no quizzing conditions ($p = .018$) on the final cumulative test. There was no significant effect of text anxiety, $F(1, 82) = .60$, $p = .44$, however, the interaction between test anxiety and quizzing condition (shown in Figure 7) was significant, $F(3, 82) = 3.36$, $p = .02$, $\eta_p^2 = .11$., indicating that the effects of quizzing condition on final test performance was significantly different between the low and high test anxiety groups.

Follow-up univariate tests of simple effects revealed that there was no significant simple effect of quizzing condition for the low test anxiety group, $F(3, 82) = .800$, $p = .50$. However, there was a significant simple effect of quizzing condition for the high test anxiety group, $F(3, 82) = 5.78$, $p = .001$, $\eta_p^2 = .17$. The pairwise comparisons indicated that among those with high test anxiety, the interspersed condition performed significantly better than the beginning ($p < .001$) and no quizzing conditions ($p = .004$) on the final cumulative test. Finally, among the high test anxiety group, the end condition performed significantly better than the beginning condition ($p = .032$) on the final cumulative test.

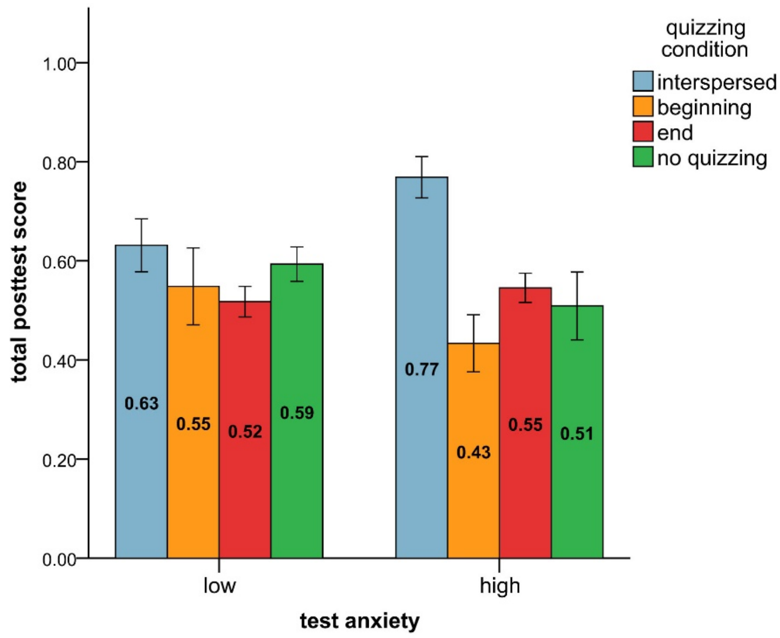

Figure 7. Total posttest performance among those with low and high test anxiety as a function of quizzing condition. Error bars represent one standard error of the mean.

Because the median-split technique may have shortcomings such as reducing statistical power, a multiple regression analysis was also conducted in order to examine the relationship between test anxiety and final test performance as a function of quizzing condition. Final test performance was the response variable and quizzing condition and cognitive test anxiety were the predictor variables. In the first step, two variables were included: quizzing condition and cognitive test anxiety. These variables accounted for a significant amount of variance in final test performance, $R^2 = .18$, $F(4, 90) = 4.81$, $p = .002$.

Next, the interaction between condition and test anxiety was added to the regression model, which accounted for a significant proportion of variance in final test performance, $R^2 = .21$, $F(5, 90) = 4.51$, $p = .001$; R^2 square change = .03, F change (1,85) = 2.99, $p = .08$. Examination of the plot shown in Figure 8 illustrates that for the interspersed condition, as test anxiety increased so did final test performance. For the beginning condition, final test performance decreased as test anxiety increased. Finally, there was only a small effect of test anxiety on final test performance for the end and no quizzing conditions. These results are similar to those in the median-split analysis reported above.

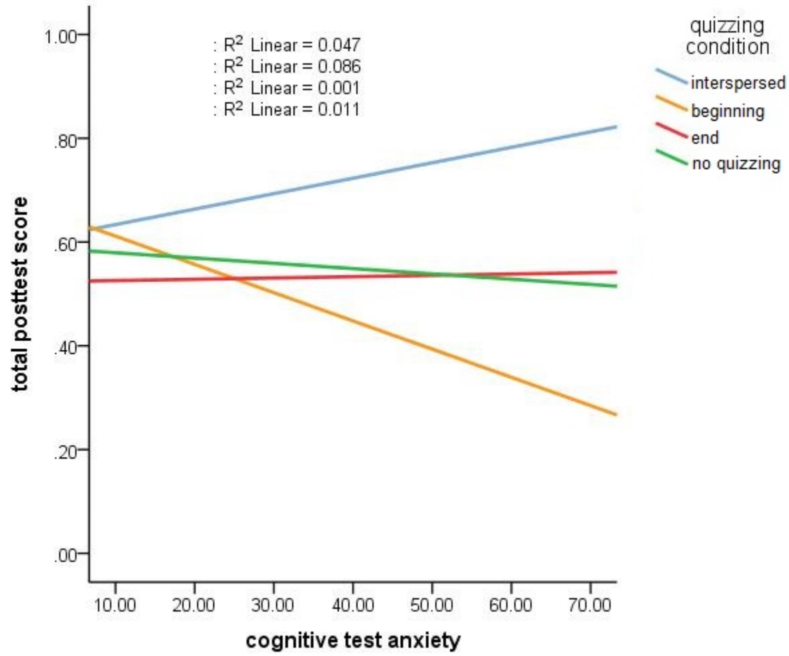

Figure 8. Regression plot of test anxiety predicting final posttest score across quizzing condition.

How does the placement of quizzing during a lecture affect final test performance for items previously seen (i.e., shown on the quiz or recap) and items not seen (i.e., not shown on the quiz or recap) while controlling for pretest, mind-wandering, and note-taking?

A mixed ANCOVA was also performed using participants' pretest scores, note-taking segment one scores, and mind wandering segment one scores as the covariate. The between-subjects variable was quizzing condition and the within-subjects variable was scores on previously seen items (i.e., items shown on the quiz or recap) and unseen items (i.e., items not shown on the quiz or recap).

The results indicated that pretest score was a significant covariate, $F(1, 64) = 22.00$, $p < .001$, $\eta_p^2 = .25$. Segment one mind wandering score was a marginally significant covariate, F(1,

64) = 3.42, p = .07, η_p^2 = .05, however note-taking score was not a significant covariate, $F(1, 64)$ = .01, p = .94. There was no significant effect of item-type, $F(1, 64)$ = 1.33, p = .25, and no significant interaction between quizzing condition and item-type, $F(3, 64)$ = 2.14, p = .10. Finally, there was no significant main effect of quizzing condition, $F(3, 64)$ = 1.03, p = .39.

Because there was no significant effect of quizzing condition, the interspersed quizzing condition was compared to the other conditions (similar to the unseen items aggregation results reported earlier) to increase statistical sensitivity. An ANCOVA was performed using pretest scores and segment one mind wandering scores as covariates; note-taking was dropped from the model since it was not a significant covariate. Previously seen items and unseen items served as the within-subjects variable.

The results indicated that pretest score was a significant covariate, $F(1, 87)$ = 29.61, p < .001, η_p^2 = .25 as well as segment one mind wandering score, $F(1, 87)$ = 6.44, p = .01, η_p^2 = .07. There was a significant effect of item-type, $F(1, 87)$ = 3.84, p = .05, indicating that performance was better on seen items compared to unseen items. There was no significant interaction between quizzing condition and item-type, $F(1, 87)$ = 3.06, p = .08. Finally, there was a significant main effect of quizzing condition, $F(1, 87)$ = 5.62, p = .02, η_p^2 = .06, indicating that the interspersed condition performed significantly better than the aggregated beginning, end, and no quizzing conditions on the final test.

Chapter 4

Discussion

A primary goal of this dissertation was to investigate how the placement of quizzing throughout a pre-recorded lecture affects memory and retention for lecture information. A large body of research has provided substantial evidence that practicing retrieval during learning (or encoding) improves long-term retention compared to re-reading or re-studying (see Rowland, 2014 for a meta-analysis). Although the literature concerning retrieval practice is large and growing, there is relatively little systematic research on how to enhance memory and long-term retention from pre-recorded lectures. Moreover, with the rise of online education and the popularity of using lectures in higher education, there is a critical need to address how to maximize student learning from lectures. The current work examined how the strategic placement of quizzing during a lecture supports cognitive mechanisms such as memory and attention, which are both important for lecture processing. This work also examined if quizzing during a lecture would promote task-relevant behaviors such as note-taking, and if the benefits of quizzing would be affected by one's level of test anxiety.

