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Disengagement during lectures: Media multitasking and mind wandering in university classrooms

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Abstract

In university classrooms, the use of laptops or smartphones for purposes unrelated to the lecture is on the rise. Consequently, it is important to understand how frequently this behavior occurs, to track whether it increases throughout a lecture, and to quantify the potential costs to learning. In two studies, we measured rates of disengagement during lectures related to media use (i.e. media multitasking; Studies 1 & 2) and lecture-unrelated thoughts (i.e. mind wandering; Study 2). We also measured the impact of these behaviors on learning using quiz questions at the end of each lecture, and students' actual course tests. In both Study 1 and 2, we found that rates of media multitasking were relatively high and increased as time elapsed in a lecture, while in Study 2, consistent with prior work, rates of mind wandering remained relatively stable. Interestingly, media multitasking - but not mind wandering - was associated with negative learning outcomes.

Keywords: media in education; post-secondary education; pedagogical issues

1. Introduction

Maintaining attention while engaging with a task, whether it be listening to a lecturer or writing a paper, is undeniably crucial for success. Indeed, the close association between attention and successful performance (Randall, Oswald, & Beier, 2014) has been repeatedly demonstrated across a number of situations, including simple laboratory-based attention tasks (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Giambra, 1995; Seli, Cheyne & Smilek, 2013) and memory tests (Smallwood, Baracaia, Lowe & Obonsawin, 2003; Thomson, Besner & Smilek, 2013), as well as during everyday life activities such as driving (Yanko & Spalek, 2013; 2014), and reading (Feng, D’Mello & Graesser, 2013; Mills, Graesser, Risko & D’Mello, 2017; Schooler, Reichle, & Halpern, 2005; Smallwood, McSpadden & Schooler, 2007; Varao Sousa, Carriere, & Smilek, 2013). Most critically, the link between lapses in attention and performance is apparent in educational settings, including situations in which students view video lectures (Kane, Smeekens, von Bastian, Lurquin, Carruth & Miyake, 2017; Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012; Szpunar, Moulton & Schacter, 2013; Wammes & Smilek, 2017; See Schacter & Szpunar, 2015, for a review), and participate in live classroom lectures (e.g. Cameron & Giuntoli, 1972; Lindquist & MacLean, 2011; Ralph, Wammes, Barr & Smilek, 2017). Given the clear dependence of performance on attentional engagement, it is important to identify and mitigate potential distractions that might capture attention and undermine performance. Here, we focus on attentional disengagement in the university classroom, a setting that is important for success later in life. Specifically, we aim to examine various modes of disengagement during undergraduate lectures, how these change over time as a lecture unfolds, and how these modes of attentional disengagement relate to learning.

One mode of disengagement that has been examined in classroom settings is the shifting of attention from lecture-related material to lecture-unrelated internal thoughts, often referred to as

“mind wandering” (Smallwood & Schooler, 2006). As one might expect, higher levels of mind wandering during lectures are associated with poorer learning outcomes (Risko et al., 2012; Wammes, Seli, Cheyne, Boucher, & Smilek, 2016). While most laboratory studies, often using video-recorded lectures, demonstrate reliable increases in mind wandering over time as a lecture or educational activity elapses (e.g. Beserra, Nussbaum & Oteo, 2017; Farley, Risko & Kingstone, 2013; Risko et al., 2012; Wammes & Smilek, 2017; Young, Robinson, & Alberts, 2009), mind wandering during *live* lectures does not appear to follow this trend. In fact, recent work has shown that mind wandering rates during live lectures tend to remain quite stable as a lecture unfolds (Wammes, Boucher, Seli, Cheyne, & Smilek, 2016; Wammes et al., 2016b; Wammes & Smilek, 2017). These findings that have emerged from studies conducted in live lectures stand in stark contrast not only to previously published laboratory findings, but also to the informal anecdotes which many instructors can offer, characterizing students as steadily losing focus over time during extended lectures.

