

TEACHER-READY RESEARCH REVIEW

Enhancing Attention and Memory During Video-Recorded Lectures

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Lectures have long been a staple of various kinds of instruction, and constitute a component of most online learning platforms. Systematic research has begun to examine how to enhance lecture learning in traditional classroom settings and in online education. This article provides a conceptual framework for thinking about attention and memory during video-recorded lectures, particularly as related to online learning, that builds on 3 key claims: (a) online learning can be conceived as a type of self-regulated learning, (b) mind wandering reflects a failure of executive control that can impair learning from lectures, and (c) providing intermittent tests or quizzes can benefit attention and learning. We then summarize recent studies based on this framework that examine the effects of interpolating brief quizzes in a video-recorded lecture. These studies reveal that interpolated quizzing during a video-recorded lecture reduces mind wandering, increases task-relevant behaviors such as note taking, boosts learning, and also improves calibration between predicted and actual performance. We conclude by discussing recommendations, open questions, and future research directions.

Keywords: interpolated testing, metacognition, mind wandering, online learning, video-recorded lectures

Lectures have long been an essential part of education. Although there has been much debate recently about the utility of lectures and whether they should be supplemented or even replaced altogether by more active forms of learning (e.g., [Herried & Schiller, 2013](#); [Mazur, 1997](#)), lectures remain a prominent feature of the traditional classroom. Moreover, one can make the case that lectures occupy a more prominent role now than ever in education, because video-recorded lectures are often used to supplement classroom lectures ([Gorissen, van Bruggen, & Jochems, 2012](#)) and perhaps most important, play a role in many online learning platforms ([Breslow et al., 2013](#)).

Online learning, of course, has developed rapidly during recent years. This development has been fueled in part by the emergence of freely accessible massive open online courses (MOOCs) involving students from all over the world, as illustrated by fast growing online platforms such as Coursera, edX, and Udacity. Yet online learning and education have existed in some form since the very inception of the Internet, and numerous studies have examined the efficacy of various aspects of online learning. For example, in a meta-analysis of evidence-based practices in online learning produced by the U.S. Department of Education ([Means et al., 2010](#)), the authors noted that a search of research literature concerning online learning from 1996 through mid-2008 turned up more than 1000 empirical studies of online learning. Research studies have typically focused on questions concerning the relative effectiveness of online versus face-to-face classroom instruction, with some evidence indicating that online learning is often as effective as classroom learning, and that a blend of the two is more effective than either one alone ([Means et al., 2010](#)).

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Many more reports have been published since the 2010 meta-analysis by Means et al., including studies of such topics as factors that discriminate between dropouts and completers of online courses (e.g., Lee, Choi, & Kim, 2013), how to predict success in online learning (e.g., Kruger-Ross & Waters, 2013), the impact of ethnic or minority status on participation in online education (e.g., Ke & Kwak, 2013), characteristics of participants in a MOOC (Breslow et al., 2013), and the priorities of online educators (e.g., Dawson, Dana, Wolkenhauer, & Krell, 2013). At the same time, “how-to” and popular books concerning various aspects of online learning and education have proliferated (e.g., Conrad & Donaldson, 2011; Khan, 2012; Thormann & Zimmerman, 2012; Vai & Sosulski, 2011).

Although it is clear that the literature concerning online learning is large and growing, given that video-recorded lectures are often part of online learning platforms, it may be surprising that there is relatively little systematic research on how to enhance learning from video-recorded lectures. Given the wide variety of participants in MOOCs and related forms of online learning (Breslow et al., 2013; Means et al., 2010), such research would have potentially broad applicability to a variety of learners, including adults seeking to supplement their education by taking online courses, college students, and even high school students. For example, a 2010 survey reported that the percentage of high school students taking at least one online course doubled from 2008 to 2009 to just over 25% (Nagel, 2010), a 2012 report by the Evergreen Education Group indicates a continuing rapid rise (Watson, Murin, Vashaw, Gemin, & Rapp, 2012), and a recent analysis from the Sloan Foundation projects that five million K-12 students—mainly high school students—will be enrolled in some type of online course by 2016 (Picciano et al., 2012).