Findings from the current study demonstrated that final test performance was affected by the placement and presence of quizzing during the lecture. Specifically, those participants who were tested after each lecture segment outperformed all the other quizzing conditions (i.e., those quizzed at the beginning of the lecture, at the end of the lecture, and those who were not quizzed) on the final cumulative test. This result was aligned with the prediction that more frequent quizzing during a lecture would result in better overall (final) test performance. Still, this result may not be surprising given that the interspersed condition was exposed to approximately half of the items on the posttest (i.e., 18 out of 33 items were previously practiced by those in the interspersed condition). Interestingly, when considering posttest items that were previously untested, there was no significant effect of quizzing condition (see Figure 4). These results imply that the overall posttest advantage of quizzing after each segment is particularly robust for items that there were previously practiced or quizzed.

Research on the testing effect suggests that the long-term benefit from retrieval practice may be limited to items that were previously tested (Wooldridge et al., 2014). More specifically, prior studies on the testing effect often include posttest items that are identical to those that were previously tested or practiced (McDaniel, Thomas, Agarwal, McDermott, & Roediger, 2013; Rohrer, Taylor, & Sholar, 2010). While giving identical questions on the quiz and final test may be ideal for learning a large of body of key terms, like in medical school (Larsen, Butler, & Roediger, 2008, 2009, 2013), many educational researchers would object to this methodology of using identical quiz and final test items if transfer is one objective of learning. As a result, there has been a recent trend to examine the benefits of testing when novel items are used on the final test (e.g., Butler, 2010; Carpenter, 2012; Chan, 2010; McDaniel et al., 2013; Rohrer et al., 2010). For example, in four experiments Butler (2010) had participants study prose passages and then take a test on the material or restudy the passages. The participants were given a final test one week later where test items included the same questions that were previously tested and new inferential questions. The results indicated that repeated testing led to greater performance for items that were previously tested and untested (i.e., the inferential questions) compared to repeated studying.

In the current work there was a small marginally significant advantage of interspersed quizzing for items on the posttest that were not seen during practice. There has been some research suggesting that repeated testing can strengthen the memory for the item being retrieved, but also cause forgetting of other related information that was not tested, commonly referred to as retrieval induced forgetting (Anderson, Bjork, & Bjork, 2000; Anderson, Bjork, & Bjork, 1994). This theoretical account may seem intuitive to explain the posttest results for items that were not previously quizzed (i.e., why there was only a small benefit for interspersed quizzing for unseen items). For participants in the interspersed condition, performing retrieval after each lecture segment may have inhibited later retrieval of the remaining material that was not previously quizzed. Still, it is not always the case that retrieval can impair one's ability to remember untested related information. The retrieval induced facilitation effect suggests that initial testing may enhance later memory for untested, related material, which is the exact opposite of retrieval induced forgetting (see Chan, McDermott, & Roediger, 2006). Thus, the direct and indirect mechanisms that have been proposed to underlie the testing effect are still up for debate.

In regards to the results in the current work, it could also simply be the case that interspersed quizzing does not transfer as well to previously untested material. Findings suggest that the benefits of interspersed testing throughout a lecture may be a result of transfer-appropriate processing (Morris et al., 1977; Pan, Gopal, & Rickard, 2016). Participants in the interspersed condition had more opportunity to practice those skills (during encoding) that would be necessary for retrieval on the final test, which ultimately enhanced posttest performance, especially for previously quizzed items. By the same reasoning given that the final test required some transfer, which introduced some item differentiation between the initial and final tests, the transfer-appropriate processing account would predict a reduction in the size of the testing effect (Rohrer et al., 2010). Thus, this may explain why there was only a small advantage of quizzing condition for items on the posttest that were not previously quizzed or shown in the recap (i.e., the size of the testing effect diminished as the final test required some degree of transfer).

One prediction of the current work was that quizzing only at the beginning of a lecture would enhance memory for subsequent lecture information, especially for information presented in segment two of the lecture. This prediction was derived based on past research showing that tests can potentiate subsequent learning or improve encoding of the subsequent study material (e.g., Grimaldi & Karpicke, 2012; Wissman, Rawson, & Pyc, 2011). Contrary to this prediction, results in the current work did not provide conclusive evidence for test potentiation. Final posttest performance for segment two items revealed that the interspersed condition significantly outperformed the beginning condition suggesting that testing only during segment one may not have improved learning for the subsequent lecture information. If there was evidence of test potentiation, the results would indicate no significant difference between the interspersed and beginning conditions for posttest items pertaining to segment two, which is what was predicted. Interestingly, the results did show, however, that there was no significant difference between the interspersed and beginning conditions for segment two posttest items that were previously seen on the quiz or shown in the recap. Perhaps participants in the beginning condition were expecting a quiz after segment two, which may have subsequently enhanced encoding for the recap information, indicating some evidence of test potentiation.

In addition, it could be the case that the potentiating effects of testing may be transient or have a short-term benefit. For example, in four experiments Wissman et al. (2011) had participants read three sections of expository texts and found that recall of the final target section was greater when prior sections had received interim tests versus no interim tests. Although this work supports test potentiation, all four experiments occurred in one session, with 5 minute spacing between reading the texts and taking an interim test. Unlike the current work, there was no final test after a long-term retention interval. Perhaps if there was a shorter retention interval in the current experiment, the results would have provided more support for test potentiation.

It has been argued that the lecture style of teaching promotes a passive mode of learning (i.e., students are not actively engaging with course material) and makes it difficult for students to maintain attention. Fortunately, similar to the current work, there has been some attempts to resolve the difficulties associated with inattentiveness during lectures (Szpunar et al., 2013; Szpunar, Moulton, & Schacter, 2013; Szpunar & Schacter, 2015). Results from the current work suggest that interspersing quizzes throughout a lecture may be one intervention to reduce moments of mind wandering or inattention. The segment results on mind wandering suggest that when participants are not quizzed throughout the lecture, there is a gradual increase in mind wandering. Most notably, these results show that quizzing only at the beginning of a lecture is not enough to sustain attention throughout the entire duration of the lecture. It seems that giving quizzes during a lecture may alter students' metacognitive strategies. The results imply that when students first realize that they may be tested on the material during the lecture (i.e., after the first quiz), attention levels increase, ultimately thwarting task irrelevant activities, specifically mind wandering.

One question in the current work was whether a reduction in mind wandering would promote task-relevant behaviors such as note-taking (i.e., if participants are not mind wandering are they taking notes?). Although participants were not required to take notes, findings suggest that implementing a quiz toward the beginning of a lecture may increase note-taking of the subsequent lecture material. Past research on note-taking suggests that note-taking behavior does not necessarily correlate with comprehension (e.g., Kiewra et al., 1991); however, reductions in note taking over time may indicate inattention on the part of students (K. K Szpunar & Schacter, 2015). For participants in the end and no quizzing conditions, segment results indicated a gradual reduction in note-taking throughout the duration of the lecture. While there is a reduction in note-taking in the last lecture segment for all conditions (especially when compared to note taking in the first segment), those in the interspersed condition did record significantly more notes compared to the end and no quizzing conditions. Taken together, these findings suggest that interspersed quizzing may help sustain note-taking throughout the lecture and may help to ease the steep decline in note-taking throughout the duration of the lecture, which is often seen in studies on student note-taking (e.g., Lindquist & McLean, 2011; Scerbo, Warm, Dember, & Grasha, 1992).

Another (less researched) effect of retrieval practice suggests that taking initial tests may help to reduce test anxiety (Agarwal et al., 2014). Past research has shown that test anxiety can have adverse effects on test performance (Chapell et al., 2005; Hembree, 1988). Because most students do not enjoy taking tests, it seems plausible to assume that interspersed quizzing throughout a lecture may raise anxiety levels in students. Surprisingly, results in the current work show that the benefits of quizzing during a lecture is more pronounced for participants with high cognitive test anxiety. The cognitive interference model suggests that individuals with high test anxiety have difficulty in suppressing competing thoughts during the test (e.g., considering the consequences of failure), ultimately resulting in poor performance (Cassady & Johnson, 2002). Perhaps the introduction of interspersed quizzing throughout the lecture helped those with high test anxiety inhibit competing thoughts and focus on the material being presented. It could be that the benefits of interspersed quizzing may not be upheld among those with low test anxiety because they are better able to allocate their attentional resources on encoding the lecture material.