However, when considering how disengagement might change over time during a lecture, it is important to keep in mind that mind wandering is not the only form of disengagement in the classroom; students are also faced with *external* distractions that can manifest in the form of off-task media multitasking – that is, using smartphones or laptops for purposes unrelated to the current lecture. This consideration might shed light on the discrepancy between live lectures and laboratory studies regarding how mind wandering changes as a lecture unfolds. In laboratory studies, participants are typically prohibited from using any media devices (i.e. smartphones or laptops), which means that any increases in disengagement over time during a lecture might primarily manifest as a higher incidence of mind wandering (since that is the most available means to disengage in those settings). In live classrooms, however, since media are often readily available, increases in disengagement over time during a lecture – if they occur – could manifest in the form of higher frequencies of media multitasking rather than an increase in mind wandering. This possibility

is consistent with the aforementioned observation that mind wandering does not increase over time in live lectures as well as with the general intuitions lecturers have that students disengage more as a lecture progresses.

The available evidence suggests that laptop and smartphone use in classrooms appears to be quite prevalent and that these media might be an important source of distraction (e.g. Aguilar-Roca, Williams & O'Dowd, 2012; Anshari, Almunawar, Shahrill, Wicaksono, & Huda, 2017; Gehlen-Baum & Weinberger, 2014; Jacobsen & Forste, 2011; Tindell & Bohlander, 2012). Ragan, Jennings, Massey, and Doolittle (2014), for instance, observed that in large classes, university students with laptops were on-task (taking notes or doing coursework) only 37% of the time, spending a whopping 63% of their time engaging in off-task activities, such as visiting social websites, browsing the web, and playing games. Early work examining the increasing usage of laptops in the classroom (the title of which ominously includes the phrase '*A Miracle or a Menace*'; Efaw, Hampton, Martinez & Smith, 2004) suggested that laptop use improved student learning, but forewarned about the potential pitfalls of surfing the web, instant messaging and other uses unrelated to education. While our interactions with technology have changed considerably in the intervening years, the sentiment captured in this article has prevailed – laptops can be an excellent facilitative tool for learning (Debevec, Shih & Kashyap, 2006; Hyden, 2005; Samson, 2010), however, they can also be quite distracting and often used for non-academic purposes (e.g. Barak, Lipson & Lerman, 2006; Finn & Inman, 2004; Fried, 2006; Ravizza, Uitvlugt & Fenn, 2017; Wurst, Smarkola, & Gaffney, 2008; Unsworth & McMillan, 2017). Indeed, a recent diary study determined that self-distraction (often through technology) was the second most frequently reported form of everyday disengagement (Unsworth & McMillan, 2017). Although some researchers have found laptop use to neither improve nor hinder learning (e.g., Unsworth & McMillan, 2017; Wurst et al., 2008), many studies have documented a negative association between laptop use, and attention, learning, understanding,

and course performance (Fried, 2006; Risko, Buchanan, Medimorec, & Kingstone, 2013; Sana, Weston & Cepeda, 2013; Wood, Zivcakova, Gentile, Archer, De Pasquale & Nosko, 2012). The negative impacts of media use in the classroom also seem to hold regardless of one's intelligence or intellectual ability (Ravizza, Hambrick & Fenn, 2014; Ravizza et al., 2017). Compounding the issue, several researchers have discovered that media multitasking, in addition to impairing the multitasker's later performance, can also distract his or her peers and impair their learning (Fried, 2006; Sana et al., 2013).

Related to our specific interest in how attentional disengagement might change over time during a lecture, there is some preliminary evidence to suggest that the frequency of lecture-unrelated computer use might change over time as a lecture unfolds and that such computer use might be inversely related to rates of mind wandering (Risko et al., 2013). In the laboratory, Risko et al (2013) asked participants to watch a lecture video while at the same time having to complete a number of pre-assigned tasks using a computer. Thought-probe responses collected during this task showed that computer use decreased and mind wandering increased as time elapsed in the lecture. While these findings are certainly intriguing, there are several aspects of this study which raise questions about whether these findings would translate to instances of natural media multitasking in live lecture settings. First, computer use was a *required* component of the foregoing study, which makes the experimental scenario clearly different from how students *volitionally* media multitask in everyday settings. Second, the way that computer use unfolded over time likely depended on how participants prioritized the assigned computer tasks relative to watching the lecture video. That is, prioritizing the computer tasks over the video likely led to the completion of the computer tasks in the early part of the lecture. It remains unclear whether students would prioritize their volitional lecture-unrelated media use in the same way in a live lecture scenario. Nevertheless, Risko et al.'s (2013) findings do suggest that there is a trade-off between computer use and mind wandering and

that this trade-off changes over time within a lecture, an intriguing finding that deserves further investigation in a more natural live lecture setting.