In view of the importance of understanding how to enhance and perhaps optimize learning from video-recorded lectures, recent research has begun to investigate how to enhance attention to, and retention of, the contents of a video-recorded lecture. This article provides a brief summary of the conceptual framework that has guided this research and the early returns from initial studies, which we believe have poten-

tially interesting implications for both online learning as well as learning in the traditional classroom.

Enhancing Learning From Video-Recorded Lectures: Conceptual Framework

Our conceptual framework consists of three key proposals that provide a foundation for attempting to enhance learning from video-recorded lectures. First, we portray online learning as a type of *self-regulated learning* (Bjork, Dunlosky, & Kornell, 2013; Zimmerman & Schunk, 2011). Second, we argue that mind wandering entails a failure of executive control that can interfere with lecture learning. Third, we discuss reasons why providing intermittent quizzes within a lecture ought to enhance learning.

Online Learning Can Be Conceived as a Type of Self-Regulated Learning

One advantage of online educational platforms is that students are given the freedom to learn on their own time and at their own pace (Khan, 2012). This advantage, however, is associated with challenges that students might not experience to the same extent in the classroom. In particular, students are left to themselves to regulate the quality of the learning experience. Thus online education depends critically on *self-regulated learning*, a form of learning in which the learner is primarily responsible for initiating, managing, and sustaining the learning process (Zimmerman & Schunk, 2011). Cognitive psychologists have long been interested in self-regulated learning (Bjork et al., 2013), and it is also widely recognized that self-regulated learning plays a crucial role in education (Zimmerman, 2008). Yet relatively little empirical or theoretical work has been carried out to link the extant literature with the emerging field of online learning.

Self-regulated learning draws heavily on metacognition, that is, awareness and knowledge of one’s own cognitive processes. Researchers in cognitive science and in education have come to increasingly realize the important role of metacognition for learning in educational contexts (e.g., Bjork et al., 2013; Grotzer & Mittlefeldt, 2012; Hacker, Bol, & Keener, 2008; Hacker, Dunlosky, & Graesser, 2009). A

useful cognitive framework for thinking about metacognition was developed by Nelson and Narens (1990), who outlined the dynamic interplay between *monitoring* (assessing the extent and nature of one's own knowledge) and *control* (cognitive processes that manage other processes) across various phases of the learning experience (e.g., acquisition, retention, and retrieval). For instance, during the initial learning of a video-recorded lecture, students may at some point generate a "judgment of learning." In other words, students may assess how well they think they have learned and will later remember the contents of the lecture. This judgment can have a causal influence on executive control processes that guide additional study (Metcalf, 2009). Consequently, students who experience difficulty grasping specific aspects of a video-recorded lecture may produce a relatively low judgment of learning and decide that they want to review specific portions of the video before moving on to subsequent lessons. However, numerous studies from cognitive psychology have shown that people are frequently inaccurate in monitoring their own learning (Bjork et al., 2013).

Much research has focused on the concept of *calibration*, or the fit between individuals' judgments about their performance and their actual performance (Keren, 1991). A good deal is known about the conditions and individual differences that affect student calibration (Bol & Hacker, 2012). Consider, for example, the calibration between students' predictions of how well they think they have learned a particular subset of materials and performance measures that assess how well they actually retain that information (Hacker et al., 2008). Calibration scores typically reveal that students are overconfident about their initial levels of learning (Hacker et al., 2008). This finding has important implications for executive control of study behavior: if students feel as though they have mastered a particular topic, when in fact they have not, then they are likely to proceed to other lessons instead of devoting the additional study time needed to master that topic. Consistent with this idea, research has shown that when students make overconfident judgments of learning, they are less likely to take advantage of subsequent opportunities to restudy target material (e.g., Dunlosky & Rawson, 2012).