Limitations and Future Directions

Although the current work highlights important theoretical and practical issues associated the effects of quizzing during a lecture, there are a few notable limitations that must be acknowledged. First, the current work used a 33 minute lecture which is considerably shorter than traditional college lecture classes, where lectures can last up to two or three hours. Thus, it could be that mind wandering may have occurred less often in the current work due to the lecture length, making it difficult to generalize the results to longer lectures. Second, the results in the current work were obtained from a single lecture. It is therefore unknown how the current findings relate to other lectures on a different topic that is perhaps more complex. Third, all items on the quiz and posttest were in multiple choice format. While multiple choice questions may be more feasible to grade (especially for large class sizes) and easier to implement on low stakes quizzes, it is unclear if multiple choice quiz questions would transfer to other question types (e.g., fill-in-the-blank and short answer) that may be more common on some formal examinations (Marsh, Roediger, Bjork, & Bjork, 2007; Smith & Karpicke, 2014). Fourth, participants in the current study were recruited on MTurk; thus, it is difficult to ascertain how familiar the participants were with the lecture style of teaching, unlike recruiting from a college subject pool where students are inherently more familiar with lectures. Given these limitations, future work should consider using a similar paradigm of interspersed quizzing in an actual college classroom throughout an entire course. Perhaps it is the novelty of interspersed quizzing during a lecture that promotes memory for lecture information (Kormi-Nouri, Nilsson, & Ohta, 2005; Yu & Chen, 2014). Testing this paradigm in a semester (or quarter) long course may provide insight into whether the effects persist after the novelty of using interspersed quizzing diminishes over time.

Conclusion

Whether lectures are delivered face-to-face or online, they remain a staple at institutions of higher education. Although this method of teaching has been criticized over the years, the recent growth in applying principles of cognitive psychology to education may help educators make empirically supported pedagogical decisions to overcome the criticisms of lecture-based teaching. Findings in the current work suggest that implementing interspersed quizzing throughout a lecture may benefit a number of important cognitive mechanisms that are essential to lecture processing. The practical implications of this work suggest that if teachers are interested in keeping students engaged throughout the duration of a lecture, interspersing quiz questions may support attention and note-taking. While this type of quiz sequence may also support retention, current findings suggest that the benefits of interspersed quizzing may depend on the student's level of test anxiety and the type of items used during the more formal assessment. The current work provides a necessary step in exploring how the placement of quiz questions during a lecture influence memory and retention for lecture information. Continued research bridging experimental paradigms in educational contexts such as lectures may provide novel insights into the basis of learning, which may eventually improve educational outcomes.

References

Agarwal, P. K., D'Antonio, L., Roediger, H. L., McDermott, K. B., & McDaniel, M. A. (2014). Classroom-based programs of retrieval practice reduce middle school and high school students' test anxiety. *Journal of Applied Research in Memory and Cognition, 3*(3), 131-139.

Agarwal, P. K., Karpicke, J. D., Kang, S. H., Roediger, H. L., & McDermott, K. B. (2008). Examining the testing effect with open-and closed-book tests. *Applied Cognitive Psychology, 22*(7), 861-876.

Anderson, M. C., Bjork, E. L., & Bjork, R. A. (2000). Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychonomic Bulletin & Review, 7*(3), 522-530.

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering can cause forgetting: Retrieval dynamics in long-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(5), 1063-1087.

Arnold, K. M., & McDermott, K. B. (2013a). Free recall enhances subsequent learning. *Psychonomic bulletin & review, 20*(3), 507-513.

Arnold, K. M., & McDermott, K. B. (2013b). Test-potentiated learning: Distinguishing between direct and indirect effects of tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(3), 940-945.

Austin, J. L., Lee, M., & Carr, J. P. (2004). The effects of guided notes on undergraduate students' recording of lecture notes. *Journal of Instructional Psychology, 31*(4), 314-320.

Baker, L., & Lombardi, B. R. (1985). Students' Lecture Notes and Their Relation to Test Performance. *Teaching of Psychology, 12*(1), 28-32. doi:10.1207/s15328023top1201_9

Bjork, R. A. (1979). Information-processing analysis of college teaching. *Educational Psychologist*, *14*, 15-23.

Brown, D. G., & Petitto, K. R. (2003). The status of ubiquitous computing. *Educause Review*, *38*(3), 24-33.

Bunce, D. M., Flens, E. A., & Neiles, K. Y. (2010). How long can students pay attention in class? A study of student attention decline using clickers. *Journal of Chemical Education*, *87*(12), 1438-1443.

Burke, L. A., & Ray, R. (2008). Re-setting the concentration levels of students in higher education: An exploratory study. *Teaching in Higher Education*, *13*(5), 571-582.

Butler, A. C. (2010). Repeated testing produces superior transfer of learning relative to repeated studying. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(5), 1118-1133.

Butler, A. C., Karpicke, J. D., & Roediger, H. L. (2007). The effect of type and timing of feedback on learning from multiple-choice tests. *Journal of Experimental Psychology: Applied*, *13*(4), 273-281.

Butler, A. C., & Roediger, H. L. (2007). Testing improves long-term retention in a simulated classroom setting. *European Journal of Cognitive Psychology*, *19*(4-5), 514-527.

Caldwell, J. E. (2007). Clickers in the large classroom: Current research and best-practice tips. *CBE-Life sciences education*, *6*(1), 9-20.

Callihan, L., & Callihan, D. (2013). *CLEP natural sciences*. Piscataway, NJ: Research & Education Association.

Carpenter, S. K. (2009). Cue strength as a moderator of the testing effect: The benefits of elaborative retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(6), 1563-1569.

Carpenter, S. K. (2012). Testing enhances the transfer of learning. *Current directions in psychological science, 21*(5), 279-283.

Carpenter, S. K., & DeLosh, E. L. (2006). Impoverished cue support enhances subsequent retention: Support for the elaborative retrieval explanation of the testing effect. *Memory and Cognition*, *34*(2), 268-276.

Carpenter, S. K., Pashler, H., & Vul, E. (2006). What types of learning are enhanced by a cued recall test? *Psychonomic Bulletin & Review, 13*(5), 826-830.

Carrier, C. A. (1983). Notetaking research. *Journal of Instructional Development*, *6*(3), 19-26.

Carter, J. F., & Van Matre, N. H. (1975). Note taking versus note having. *Journal of Educational Psychology, 67*(6), 900-904.

Cashin, W. E. (1985). *Improving lectures* (IDEA Paper No. 14 ed.). Manhattan, KS: Kansas State University Center for Faculty Evaluation and Development.

Cassady, J. C., & Finch, W. H. (2014). Confirming the factor structure of the Cognitive Test Anxiety Scale: Comparing the utility of three solutions. *Educational Assessment, 19*(3), 229-242.

Cassady, J. C., & Johnson, R. E. (2002). Cognitive test anxiety and academic performance. *Contemporary educational psychology, 27*(2), 270-295.

Chan, J. C. (2010). Long-term effects of testing on the recall of nontested materials. *Memory, 18*(1), 49-57.

Chan, J. C., McDermott, K. B., & Roediger, H. L. (2006). Retrieval-induced facilitation: Initially nontested material can benefit from prior testing of related material. *Journal of Experimental Psychology: General, 135*(4), 553-571.

Chapell, M. S., Blanding, Z. B., Silverstein, M. E., Takahashi, M., Newman, B., Gubi, A., & McCann, N. (2005). Test anxiety and academic performance in undergraduate and graduate students. *Journal of educational Psychology*, *97*(2), 268.

Chen, X. (2002). *Teaching undergraduates in U.S. postsecondary institutions: Fall 1998*. Washington, D.C.: U.S. Government Printing Office.

Cook, L. K., & Mayer, R. E. (1983). Reading strategies training for meaningful learning from prose. In M. Pressley & J. Levin (Eds.), *Cognitive strategy research: Educational applications* (pp. 87-131). New York, NY: Springer-Verlag.

Cooper, E. (2009). Overloading on slides: Cognitive load theory and Microsoft's slide program PowerPoint. *AACE Journal*, *17*(2), 127-135.

Costin, F. (1972). Lecturing versus other methods of teaching: A review of research. *British Journal of Educational Technology*, *3*(1), 4-31. doi:10.1111/j.1467-8535.1972.tb00570.x

Credé, M., Roch, S. G., & Kieszczynka, U. M. (2010). Class attendance in college a meta-analytic review of the relationship of class attendance with grades and student characteristics. *Review of Educational Research, 80*(2), 272-295.

DeCaro, M. S., Thomas, R. D., Albert, N. B., & Beilock, S. L. (2011). Choking under pressure: Multiple routes to skill failure. *Journal of Experimental Psychology: General, 140*(3), 390-406.

deWinstanley, P. A., & Bjork, R. A. (2002). Successful lecturing: Presenting information in ways to engage effective processing. *New Directions for Teaching and Learning, 89*, 19 - 31.

Di Vesta, F. J., & Gray, G. S. (1972). Listening and note taking. *Journal of educational psychology, 63*(1), 8-14.

Einstein, G. O., Morris, J., & Smith, S. (1985). Note-taking, individual differences, and memory for lecture information. *Journal of Educational psychology, 77*(5), 522-532.

Etkina, E. (2000). Weekly reports: A two-way feedback tool. *Science Education, 84*(5), 594-605.

Exeter, D. J., Ameratunga, S., Ratima, M., Morton, S., Dickson, M., Hsu, D., & Jackson, R. (2010). Student engagement in very large classes: The teachers' perspective. *Studies in Higher Education, 35*(7), 761-775. doi:10.1080/03075070903545058

Exley, K., & Dennick, R. (2009). *Giving a lecture: From presenting to teaching*. London, UK: Routledge.