Despite the many advances in our understanding of the prevalence and impact of disengagement via media multitasking and mind wandering in educational settings, several issues remain unaddressed. First, it remains unclear to what extent the available studies of disengagement via media use generalize to real-world live lecture settings. Many of the studies that have investigated the learning impairments associated with media multitasking in lectures are limited by their reliance of video-recorded or staged lectures (Hembrooke & Gay, 2003; Risko et al., 2013; Sana et al., 2013), or by their inclusion of only a small set of actual lectures (Clayson & Haley, 2013; Unsworth & McMillan, 2017). Second, notwithstanding the findings reported by Risko et al. (2013), it remains unknown how the tendency to media multitask volitionally trends over time during ecological live lectures and how these external distractions relate to changes in mind wandering as a lecture unfolds. Further, whether or not there are tradeoffs between, or differential impacts on learning across these two potential sources of distraction is poorly understood.

Building on previous work, in the two studies presented here, we explored how rates of media multitasking (Study 1 and Study 2) and mind wandering (Study 2) unfold over time during an average live university lecture, measuring these forms of disengagement in classes across half a semester (Study 1) and an entire semester (Study 2). Media multitasking and mind wandering were assessed with thought probes presented during the live lectures. We used the thought-probe method to measure mind wandering as has been done in the past because mind wandering is an internal, private experience and so is most directly assessed through subjective report (e.g. Giambra, 1995; Smallwood & Schooler, 2006). While state-level media multitasking can be quantified through observation and manual coding (e.g. Brasel & Gips, 2011; Rosen, Carrier & Cheever, 2013; Yeykelis,

Cummings, & Reeves, 2014) in the current work we also measured media multitasking using probe-caught self-reports to maintain consistency across mind wandering and media multitasking measures. We also examined the associations of media multitasking and mind wandering with learning, which was measured by performance on in-class quizzes and later course tests. Consistent with the anecdotal observations of many lecturers, our hypothesis was that attention to lecture material does wane over time during a live lecture (e.g. Risko et al., 2012). However, we suspected that this decrease in lecture engagement is not related to changes in the likelihood of attention shifting inward in the form of mind wandering, consistent with our prior studies (*authors omitted for blind review*). Rather, in line with prior work suggesting increased disengagement over time, (Kane et al., 2017; Risko et al., 2013), we hypothesized that as a lecture unfolds, attention may become increasingly co-opted by external media (leading to more media multitasking). Along these lines, we explored the predictions that (a) media multitasking would increase over time during a live university lecture while (b) mind wandering rates would remain relatively stable over time. With respect to the impact of these behaviors on retention of lecture material, we investigated whether (c) both media multitasking and mind wandering would be negatively associated with performance, and whether (d) media multitasking would have a more severe impact on performance than mind wandering. In addressing these primary areas of focus, we hoped to determine *how* students are disengaging during lectures, and to contrast the relative performance costs of these alternative types of disengagement.

2. Method: Studies 1 and 2

2.1. Participants

In Study 1, we recruited students from a second-year Physiological Psychology course (among the second-year requirements for all psychology majors) at the University of Waterloo, with coauthor [*authors omitted for blind review*] as the instructor. All enrolled students had an

opportunity to participate in the study, and a 5-minute presentation was given to inform them of the details of the study. While all students used i>clicker (www.iclicker.com) response pads to provide responses to quiz questions, only the data from those who signed up and consented to participate in the study were included in the analysis. The final sample consisted of 173 participants (out of 252 enrolled students), ranging in age from 18 to 28 ($M = 20.31$, $SD = 1.28$). Participants received partial course credit for their participation. It was made clear to participants that the instructor and teaching assistants would have no knowledge of who had or had not participated in the study, at least until final grades were cemented. In Study 2, participants were recruited from those enrolled in an offering of Physiological Psychology in the subsequent term; recruitment was conducted in the same manner as in Study 1, though i>clickers were only used for quiz questions, but not for thought probes in Study 2. The final sample consisted of 76 participants (out of 220 enrolled students), ranging in age from 18 to 23 ($M = 20.18$, $SD = 1.50$).