Although we have focused on aspects of self-regulated learning that are most directly related to video-recorded lectures and online education, we also note that classroom lectures and learning, too, include self-regulated components. For example, students can ask questions of lecturers in live classrooms when they do not fully understand a point in the lecture, and students engage in considerable self-regulated learning when studying outside the classroom (for further discussion, see Bjork et al., 2013). However, we also suggest that some aspects of self-regulated learning, such as viewing a video-recorded lecture, may take on heightened importance in online education given that students frequently experience such lectures in situations that lack the structure of the classroom, such as a home or dormitory environment (for discussion, see Song & Hill, 2007; Tsai, 2009).

Mind Wandering Reflects a Failure of Executive Control That Can Impair Learning From Lectures

Learning from either video-recorded lectures or classroom lectures requires students to direct their attentional resources to the content of the lecture in a controlled manner that includes active avoidance of external or internal distraction (cf. Baddeley, 1993; Kane & Engle, 2002). Nonetheless, this executive control of attention can sometimes fail, and bouts of inattention are not uncommonly consumed by self-relevant thoughts unrelated to the content of ongoing external stimulation (Smallwood, 2013; Smallwood & Schooler, 2006). Importantly, once an episode of mind wandering has been initiated, performance associated with the external task of interest can suffer (for review, see Smallwood & Schooler, 2006).

It has been long recognized among educators that students have difficulty sustaining attention to lectures in the classroom (e.g., Brown, 1927), and advocates of online learning have similarly recognized that learners have difficulty sustaining attention (e.g., Khan, 2012; Koller, 2011). However, there has been relatively little systematic research concerning the topic despite its critical importance for both traditional and online education. A recent detailed review of the literature concerning attention and mind wandering during both classroom and online lectures (Szpunar, Moulton, & Schacter, 2013)

supports the general conclusion that lapses of attention constitute a significant barrier to learning. For example, studies of classroom lectures indicate that students have increasing difficulty paying attention as a lecture goes on, and that lapses of attention during lectures have a negative impact on note taking and retention (e.g., Bunce, Flens, & Neiles, 2010; Cameron & Giuntoli, 1972; Johnstone & Percival, 1976; Lindquist & McLean, 2011; Scerbo, Warm, Dember, & Grasha, 1992; Schoen, 1970; Stuart & Rutherford, 1978; Unsworth, McMillan, Brewer, & Spillers, 2012).

Emerging evidence indicates that similar difficulties arise during video-recorded lectures. In a recent study of attention during video-recorded lectures, Risko, Anderson, Sarwal, Engelhardt, and Kingstone (2012) reported two experiments in which students watched 1-hr lectures on different topics (psychology, economics, or classics). Students were probed at various different times into a lecture and were asked if they were mind wandering at that moment. Overall, participants in both experiments indicated that they were mind wandering in response to around 40% of the probes, with significantly more mind wandering observed in response to probes given during the second half of the lecture than to those given during the first half. There was some variability in the overall incidence of mind wandering across three lectures and in how much mind wandering increased from the first half to the second half of the lecture, that is, 30% to 61% incidence during the first and second halves of the Classics lecture, compared with 39% to 47% for Economics and 31% to 44% for Psychology (Risko et al., 2012). Nonetheless, for all three lectures the increase in mind wandering across the lecture was associated with poorer performance on a test of lecture material given shortly after the lecture. In a follow-up study, Risko, Buchanan, Medimorec, and Kingstone (2013) reported similar results, and also found that student attention to video-recorded lectures was impaired by computer-dependent activities that were unrelated to the lecture, such as e-mail or surfing the web. Note that studies of classroom lectures, too, have documented that engaging in computer-dependent activities unrelated to a lecture can disrupt learning (e.g., Sana, Weston, & Cepeda, 2013). An interesting question for future research would be to compare the effects of

computer-related multitasking in the classroom and during online learning with a view toward determining whether such activities are more or less of a problem in one or the other setting.

There are contexts in which mind wandering can be beneficial, as when individuals think about ways to achieve personally relevant future goals during mind wandering episodes (Baird, Smallwood, & Schooler, 2011). Nonetheless, the foregoing studies make it clear that lapses of attention such as mind wandering represent a potential barrier to lecture learning and should be a focus of any attempt to improve lecture learning.