Farley, J., Risko, E. F., & Kingstone, A. (2013). Everyday attention and lecture retention: The effects of time, fidgeting, and mind wandering. *Frontiers in Psychology, 4*(619), 1-9. doi:10.3389/fpsyg.2013.00619

Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Engineering education, 78*(7), 674-681.

Fies, C., & Marshall, J. (2006). Classroom response systems: A review of the literature. *Journal of Science Education and Technology, 15*(1), 101-109.

Foos, P. W., Mora, J. J., & Tkacz, S. (1994). Student study techniques and the generation effect. *Journal of Educational Psychology, 86*(4), 567-576.

Fry, H., Ketteridge, S., & Marshall, S. (2008). *A handbook for teaching and learning in higher education: Enhancing academic practice*. London, UK: Routledge.

Goodwin, B., & Miller, K. (2013). Evidence on flipped classrooms is still coming in. *Educational Leadership, 70*(6), 78-80.

Grimaldi, P. J., & Karpicke, J. D. (2012). When and why do retrieval attempts enhance subsequent encoding? *Memory and Cognition, 40*(4), 505-513.

Hansen, C., & Jensen, C. (1994). *Evaluating lecture comprehension*. New York, NY: Cambridge University Press.

Hembree, R. (1988). Correlates, causes, effects, and treatment of test anxiety. *Review of educational research, 58*(1), 47-77.

Hinze, S. R., & Wiley, J. (2011). Testing the limits of testing effects using completion tests. *Memory, 19*(3), 290-304.

Johnstone, A. H., & Percival, F. (1976). Attention breaks in lectures. *Education in Chemistry, 13*(2), 49-50.

Judson, E., & Sawada, D. (2002). Learning from past and present: Electronic response systems in college lecture halls. *Journal of Computers in Mathematics and Science Teaching*, *21*(2), 167-182.

Kang, S. H., McDermott, K. B., & Roediger, H. L. (2007). Test format and corrective feedback modify the effect of testing on long-term retention. *European Journal of Cognitive Psychology*, *19*(4-5), 528-558.

Karpicke, J. D., & Aue, W. R. (2015). The testing effect is alive and well with complex materials. *Educational Psychology Review, 27*(2), 317-326.

Karpicke, J. D., & Blunt, J. R. (2011). Retrieval practice produces more learning than elaborative studying with concept mapping. *Science, 331*(6018), 772-775.

Karpicke, J. D., Blunt, J. R., & Smith, M. A. (2016). Retrieval-based learning: Positive effects of retrieval practice in elementary school children. *Frontiers in Psychology*, *7*(350), 1-8.

Karpicke, J. D., Lehman, M., & Aue, W. R. (2014). Retrieval-based learning: An episodic context account. *Psychology of learning and motivation*, *61*, 237-284.

Karpicke, J. D., & Roediger, H. L. (2007). Repeated retrieval during learning is the key to long-term retention. *Journal of Memory and Language, 57*(2), 151-162.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science, 319*(5865), 966-968.

Kiewra, K. A. (1987). Notetaking and review: The research and its implications. *Instructional Science*, *16*(3), 233-249.

Kiewra, K. A. (1989). A review of note-taking: The encoding-storage paradigm and beyond. *Educational Psychology Review*, *1*(2), 147-172.

Kiewra, K. A., DuBois, N. F., Christian, D., McShane, A., Meyerhoffer, M., & Roskelley, D. (1991). Note-taking functions and techniques. *Journal of Educational Psychology*, *83*(2), 240-245.

Kim, M. K., Kim, S. M., Khera, O., & Getman, J. (2014). The experience of three flipped classrooms in an urban university: An exploration of design principles. *The Internet and Higher Education*, *22*, 37-50.

Kormi-Nouri, R., Nilsson, L. G., & Ohta, N. (2005). The novelty effect: Support for the novelty-encoding hypothesis. *Scandinavian Journal of Psychology*, *46*(2), 133-143.

Kornell, N., Hays, M. J., & Bjork, R. A. (2009). Unsuccessful retrieval attempts enhance subsequent learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(4), 989-998.

Lambiotte, J. G., Skaggs, L. P., & Dansereau, D. F. (1993). Learning from lectures: Effects of knowledge maps and cooperative review strategies. *Applied Cognitive Psychology, 7*(6), 483-497.

Larsen, D. P., Butler, A. C., & Roediger, H. L. (2008). Test-enhanced learning in medical education. *Medical education, 42*(10), 959-966.

Larsen, D. P., Butler, A. C., & Roediger, H. L. (2009). Repeated testing improves long-term retention relative to repeated study: A randomised controlled trial. *Medical education, 43*(12), 1174-1181.

Larsen, D. P., Butler, A. C., & Roediger, H. L. (2013). Comparative effects of test-enhanced learning and self-explanation on long-term retention. *Medical Education, 47*(7), 674-682.

Leeming, F. C. (2002). The exam-a-day procedure improves performance in psychology classes. *Teaching of Psychology, 29*(3), 210-212.

Lindquist, S. I., & McLean, J. P. (2011). Daydreaming and its correlates in an educational environment. *Learning and Individual Differences, 21*(2), 158-167.

Maass, J., Pavlik Jr, P., & Hua, H. (2015). *How spacing and variable retrieval practice affect the learning of statistics concepts.* Paper presented at the International Conference on Artificial Intelligence in Education.

Maki, R. H., & Hasher, L. (1975). Encoding variability: A role in immediate and long-term memory? *The American Journal of Psychology*, 217-231.

Marsh, E. J., Roediger, H. L., Bjork, R. A., & Bjork, E. L. (2007). The memorial consequences of multiple-choice testing. *Psychonomic Bulletin & Review, 14*(2), 194-199.

Marsh, E. J., & Sink, H. E. (2009). Access to handouts of presentation slides during lecture: Consequences for learning. *Applied Cognitive Psychology, 24*(5), 691-706. doi:10.1002/acp.1579

Mayer, R. E. (2002). Multimedia learning. *Psychology of learning and motivation, 41*, 85-139.

Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed.). New York, NY: Cambridge University Press.

Mayer, R. E., Stull, A., DeLeeuw, K., Almeroth, K., Bimber, B., Chun, D., . . . Zhang, H. (2009). Clickers in college classrooms: Fostering learning with questioning methods in large lecture classes. *Contemporary Educational Psychology, 34*(1), 51-57.

McDaniel, M. A., Roediger, H. L., & McDermott, K. B. (2007). Generalizing test-enhanced learning from the laboratory to the classroom. *Psychonomic bulletin & review, 14*(2), 200-206.

McDaniel, M. A., Thomas, R. C., Agarwal, P. K., McDermott, K. B., & Roediger, H. L. (2013). Quizzing in middle-school science: Successful transfer performance on classroom exams. *Applied Cognitive Psychology, 27*(3), 360-372.

McDermott, K. B., Agarwal, P. K., D'Antonio, L., Roediger, H. L., & McDaniel, M. A. (2014). Both multiple-choice and short-answer quizzes enhance later exam performance in middle and high school classes. *Journal of Experimental Psychology: Applied, 20*(1), 3-21.

McKeachie, W. J. (1986). *Teaching and learning in the college classroom: A review of the research literature*. Ann Arbor, MI: National Center for Research to Improve Postsecondary Teaching and Learning.

Morris, D. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of verbal learning and verbal behavior, 16*(5), 519-533.

Narloch, R., Garbin, C. P., & Turnage, K. D. (2006). Benefits of prelecture quizzes. *Teaching of Psychology, 33*(2), 109-112.

Nyroos, M., Schéle, I., & Wiklund-Hornqvist, C. (2016). Implementing Test Enhanced Learning: Swedish Teacher Students' Perception of Quizzing. *International Journal of Higher Education*, *5*(4), 1-12.

Pallant, J. (2013). *SPSS survival manual*. Maidenhead, UK: McGraw-Hill Education

Pan, S. C., Gopal, A., & Rickard, T. C. (2016). Testing with feedback yields potent, but piecewise, learning of history and biology facts. *Journal of Educational Psychology, 108*(4), 563-575.

Paolacci, G., Chandler, J., & Ipeirotis, P. G. (2010). Running experiments on amazon mechanical turk. *Judgment and Decision making, 5*(5), 411-419.

Pavlik Jr, P. I. (2007). Understanding and applying the dynamics of test practice and study practice. *Instructional Science, 35*(5), 407-441.

Pyc, M. A., & Rawson, K. A. (2009). Testing the retrieval effort hypothesis: Does greater difficulty correctly recalling information lead to higher levels of memory? *Journal of Memory and Language, 60*(4), 437-447.

Pyc, M. A., & Rawson, K. A. (2012). Why is test–restudy practice beneficial for memory? An evaluation of the mediator shift hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*(3), 737-746.

Revell, A., & Wainwright, E. (2009). What makes lectures ‘unmissable’? Insights into teaching excellence and active learning. *Journal of Geography in Higher Education, 33*(2), 209-223.

Risko, E. F., Anderson, N., Sarwal, A., Engelhardt, M., & Kingstone, A. (2012). Everyday attention: Variation in mind wandering and memory in a lecture. *Applied Cognitive Psychology*, *26*(2), 234-242.

Risko, E. F., Buchanan, D., Medimorec, S., & Kingstone, A. (2013). Everyday attention: Mind wandering and computer use during lectures. *Computers & Education, 68*, 275-283. doi:10.1016/j.compedu.2013.05.001

Roediger, H. L., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in cognitive sciences*, *15*(1), 20-27.

Roediger, H. L., & Karpicke, J. D. (2006). Test-enhanced learning taking memory tests improves long-term retention. *Psychological science*, *17*(3), 249-255.

Roediger, H. L., & Marsh, E. J. (2005). The positive and negative consequences of multiple-choice testing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(5), 1155-1159.

Rohrer, D., Taylor, K., & Sholar, B. (2010). Tests enhance the transfer of learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(1), 233-239.

Roschelle, J., Penuel, W. R., & Abrahamson, L. (2004). *Classroom response and communication systems: Research review and theory*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Rowland, C. A. (2014). The effect of testing versus restudy on retention: A meta-analytic review of the testing effect. *Psychological Bulletin, 140*(6), 1432-1463.

Scerbo, M. W., Warm, J. S., Dember, W. N., & Grasha, A. F. (1992). The role of time and cuing in a college lecture. *Contemporary Educational Psychology*, *17*(4), 312-328.

Schwartz, P. L. (1989). Active, small group learning with a large group in a lecture theatre: A practical example. *Medical teacher, 11*(1), 81-86.

Simpson, V., & Oliver, M. (2007). Electronic voting systems for lectures then and now: A comparison of research and practice. *Australasian Journal of Educational Technology, 23*(2), 187-208.

Smallwood, J., Fishman, D. J., & Schooler, J. W. (2007). Counting the cost of an absent mind: Mind wandering as an underrecognized influence on educational performance. *Psychonomic Bulletin & Review, 14*(2), 230-236.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological bulletin, 132*(6), 946-958.

Smith, M. A., & Karpicke, J. D. (2014). Retrieval practice with short-answer, multiple-choice, and hybrid tests. *Memory, 22*(7), 784-802.

Steinert, L. S., & Snell, Y. (1999). Interactive lecturing: Strategies for increasing participation in large group presentations. *Medical Teacher, 21*(1), 37-42.

Szpunar, K. K., Khan, N. Y., & Schacter, D. L. (2013). Interpolated memory tests reduce mind wandering and improve learning of online lectures. *Proceedings of the National Academy of Sciences, 110*(16), 6313-6317.

Szpunar, K. K., Moulton, S., & Schacter, D. L. (2013). Mind wandering and education: From the classroom to online learning. *Frontiers in psychology, 4,* 495.

Szpunar, K. K., & Schacter, D. L. (2015). Enhancing attention and memory during video-recorded lectures. *Scholarship of Teaching and Learning in Psychology, 1*(1), 60-71.

Tabachnick, B. G., & Fidell, L. S. (2007). *Experimental designs using ANOVA*. Belmont, Ca: Duxbury.

Trees, A. R., & Jackson, M. H. (2007). The learning environment in clicker classrooms: Student processes of learning and involvement in large university-level courses using student response systems. *Learning, Media and Technology, 32*(1), 21-40.

Tufte, E. R. (2003). *The cognitive style of PowerPoint*. Cheshire, CT: Graphics Press.

Tulving, E. (1967). The effects of presentation and recall of material in free-recall learning. *Journal of verbal learning and verbal behavior, 6*(2), 175-184.

van der Meer, J. (2012). Students' note-taking challenges in the twenty-first century: Considerations for teachers and academic staff developers. *Teaching in higher education, 17*(1), 13-23.

Weinstein, Y., Nunes, L. D., & Karpicke, J. D. (2016). On the placement of practice questions during study. *Journal of Experimental Psychology: Applied, 22*(1), 72-84.

Wheeler, M., Ewers, M., & Buonanno, J. (2003). Different rates of forgetting following study versus test trials. *Memory, 11*(6), 571-580.

Wheeler, M., & Roediger, H. L. (1992). Disparate effects of repeated testing: Reconciling Ballard's (1913) and Bartlett's (1932) results. *Psychological Science, 3*(4), 240-245.

Wilson, K., & Korn, J. H. (2007). Attention during lectures: Beyond ten minutes. *Teaching of Psychology*, *34*(2), 85-89.

Wissman, K. T., Rawson, K. A., & Pyc, M. A. (2011). The interim test effect: Testing prior material can facilitate the learning of new material. *Psychonomic Bulletin & Review, 18*(6), 1140-1147.

Wood, W. B. (2004). Clickers: A teaching gimmick that works. *Developmental Cell, 7*, 796-798.

Wooldridge, C. L., Bugg, J. M., McDaniel, M. A., & Liu, Y. (2014). The testing effect with authentic educational materials: A cautionary note. *Journal of Applied Research in Memory and Cognition, 3*(3), 214-221.

Young, D. R., & Bellezza, F. S. (1982). Encoding variability, memory organization, and the repetition effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*(6), 545-559.

Yu, F. Y., & Chen, Y. J. (2014). Effects of student-generated questions as the source of online drill-and-practice activities on learning. *British Journal of Educational Technology, 45*(2), 316-329.

Appendix A

General Physical Science Pretest

P1 Of the following, the one which expands when it freeze is

- carbon dioxide
- iron
- glass
- water

P2 The loss of a neutron from the nucleus of an atom

- changes the chemical nature of the atom
- causes the gain of a proton
- causes the subsequent loss of an electron
- changes the physical property of an atom

P3 Of the following phases of the moon, the invisible one is called

- crescent
- full moon
- new moon
- waxing and waning

P4 All of the following units measure the same physical characteristic EXCEPT

- calorie
- kilowatt
- gram
- joule

P5 Of the following planets, the one which has the shortest evolutionary period around the sun is

- Earth
- Mercury
- Jupiter
- Venus

P6 Alcoholic beverages contain

- wood alcohol
- isopropyl alcohol
- glycerol alcohol
- ethyl alcohol

P7 Oxidation may be defined as
- the gain of hydrogen
- the loss of electrons
- an increase in negative charge
- the loss of neutrons

P8 Which of the following is true about the temperature of liquid water in a lake that has frozen over during the winter?
- The coldest water can be found at the lake bottom.
- The coldest water can be found at middle depths.
- The warmest water can be found at the lake bottom.
- The warmest water can be found just beneath the ice.

P9 Ocean currents are caused chiefly by
- unequal rainfall over the oceans
- the earth's rotation
- the planetary winds
- the moon's gravitation

P10 When an object exhibits inertia it
- resists being set in motion
- exhibits velocity in a specified direction
- possesses direction and magnitude
- resists friction and slows down

Appendix B

Lecture Transcript

[Segment 1]