Providing Intermittent Tests or Quizzes Can Benefit Attention and Learning

Many studies have demonstrated that retrieving information from memory (also known as the “testing effect”) can enhance long-term retention of that information, even more than additional study (Roediger & Karpicke, 2006). In addition, the benefits of retrieval/testing have been shown to extend beyond the specific material that is tested such that students who practice retrieval are better able to transfer their knowledge to answer related questions in novel contexts (Butler, 2010; Carpenter, 2012).

These *direct benefits* of retrieval on retention have been demonstrated in numerous laboratory studies (for reviews, see Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Roediger, & Butler, 2011). Moreover, recent studies have demonstrated that these direct benefits of retrieval extend to classroom settings (McDaniel, Agarwal, Huelser, McDermott, & Roediger, 2011; Roediger, Agarwal, McDaniel, & McDermott, 2011). In addition, and critically for our purposes, a growing line of research has demonstrated *indirect benefits* of retrieval/testing for learning, such as when interpolating quizzes in a series of word lists enhances learning of new word lists that are presented subsequent to the retrieval/testing manipulation (Szpunar, McDermott, & Roediger, 2008; for recent reviews, see Pastötter & Bäuml, 2014; Roediger, Putnam, & Smith, 2011). Such indirect benefits of retrieval/testing on subsequent learning have been attributed to reductions in proactive interference (Szpunar et al., 2008; see also, Tulving & Watkins, 1974) and, of particular interest for present purposes, heightened

attention to the study materials elicited by the probable occurrence of an upcoming quiz on the materials (Pastötter, Schicker, Niedernhuber, & Bäuml, 2011; Weinstein, Gilmore, Szpunar, & McDermott, 2014).

Although these studies indicate that interpolated retrieval/testing can benefit learning indirectly by enhancing attention to and learning of subsequent study materials, the educational implications of the effect remain to be explored. The studies summarized in the next section directly examine the effects of interpolated quizzing on enhancing attention to and learning of video-recorded lectures.

Enhancing Learning From Video-Recorded Lectures: An Experimental Approach

To determine whether interpolated quizzing could improve attention, by reducing mind wandering, and enhance learning during a video-recorded lecture, Szpunar, Khan, and Schacter (2013) conducted two experiments that used a video-recorded statistics lecture and interpolated within the lecture brief quizzes that probed students' comprehension of lecture content. In both experiments, a 21-min statistics lecture was divided into four segments of equal length. All participants in both experiments were instructed just before the lecture that they might or might not be quizzed after each segment, which would be determined randomly by a computer. They were also informed that they would receive a final test after the conclusion of the lecture. Participants were given lecture slides that could be used to take notes during the lecture, and after each lecture segment, all participants in both experiments completed arithmetic problems unrelated to the lecture for one minute.

In Experiment 1, there were two groups, which were distinguished by what the participants did for the next two minutes after each lecture segment. The *interpolated* group received quizzes consisting of brief questions about the content of each segment (e.g., *Explain the relation between a population and a sample*). There were six such questions per segment, with 20 sec allowed for responses to each question. The *noninterpolated* group continued to work on arithmetic problems for an additional two minutes for each of the segments preceding the final segment. After the fourth

and final lecture segment, both groups did arithmetic problems for a minute and then received quiz questions for the final segment. Finally, five minutes later all participants received a final cumulative test concerning all four lecture segments. After the lecture and before the final cumulative test, participants used 7-point rating scales to indicate the extent to which they had mind wandered during the lecture and their level of anxiety toward the final test.

The results indicated a clear advantage for students in the interpolated group. Specifically, participants in the interpolated group (a) answered significantly more questions correctly than students in the noninterpolated group concerning the critical fourth lecture segment (84% vs. 59%) and answered significantly more questions correctly than students in the noninterpolated group on the final cumulative test for all four lecture segments (88% vs. 66%), (b) reported that they had mind wandered significantly less often than students in the noninterpolated group, (c) took notes on a much higher proportion of slides during the lecture than did students in the noninterpolated group, and (d) reported significantly less anxiety about the upcoming final cumulative test than did students in the noninterpolated group.