So what I want to do in this lecture is give you an overview or a brief introduction to the phenomenon of light. And so by an introduction to light, I'm not talking about how a light bulb works or how the sun provides energy or nourishment to plants. I'm going to be talking more about kind of the physical properties of light. The kind of basic fundamentals of light...looking at it from more of a scientific perspective. And when I mean basic, I mean basic, because obviously you can go much deeper into some of the concepts that I'm going to be talking about but I just want to hopefully give you a basic understanding of some of the physical properties of light. So light has this wave-particle duality. And just to kind of take a step back from this we can think about just kind of everyday scenarios or just certain things within our environment where things actually behave as particles in a sense. So we can think about bouncing a basketball and that basketball is just going to follow this certain trajectory or this certain pattern. It's just going to follow this kind of parabola shape, this kind of arch shape. And so this is a scenario or situation where things in our environment can behave like particles that are just bouncing around. However, you can also think of a scenario where things kind of behave as waves. Imagine you're out fishing on a lake and you're a boat and there are waves and as you are moving throughout the lake that boat is actually creating waves so if you actually look behind you, you can actually see that these waves are forming in the ocean or the lake. So this an example of how we can experience waves in our everyday lives. But there is something very unique when you're talking about light and when you're talking about the physical properties of light. And that is light behaves as both a wave and a particle. And this actually fairly new I guess you can say because before this scientists were like okay light is just basically a wave that's all it is it's just electromagnetic waves. Well they even formed this theory that was called the pure wave theory of light. Well Einstein came along genius guy of course and he said you know what light is not just a wave it can actually have these kind of particle like properties. And so light has both this wave property and this particle property. And that is pretty kind of consistent among the research today among scientists today is that most people will say you know what light has both. And it can be a wave. It can also be a particle. And it's not just one or the other. That's pretty consistent today. And so we're going to first talk about the wave nature of light. So light can behave as a wave. And in it's wave form it has all the characteristics of a wave. So a wave can be characterized by a frequency, wavelength, and velocity. And so basically the wavelength is just the distance between the two crests of a wave. So the two different peaks of a wave that'll be the wavelength. And the frequency is basically how many repetitions or how many cycles a wave will actually make within one second. And when you multiply the frequency and the wavelength it gives you the velocity. And light can actually have all these characteristics. It's measured in nanometers. So it has all these, it has a frequency, it has a wavelength, and it has a velocity. And you can actually see an example of a wave, light as a wave, in an actual CD-ROM. So hopefully most of us in here are familiar with CD-ROMs although we're now changing to mp3s but I'm assuming that most of us in here are used to CDs and you can actually see kind of some of the wave properties. When you look at a CD you can actually see some of those waves. And this would be an example of kind of light behaving as a wave. So all it's doing is that the light in this room is basically bouncing off of this CD and creating these waves that you see. So it's just bouncing off of the surface here. So this is just one example of light behaving as a wave. Now besides a wave, as I mentioned briefly, light can also be viewed as a train of particles right and so as I mentioned Einstein came about and he described it in his photoelectric effect and I won't go into the details behind that, that's far beyond the scope of this talk here. But light can also be viewed as a train of particles. And we call these particles photons. And so photons are basically these massless particles that carry small amounts of energy. And those are called photons. And I like to think of photons as kind of like pixels. So whenever you take a photograph in a digital camera those pixels are activated by the light energy that is being carried by these photons. And so you can see this image here and it's very pixelated so that's because of the light energy. Different variations in the light here. And what I noticed is that whenever we are kind of distinguishing between light as a wave and light as a particle, I noticed that scientists often talk about when their describing the wave property of light they're usually describing the behavior. So the action of light. So light can do certain things. And I'll mention that in the next slide. When they're talking about the particle aspects of light or the particle properties of light, they're actually talking about how it can be seen or how it can be viewed. So you can actually like see the actual kind of pixelated images. So that's one trick to kind of understanding these concepts is that when I'm talking about the wave property of light I'm usually referring to the behavior. When I'm talking about the particle property of light, I'm usually talking about how it can be seen or viewed. And so the next concept I want to introduce is how does light travel. Well light will normally travel in a straight line. However, when it's actually in the face of certain objects in our environment. It'll actually will not travel in a straight line. Actually light can travel in three different kind of distinct ways. And some of these are fairly familiar. Light can be reflected, so you can think of a mirror for example. And all it's doing is that light is basically bouncing off the surface of an object here. So that's what a reflection is, it's just light bouncing off the surface. And here in this example of these images you can see that the sunlight is actually bouncing off the surface of this water and you can actually see a reflection of the mountains in the background. And depending upon the texture of that surface. It depends on the angle at which that light will actually bounce off. And so for instance, if you have a smooth surface you will actually be able to see a somewhat clear image or clear reflection. However when that surface is very choppy so in this picture here the water is very choppy very wave-like you can actually see a somewhat blurry reflection as well. So that's an example of kind of the reflection of light and how light can actually be reflected. But besides being reflected, light can also be refracted. So light being refracted is basically bending. So light being bent. The refraction of light usually occurs whenever light is actually going from two different distinct mediums here. So in this example you can actually see it almost gives the illusion that this spoon is being bent. When in actuality it's not. It's actually just going from two different mediums here. So you can see that in this glass that's not completely filled with water, you can see that it's actually traveling, light is actually being traveled, it's going from kind of an air basically to water so that's two different distinct mediums. And usually what happens with refraction is whenever it's going from a faster medium so air is a faster medium compared to water which is a slower medium. So that's usually when you'll see refraction occur. And finally light can be diffracted. So that's a little bit confusing, even I got somewhat confused when trying to disentangle these concepts because they sound alike right. Yeah refraction diffraction, you're like okay how do I not get these two confused. Well diffraction of light refers to how light has to basically move around some object in our environment that's blocking it from passing or following this kind of straight line pattern here. So in this example you'll see that this kind of line would be for instance a hypothetical object that's blocking light. So light has to actually go thru this slit here and you'll see actually the pattern changes because it's having to go in a different kind of pattern and it's having to be able to go thru this tight space. And a more real-world example you can think of is actually whenever it rains outside or there's kind of moisture in the air. So the water particles in the air is basically what's obstructing the light from actually following this straight line pattern. And so what happens is that the light actually has to kind of move around the edges of these water particles. And so you actually get these patterns. So it's no longer straight lines but you actually get these kind of arch shape patterns. So that's an example of kind of the different ways in which light can behave here.

[Segment 2]

So the next concept that I would like to briefly introduce is how light in its wave form can produce interference. Imagine that you are standing above a calm pond (or a bath full of water) and you dip your finger in (or allow a single drop to drip down to the surface of the water from a height), you'll see ripples of energy spreading outwards from the point of the impact. If you do this in two different places, the two sets of ripples will move toward one another, crash together, and form a new pattern of ripples called an interference pattern. Light behaves in exactly the same way. If two light sources produce waves of light that travel together and meet up, the waves will interfere with one another where they cross. In some places the crests of waves will reinforce and get bigger, but in other places the crest of one wave will meet the trough of another wave and the two will cancel out. Constructive interference occurs at any location along the medium where the two interfering waves have a displacement in the same direction. For example, if the crest of one wave meets the crest of a second wave, they will interfere in such a manner as to produce a "super-crest." Similarly, the interference of a trough and a trough interfere constructively to produce a "super-trough." Destructive interference occurs at any location along the medium where the two interfering waves have a displacement in the opposite direction. For example, the interference of a crest with a trough is an example of destructive interference. What are lenses? A lens is a transparent piece of glass or plastic with at least one curved surface. It gets its name from the Latin word for "lentil" (a type of pulse used in cooking), but don't let that confuse you. There's no real reason for this other than that the most common kind of lens (called a convex lens) looks very much like a lentil! A lens works by refraction: it bends light rays as they pass through it so they change direction. That means the rays seem to come from a point that's closer or further away from where they actually originate—and that's what makes objects seen through a lens seem either bigger or smaller than they really are.

There are two main types of lenses, known as convex (or converging) and concave (or diverging). So with a convex lens (sometimes called a positive lens), the glass (or plastic) surfaces bulge outwards in the center giving the classic lentil-like shape. A convex lens is also called a converging lens and that is because it makes parallel light rays passing through it bend inward and meet (converge) at a spot just beyond the lens known as the focal point. So the focal point is just the single point to which the light rays are converging. The distance from the lens to the focal point is known as the focal length. Convex lenses are used in things like telescopes and binoculars to bring distant light rays to a focus in your eyes. A concave lens is exactly the opposite with the outer surfaces curving inward, so it makes parallel light rays curve outward or diverge. That's why concave lenses are sometimes called diverging lenses. (One easy way to remember the difference between concave and convex lenses is to think of concave lenses as caving inwards.) Concave lenses are used in things like TV projectors to make light rays spread out into the distance. It's possible to make lenses that behave in more complex ways by combining convex and concave lenses. A lens that uses two or more simpler lenses in this way is called a compound lens. If you've ever looked through binoculars, a telescope, or a magnifying glass, you'll know that some lenses magnify (or reduce) the apparent size of an object much more than others. There's a simple measurement that tells you how powerful a lens is and it's known as the focal length. The focal length of a lens is the distance from the center of the lens to the point at which it focuses light rays. The shorter the focal length, the more powerful the lens. (It's easy to see why: an ordinary piece of glass would be like a lens of infinite focal length and wouldn't bring light rays to a focus at all. On the other hand, an infinitely powerful lens would bring rays to a focus in an infinitely short distance, with zero focal length. A real lens is somewhere between these two extremes.) You'll find focal lengths written either in ordinary units of length (such as centimeters, millimeters, or inches) or in special optical units called diopters. The diopter measurement of a lens is the reciprocal of the focal length in meters (one divided by the focal length), so 1 diopter = 1 m, 2 diopters = 0.5 m, 3 diopters = 0.33 meters, and so on. Eyeglass prescriptions from opticians typically show the strength of the corrective lenses you need in diopters. The focal length isn't the only important feature of a lens. Bigger lenses gather more light than smaller ones, so they make a brighter image. This is particularly important if you're choosing a lens for a camera, because the amount of light the lens gathers will determine what the image looks like. Camera lenses are usually rated with a measurement called the f-number, which is the focal length divided by the diameter. Generally speaking, lenses with a small f-number make brighter images. Lenses with a higher f-number have a bigger depth of focus: essentially, more of the object you're photographing and its surroundings are in focus at the same time. So there's almost something somewhat unique about light that's different from other waves and other scientific phenomena. And that is unlike most waves light does not require a medium to travel thru. And in fact, light will actually travel fastest in a vacuum. So in the case of sound waves, sound can travel thru solids, liquids, and gases, but sound cannot travel in space. So you'll be able to detect light in space. Whereas with sound waves you won't be able to detect it because sound waves actually require a medium to travel whereas light it will travel fastest in a vacuum and doesn't require a medium to travel. And speaking of kind of the light traveling fast, light is the fastest speed known to physicists today. So there's nothing faster than the speed of light. So you can think of a cheetah. A cheetah is a very fast animal. It's perhaps the fastest animal I think on this planet. But guess what, light beats a cheetah. There's nothing faster than light. And in fact light will travel fastest at 3X10^8 (this is approximate here), 3X10^8 meters per second squared. So that's pretty fast. So that's about 300 million meters per second. And another way of thinking about it is the fact that it would take light probably less than a seventh of a second to travel around the earth. So light will travel fastest probably more than 7 times. It would be able to kind of circle the earth more than 7 times in a second. So that's pretty fast. And like I said it's the fastest. So there's nothing faster, I don't care who tells you what, a cheetah is not faster, Usain Bolt is not faster. Light is the fastest scientific phenomenon on Earth today.