Experiment 2 attempted to replicate these results, and also to address two critical issues raised by Experiment 1. First, Experiment 1 assessed mind wandering only after the lecture had concluded. Because this is a retrospective measure, the results could have been influenced by forgetting or memory distortion. Accordingly, Experiment 2 overcame this problem by using a direct probe measure that has been used frequently in the experimental literature on mind wandering (e.g., Smallwood, 2013; Smallwood & Schooler, 2006). Students were informed before the lecture that at random points during the lecture, they would be asked to indicate whether or not their attention had strayed away from lecture content (i.e., *Are you mind wandering?*). The mind wandering probes occurred once during each of the four lecture segments at a randomly determined point that occurred at least 30 seconds into the segment and 30 seconds before the segment ended. Second, Experiment 2 was designed to help determine whether some or all of the benefits observed for the interpolated group in Experiment 1 were attributable to simple reexposure to the

study materials that is afforded by interpolated quizzes. Thus, in addition to including interpolated and noninterpolated groups, as in Experiment 1, Experiment 2 also included a *restudy* group that was presented with the same quiz questions as the interpolated group, but was not required to answer these questions during the first three lecture segments (i.e., the answers were provided along with the questions).

The results of Experiment 2 nicely replicated and extended those from Experiment 1 (see Figure 1). Participants in the interpolated group (89%) correctly answered more questions about the fourth and final lecture segment than participants in the noninterpolated (70%) and *restudy* (65%) groups, were less anxious about a final test that followed the lecture, and produced more correct items on that final test than those in the other groups (93% for interpolated group vs. approximately 73% for other groups). With respect to mind wandering probes, participants in the noninterpolated and *restudy* groups indicated that they were mind wandering in response to about 40% of the probes. By contrast, the incidence of mind wandering was cut in half, to about 20%, in the interpolated group,

which was significantly lower than in either of the other two groups. Participants in the interpolated group took three times as many lecture notes (24% of slides with additional notes) as did participants in the other two groups (approximately 8% for other groups). These results indicate that the value of interpolated quizzes is not attributable to simple reexposure to study materials, because the *restudy* group performed identically to the noninterpolated group on all key dependent measures in Experiment 2. Thus, these experiments provide empirical support for the claim that interpolated quizzes encourage people to sustain attention to a lecture in a way that discourages task-irrelevant activities such as mind wandering and encourages task-relevant activities such as note taking, resulting in a clear benefit to learning.

One additional result is worth noting. After the lecture in Experiment 2, participants in each condition were asked to make subjective estimates of how cognitively demanding they found the experience of attending to the lecture. Participants in the interpolated group reported that their experience of learning the lecture was less mentally taxing compared

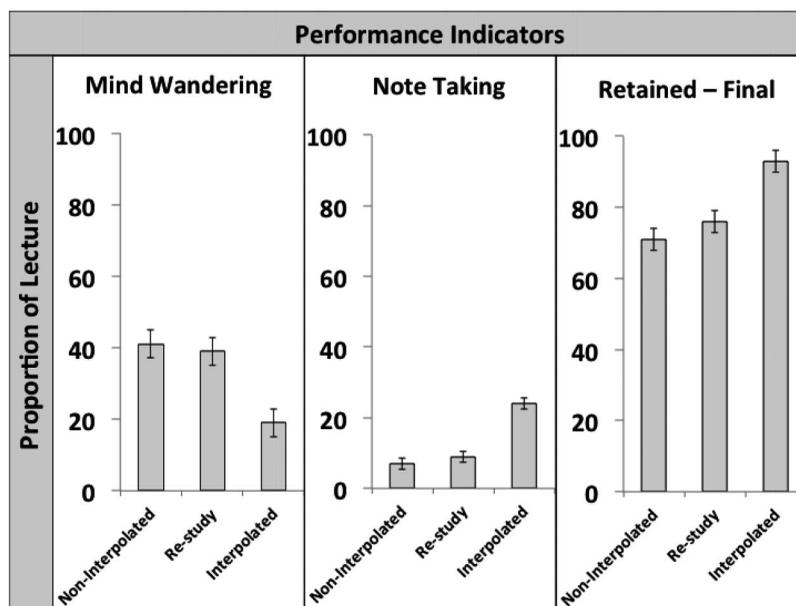


Figure 1. Mind wandering, note taking, and final cumulative test performance for noninterpolated, *restudy*, and interpolated groups in Szpunar, Khan, and Schacter (2013, Experiment 2).