[Segment 3]

And so the last concept I want to introduce is how light is related to the electromagnetic spectrum. The electromagnetic spectrum is the collective term for all possible frequencies of electromagnetic radiation. And in a sense, visible light is just one form of electromagnetic radiation. So when we're describing light as a wave, light is just electromagnetic waves. And so we can think about electromagnetic waves being represented on electromagnetic spectrum. And so you might imagine the electromagnetic spectrum as a rainbow or the different colors of a rainbow. And rainbow really happen because the light from the sun, the white light, is being refracted by these little water particles and you can see that in a clearer way when you see the light being refracted by a prism. So basically the sun is white light and white light encompasses all visible wavelengths. And there's certain frequencies of light that we as humans can perceive with the unaided eye. And that's usually between 400 and 700 nanometers. And so the different frequencies or the different frequency wavelengths of light actually gives the perceptions of different colors right. And so you can see here that in the 400 nanometers if you're detecting a 400 nanometer source it will be more of the violets and the blues. Whereas 700 nanometers will be more oranges and reds. And we can only perceive as I mentioned only between these different colors. We can't perceive anything beyond this spectrum and you're probably wondering why. Why can we only perceive certain frequencies of light? And that answer has not been addressed yet. Scientists are actually still trying to figure out why as humans we can only perceive certain frequencies of light with the unaided eye. And so there's no complete answer to why that is. One hypothesis could be that this is where the sun is dumping a lot energy and that energy is allowing us to be able to perceive these certain frequencies of light. As I mentioned this is just a hypothesis so scientists are actually still trying to figure out why that is occurring. And there's also something interesting is that there's a direct correlation between the energy of the light and the frequency of the light right. So the high frequency waves right, the gamma rays, the violets and blues, actually have higher energy. So the higher the frequency the higher the energy of that light. And the lower the energy the lower the frequency of that light. So you might be thinking how this is related to temperature. All objects emit electromagnetic radiation, and the amount of radiation emitted at each wavelength depends on the temperature of the object. Hot objects emit more of their light at short wavelengths, and cold objects emit more of their light at long wavelengths. The temperature of an object is related to the wavelength at which the object gives out the most light. We can also think about how temperature is related color. So if you ever noticed that how the red flame and the orange flames are actually at a much lower temperature compared to a blue flame. That's because the energy right. So the energy is much slower for the red colors and it gives that red hue compared to the blues and the violets. Those have higher energy and so the temperature is directly related to that so that means the temperature is also increase because of the high energy as well. So another way to think about this relationship is that the amount of light produced at each wavelength depends on the temperature of the object producing the light. Stars hotter than the Sun (over 6,000 degrees C) put out most of their light in the blue and ultraviolet regions of the spectrum. Stars cooler than the Sun (below 5,000 degrees C) put out most of their light in the red and infrared regions of the spectrum. Solid objects heated to 1,000 degrees C appear red but are putting out far more (invisible) infrared light than red light. Now, I keep referring to this idea of the visible light. And you might say, “What is beyond visible light?” And what you’ll find is that light is just a part of a much broader phenomenon that is just a part that we happen to observe. And if we want to broaden the discussion a little bit, visible light is just really part of the electromagnetic spectrum. So light is really just electromagnetic radiation. And everything that I told you about light just now, it has a wave property and it has particle properties. This not just specific to visible light, this is true of all of electromagnetic radiation. So at very low frequencies or very long wavelengths, we’re talking about things like radio waves, the things that allow radio to reach your car, the things that allow your cell phone to communicate with the cell towers; microwave, the thing that start vibrating water molecules in your food so that they heat up; infrared which is what our body releases and that’s way you can detect people thought walls with infrared cameras; visible light, ultraviolet light –the UV light coming from the sun that’ll give you sun burn, X-rays –the radiation that allows us to see through the soft material and just visualize the bones, gamma rays –the super high energy that comes from quasars and other certain types of physical phenomenons. These are all the examples of the exact same thing. We just happen to perceive certain frequencies of this as visible light. How does light carry information about stars, galaxies and other celestial objects? Light is a form of electromagnetic radiation. Visible light is a narrow range of wavelengths of the electromagnetic spectrum. By measuring the wavelength or frequency of light coming from objects in the universe, we can learn something about their nature. Since we are not able to travel to a star or take samples from a galaxy, we must depend on electromagnetic radiation to carry information to us from distant objects in space. The human eye is sensitive to a very small range of wavelengths called visible light. However, most objects in the universe radiate at wavelengths that our eyes cannot see. Astronomers use telescopes with detection devices that are sensitive to wavelengths other than visible light, allowing astronomers to study objects that emit this radiation, otherwise invisible to us. Computer techniques then code the light into arbitrary colors that we CAN see. The Hubble Space Telescope is able to measure wavelengths from about 0.1150 to 2 micrometers, a range that covers more than just visible light. These measurements of light enable astronomers to determine certain physical characteristics of objects, such as their temperature, composition, and velocity.

Appendix C

Quiz Items

Segment 1 Quiz Items:

1 The idea that light consists of waves and particles describes which of the following theories?

- ❍ Theory of wave-particle duality
- ❍ Pure wave theory of light
- ❍ The photoelectric effect
- ❍ Newton's first law of motion

2 Light normally travels ________.

- ❍ Along the outer surface of an object
- ❍ In straight line segments
- ❍ In a curved direction
- ❍ Along the inside edges of an object

3 Massless particles that carry small amounts of energy are known as_________.

- ❍ protons
- ❍ phonons
- ❍ photons
- ❍ quarks

4 How do you calculate the velocity of a wave?

- ❍ Multiply the frequency and amplitude
- ❍ Multiply the frequency and wavelength
- ❍ Divide the frequency and amplitude
- ❍ Divide the frequency and wavelength

5 The pure wave theory of light asserted that light was___________.

- ❍ particles
- ❍ radiation
- ❍ electromagnetic waves
- ❍ reflected

6 Diffraction occurs when____________.

- ❍ A light wave encounters an obstruction
- ❍ Light is displaying particle properties
- ❍ Light is being absorbed by an object's surface
- ❍ Light bounces of the surface of an object

Segment 2 Quiz Items:

1 If two light sources produce waves of light that travel together and meet up, where will they interference?

- ❍ at the focal point
- ❍ in the same direction
- ❍ where they cross
- ❍ they won't interfere

2 Destructive interference occurs at any location along the medium where the two interfering waves have a displacement _______________.

- ❍ in the same direction
- ❍ in the opposite direction
- ❍ parallel to each other
- ❍ alongside the wave with biggest wavelength

3 A convex lens makes parallel light rays passing through it _________.

- ❍ bend inward and diverge
- ❍ bend outward and diverge
- ❍ bend inward and meet
- ❍ bend outward and meet

4 What is the diopter measurement of a lens with a focal length of 3 meters?

- ❍ 3 meters
- ❍ .33 meters
- ❍ 1.5 meters
- ❍ 6 meters

5 Light travels at approximately___________.

- ❍ 3 X 10^8 m/s
- ❍ 10 X 8^3 m/s
- ❍ 3 X 8^10 m/s
- ❍ 2 X 10^8 m/s

6 Light would be able to travel around the earth ___________ in a second.

- ❍ less than 2 times
- ❍ less than 3 times
- ❍ more than 7 times
- ❍ more than 12 times

Segment 3 Quiz Items

1 Visible light is one form of _______________.

- ❍ electromagnetic radiation
- ❍ electromagnetic wavelengths
- ❍ infrared light
- ❍ high energy light

2 What kind of light encompasses all visible wavelengths?

- ❍ low energy light
- ❍ infrared light
- ❍ white light
- ❍ red light

3 Hot objects emit more of their light at _______wavelengths; whereas, cold objects emit more of their light at _________ wavelengths.

- ❍ long; short
- ❍ short; long
- ❍ faster; slower
- ❍ slower; faster

4 The amount of light produced at each wavelength depends on the __________ of the object producing the light.

- ❍ velocity
- ❍ surface
- ❍ energy
- ❍ temperature

5 Which of these electromagnetic waves has the shortest wavelength?

- ❍ visible light
- ❍ gamma rays
- ❍ x-rays
- ❍ microwaves

6 The super high energy that comes from quasars and other certain types of physical phenomenons are known as ___________.

- ❍ x-rays
- ❍ gamma rays
- ❍ photons
- ❍ microwaves

Appendix D

Final Cumulative Test Items

T1.1 The idea that light consists of waves and particles describes which of the following theories?
- ❍ Theory of wave-particle duality
- ❍ Pure wave theory of light
- ❍ The photoelectric effect
- ❍ Newton's first law of motion

T1.2 The pure wave theory of light asserted that light was____________.
- ❍ particles
- ❍ radiation
- ❍ electromagnetic waves
- ❍ reflected

T1.3 How do you calculate the velocity of a wave?
- ❍ Multiply the frequency and amplitude
- ❍ Multiply the frequency and wavelength
- ❍ Divide the frequency and amplitude
- ❍ Divide the frequency and wavelength

T1.4 Massless particles that carry small amounts of energy are known as__________.
- ❍ protons
- ❍ phonons
- ❍ photons
- ❍ quarks

T1.5 Light normally travels _________.
- ❍ Along the outer surface of an object
- ❍ In straight line segments
- ❍ In a curved direction
- ❍ Along the inside edges of an object

T1.6 Diffraction occurs when____________.

- A light wave encounters an obstruction
- Light is displaying particle properties
- Light is being absorbed by an object's surface
- Light bounces of the surface of an object

T2.1 If two light sources produce waves of light that travel together and meet up, where will they interference?

- at the focal point
- in the same direction
- where they cross
- they won't interfere

T2.2 Destructive interference occurs at any location along the medium where the two interfering waves have a displacement ______________.

- in the same direction
- in the opposite direction
- parallel to each other
- alongside the wave with biggest wavelength

T2.3 A convex lens makes parallel light rays passing through it ________.

- bend inward and diverge
- bend outward and diverge
- bend inward and meet
- bend outward and meet

T2.4 What is the diopter measurement of a lens with a focal length of 3 meters?

- 3 meters
- .33 meters
- 1.5 meters
- 6 meters

T2.5 Light travels at approximately__________.

- 3 X 10^8 m/s
- 10 X 8^3 m/s
- 3 X 8^10 m/s
- 2 X 10^8 m/s

T2.6 Light would be able to travel around the earth __________ in a second.
- ❍ less than 2 times
- ❍ less than 3 times
- ❍ more than 7 times
- ❍ more than 12 times

T3.1 Visible light is one form of _______________.
- ❍ electromagnetic radiation
- ❍ electromagnetic wavelengths
- ❍ infrared light
- ❍ high energy light

T3.2 What kind of light encompasses all visible wavelengths?
- ❍ low energy light
- ❍ infrared light
- ❍ white light
- ❍ red light

T3.3 Hot objects emit more of their light at _______wavelengths; whereas, cold objects emit more of their light at _________ wavelengths.
- ❍ long; short
- ❍ short; long
- ❍ faster; slower
- ❍ slower; faster

T3.4 The amount of light produced at each wavelength depends on the __________ of the object producing the light.
- ❍ velocity
- ❍ surface
- ❍ energy
- ❍ temperature

T3.5 Which of these electromagnetic waves has the shortest wavelength?
- ❍ visible light
- ❍ gamma rays
- ❍ x-rays
- ❍ microwaves

T3.6 The super high energy that comes from quasars and other certain types of physical phenomenons are known as ___________.

- ❍ x-rays
- ❍ gamma rays
- ❍ photons
- ❍ microwaves

UT1.1 What are the three components of a wave?

- ❍ Frequency, wavelength, velocity
- ❍ Frequency, wavelength, photons
- ❍ Wavelength, velocity, photons
- ❍ Reflection, refraction, diffraction

UT1.2 Light waves are measured in _______.

- ❍ meters
- ❍ kilometers
- ❍ diopters
- ❍ nanometers

UT1.3 Light in its wave nature can be ________, _________, and _________.

- ❍ reflected, refracted, diffracted
- ❍ reflected, refracted, transformed
- ❍ refracted, transformed, diffracted
- ❍ reflected, bent, absorbed

UT1.4 A reflection occurs when_________

- ❍ Light is behaving as a particle
- ❍ Light encounters an obstruction
- ❍ Light is being bent
- ❍ Light bounces of the surface of an object

UT1.5 The angle at which that light will actually bounce off depends upon the ______ of that surface.

- ❍ texture
- ❍ temperature
- ❍ color
- ❍ size

UT2.1 Constructive interference occurs at any location along the medium where the two interfering waves have a displacement _______________.

- ❍ in the same direction
- ❍ in the opposite direction
- ❍ parallel to each other
- ❍ alongside the wave with the biggest wavelength

UT2.2 A lens work by________.

- ❍ reflection
- ❍ refraction
- ❍ diffraction
- ❍ absorption

UT2.3 What are the two main types of lenses?

- ❍ converging and diverging
- ❍ converging and transparent
- ❍ diverging and transparent
- ❍ refracting and diffracting

UT2.4 The single point to which light rays are converging is known as the ___________.

- ❍ vertex
- ❍ focal point
- ❍ radius
- ❍ point of convergence

UT2.5 Lenses whose outer surfaces curve inward are known as ___________.

- ❍ concave lenses
- ❍ convex lenses
- ❍ interfering lenses
- ❍ compound lenses

UT3.1 All possible frequencies of electromagnetic radiation are represented _______________.

- ❍ within gamma rays
- ❍ within mircowaves
- ❍ within a rainbow
- ❍ within the electromagnetic spectrum

UT3.2 Which statement best describes the formation of a rainbow?

- ❍ White light from the sun is being absorbed from water particles.
- ❍ All light from the spectrum is being refracted from water particles.
- ❍ White light from the sun is being refracted from water particles.
- ❍ Rainbows occur because of too much moisture in the atmosphere.

UT3.3 Humans can perceive frequencies of light between __________ nanometers with the unaided eye.

- ❍ 400 - 700
- ❍ 400 - 600
- ❍ 400 - 500
- ❍ 300 - 700

UT3.4 What is one hypothesis as to why humans can only perceive certain frequencies of light?

- ❍ this is where the sun is dumping a lot energy which allows us to perceive these certain frequencies of light
- ❍ this is where the sun absorbs a lot energy which allows us to perceive these certain frequencies of light
- ❍ our eyes do not have components of compound lenses
- ❍ the radiation from the sun is too powerful

UT3.5 Compared to ultraviolet waves, the wavelength of infrared waves is_______.

- ❍ shorter
- ❍ longer
- ❍ the same
- ❍ faster

Appendix E

Cognitive Test Anxiety Scale

CTA1 I lose sleep over worrying about examinations.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA2 While taking an important examination, I find myself wondering whether the other students are doing better than I am.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA3 I tend to freeze up on things like intelligence tests and final exams.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA4 During tests, I find myself thinking of the consequences of failing.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA5 At the beginning of a test, I am so nervous that I often can’t think straight.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA6 My mind goes blank when I am pressured for an answer on a test.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA7 During tests, the thought frequently occurs to me that I may not be too bright.
- ❍ Not at all typical of me.
- ❍ Only somewhat typical of me.
- ❍ Quite typical of me.
- ❍ Very typical of me.

CTA8 During a course examination, I get so nervous that I forget facts I really know.
- ❍ Not at all typical of me.
- ❍ Only somewhat typical of me.
- ❍ Quite typical of me.
- ❍ Very typical of me.

CTA9 After taking a test, I feel I could have done better than I actually did.
- ❍ Not at all typical of me.
- ❍ Only somewhat typical of me.
- ❍ Quite typical of me.
- ❍ Very typical of me.

CTA10 I worry more about doing well on tests than I should.
- ❍ Not at all typical of me.
- ❍ Only somewhat typical of me.
- ❍ Quite typical of me.
- ❍ Very typical of me.

CTA11 During tests, I have the feeling that I am not doing well.
- ❍ Not at all typical of me.
- ❍ Only somewhat typical of me.
- ❍ Quite typical of me.
- ❍ Very typical of me.

CTA12 When I take a test that is difficult, I feel defeated before I even start.
- ❍ Not at all typical of me.
- ❍ Only somewhat typical of me.
- ❍ Quite typical of me.
- ❍ Very typical of me.

CTA13 I am a poor test taker in the sense that my performance on a test does not show how much I really know about a topic.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA14 I am not good at taking tests.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA15 When I first get my copy of a test, it takes me a while to calm down to the point where I can begin to think straight.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA16 I do not perform well on tests.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.

CTA17 When I take a test, my nervousness causes me to make careless errors.
- Not at all typical of me.
- Only somewhat typical of me.
- Quite typical of me.
- Very typical of me.