with participants in the noninterpolated or restudy groups. Thus, interpolated quizzing might help students to sustain attention to a lecture over even longer time periods by reducing the subjective sense of mental effort associated with attending to a lecture.

Metacognition and Calibration During Video-Recorded Lectures

A critical issue in education generally, and one that is especially relevant to online learning, concerns whether students can accurately monitor their own learning. A benefit of making lecture materials available to students online is that it allows students to study those materials on their own time and at their own pace. However, as we discussed earlier, educational research has demonstrated that students are not necessarily well equipped to monitor their own learning (Bjork et al., 2013; Bol & Hacker, 2012), and such limitations may be especially likely to manifest themselves in the absence of face-to-face interactions that support monitoring processes in traditional classroom settings (e.g., asking instructors to clarify or elaborate upon points of confusion; cf. Song & Hill, 2007). This metacognitive vulnerability might be accentuated with video-recorded lectures because previous studies have shown that students subjectively assess video-recorded materials as easier to learn and more memorable than text materials (e.g., Choi & Johnson, 2005; Salomon, 1984), which could lead them to mistakenly believe that they had learned the target information to a greater degree than they actually did (Bjork et al., 2013). Indeed, an early study by Salomon (1984) provided evidence along these lines, showing that learners rated comparable material as easier to learn when it was presented in video than textual form, even though objective measures of retention and learning failed to reveal a corresponding advantage for video over text. Given that overconfident judgments of learning can result in students failing to take advantage of opportunities to restudy target materials (Dunlosky & Rawson, 2012), it is important to assess strategies that could help students to produce more accurate judgments of learning.

To investigate the issue, Szpunar, Jing, and Schacter (2014) used a variation of the interpolated quizzing paradigm described earlier in an experiment that included three groups of high school students. Each group viewed the same 21-min introductory statistics lecture used in the Szpunar et al. (2013) study, which as before was divided into four segments. All groups were informed before the beginning of the lecture that a computer would randomly determine whether they would be quizzed after each lecture segment, and that there would be a final test on the entire lecture. A *4-test group* received interpolated quizzes after each lecture segment, whereas a *0-test group* performed math problems after each lecture segment. Just before the final test, participants in both groups were asked to predict, on a 0–100% scale, how well they would perform on the final test. Based on the findings discussed earlier, participants in both the 4-test and 0-test groups should predict high levels of performance on the final test, but participants in the 4-test group should perform closer to the predicted level than those in the 0-test group. An additional *1-test group* received a quiz only on the fourth and final lecture segment to determine whether a single quiz could help students to combat the overconfidence that was expected to occur in the 0-test group.

The main results of the experiment were generally consistent with predictions. Students in the 4-test group predicted that they would perform at a high level on the final test (77%), and their actual performance (75%) closely matched their predicted performance. By contrast, students in the 0-test group also predicted that they would perform well on the final test (78%), but their actual performance (48%) was significantly and dramatically lower than their predicted performance. Students in the 1-test group fell in between the other two groups: their predicted performance (60%) was considerably lower than students in the other two groups, but still somewhat higher than their actual performance (50%).

Overall, these results support the conclusion that during learning of video-recorded lectures, interpolated quizzing can help to produce enhanced calibration with actual performance. Such increased calibration is likely to be important in actual course settings where accurate assessment of learning is es-

sential to making good use of opportunities to restudy materials that in fact require additional study.

Conclusions, Questions, and Recommendations

The studies described in this article represent what we believe to be a promising first step in exploring the nature of attention and memory during lectures, and developing methods for enhancing lecture learning. Interpolated quizzing reduced mind wandering, increased task-relevant behaviors such as note taking, boosted learning, and also improved calibration between predicted and actual performance. Thus, we believe that this research provides some basis for recommending to teachers that they include interpolated quizzes in either video-recorded or live classroom lectures. However, because these experiments are indeed only a first step, much work remains to be done and several critical issues need to be explored.

First, the studies we reviewed made use of an arbitrary 5-min interval for separating the presentation of interpolated quizzes. One important avenue for future research will be to determine the optimal presentation frequency and spacing of interpolated quizzes in the service of improving attention to and learning from lecture materials. To provide better guidance for teachers, research will need to address how early interpolated quizzes need to be introduced into a lecture and how much time may elapse between interpolated quizzes before attention begins to wane and learning suffers.

Second, the results described in the preceding section from the studies by Szpunar et al. (2013, 2014) have been obtained with a single lecture—a 21-min introductory statistics lecture. It is thus unknown whether these results will hold with other lectures. One notable feature of the statistics lecture is that it yielded relatively high levels of mind wandering in nontested groups, in the vicinity of 40% for both college students (Szpunar et al., 2013) and high school students (Szpunar et al., 2014). This estimate is similar to those obtained from other video-recorded lectures (Risko et al., 2012) as well as from research concerning classroom lectures (Lindquist & McLean, 2011). However, as noted earlier, Risko et al. (2012) observed variability in levels of mind wandering across lec-

tures. One possibility is that interpolated retrieval/testing might have less of an effect on attention during highly engaging lectures that produce relatively low baseline rates of mind wandering. Ongoing studies in our laboratory led by Nicole Rosa and Helen Jing that use lectures that produce relatively low (i.e., <30%) baseline rates of mind wandering have thus far yielded results consistent with this idea.

Third, and related to the preceding point, it will be important for future studies to examine the influence of specific design features of video-recorded lectures on performance measures related to attention and learning. The statistics lecture used in the aforementioned studies required students to watch a video showing only the lecture slides accompanied by audio of the instructor. Whether other presentation formats are associated with better or worse baseline performance in terms of attention and learning awaits future work (e.g., a video presentation that includes both the lecture slides and instructor moving around the classroom). More generally, exploring questions regarding the construction of lecture slides for multimedia presentation and their impact on attention and learning will also be informative (for a recent review, see Mayer, 2008).

Fourth, the studies discussed here have used measures of literal or rote retention to assess lecture learning. An important question is whether interpolated retrieval/testing also enhances learning at a conceptual level, such that students are better able to transfer what they have learned to novel contexts. Previous research on the *direct* benefits of testing have already been shown to extend beyond the specific material that is tested, such that students who are tested are better able to transfer their knowledge to answer related questions in novel contexts (Butler, 2010; Carpenter, 2012). We do not yet know whether the same applies to interpolated retrieval/testing during lectures, but the issue clearly merits investigation.

Fifth, students participating in the aforementioned studies were given a fixed amount of time to study each lecture segment. In reality, and as we alluded to earlier, online learning typically affords students the luxury of progressing through video-recorded lectures at their own pace. Hence, it will be important for future studies to assess the extent to which students mind wander during and learn from

self-paced viewings of video-recorded lectures, whether interpolated retrieval/testing serves to reduce mind wandering and enhance learning during self-paced viewings of video-recorded lectures, and finally whether interpolated retrieval/testing may help to improve the efficiency with which students are able to complete self-paced viewings of video-recorded lectures.

Finally, although not directly tied to the issues we raise above, it will be important for future work to develop an understanding of the manner in which the human brain is involved in learning from lectures. Although applying brain imaging techniques to learning from complex materials such as lectures represents an important challenge for educational neuroscience, recent advances in understanding the manner in which brain networks associated with attention, mind wandering, and cognitive control interact with one another provide important clues about a potential starting point (see Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010; Spreng & Schacter, 2012). The development of experimental paradigms that can bridge the gap between real-world educational contexts such as lectures and neuroscience methods represents an exciting avenue for future work that should provide novel insights into the basis of learning.

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