2.2. The Course

Physiological Psychology is meant to serve as an introduction to the physiology of the brain, including gross and fine brain anatomy, and neural structure. The course also focuses on how the brain's structures subserve various functions such as perception, cognition, emotion and behavior. When Study 1 was conducted, the course was held on Monday and Wednesdays from 4:00 PM until 5:20 PM, and when Study 2 was conducted, it was held on Mondays and Wednesdays from 1:00 PM until 2:20 PM. The course grade is a combination of class participation (i>clicker questions), participation in research experiments, and most prominently, three to four midterm tests.

2.3. Materials and Procedure

The general structure of the studies was that participants completed a pre-term questionnaire containing a number of questions of interest. They were then randomly presented with thought

probes during lectures, and answered quiz questions at the end of each lecture. These individual components are explained in more detail below, with key differences between studies highlighted.

2.3.1. Pre-term questionnaire. Near the beginning of the term and before the onset of the study, students that agreed to participate in the study completed a ‘pre-term’ questionnaire. Completing the questionnaire involved participants giving their consent, providing several demographic items, answering questions about their prior knowledge in the subject area, and their motivation to learn the course material. Participants also indicated the likelihood that they would mind wander or media multitask during the lecture (Appendix A). In Study 2, the questionnaire was modified (Appendix B), and also included the Spontaneous (MW-S) and Deliberate (MW-D) Mind Wandering questionnaires (Carriere, Seli, & Smilek, 2013), and the 8-item Grit Scale (Duckworth, Peterson, Matthews & Kelly, 2007). Many of these measures were included to allow for confirmation of relations that are strongly assumed to be present. As examples, the amount of prior knowledge should be associated with later test performance; those who expect to media multitask a lot should media multitask a lot; and students with a high interest in the subject should be more attentive. Consistent with prior work, we predicted that grit would be negatively associated with mind wandering, as the general tendency to drift away from momentary goals may disrupt longer-term goal completion (Ralph, Wammes, Barr & Smilek, 2017). At the beginning of the pre-term questionnaire in Study 2, participants downloaded and installed an application for their laptop. Following successful installation, they were provided with a confirmation code, which they could input into the questionnaire. The questionnaire was designed such that participants could not continue until they had input the confirmation code. This step was taken because partial participation credit was awarded following completion of the questionnaire, and code entry ensured that participants had actually downloaded the application.

2.3.2. Thought Probes.

2.3.2.1. Study 1 Thought Probes. In Study 1, we used a basic dichotomous probe, which asked participants to simply indicate whether or not they were media-multitasking. The probes came in the form of PowerPoint slides, inserted at pseudo-random locations in the slide deck. All participants were therefore probed at exactly the same time, and we could easily set precisely where the probe was positioned. However, for this reason, and because a probe required a stoppage in the lecture to allow for responses, probe placement was relatively sparse (see Figure 1). Probes were presented up to three times per class for the second half of a semester (10 lectures)¹. These were presented in white text on a black background, and read as follows:

JUST BEFORE this screen appeared, were you using your laptop or smartphone for something unrelated to the lecture?

- Yes
- No

Responses were provided using i>clickers. When a probe appeared, participants were told to respond and had approximately 30 to 45 seconds to do so. The instructor would often make a remark that a thought probe had appeared, and the students were to respond to it honestly. Following this, the instructor would pick up where he had left off and carry on with the lecture as normal.

2.3.2.2. Study 2 Thought Probes. In Study 2, we altered our thought-probe methodology in three ways. First, thought-probes were presented via a laptop application. Since the application allowed us to not be bound to embedding probe presentations within the lecture slides, probes were *independently* random for each participant, enabling a vastly more comprehensive sampling of time

¹ During the first half of the semester, participants were also presented with thought probes. However, these were presented at the end of the lecture rather than throughout, and simply asked them to retrospectively report how often they were mind wandering, media multitasking, or how motivated they were in that particular class. This study was not relevant to the current experiment, but we mention it here for transparency, and would like to direct interested readers to the relevant manuscript (*authors omitted for blind review*).

points across participants in the lecture (see Figure 1). Second, because the probes no longer interrupted the whole class, we were able to present more probes per class to each individual without losing additional lecture time. Third, additional response options were provided in order to obtain a more qualitative measure of *how* students were disengaging, allowing us to better assess the relative costs of different kinds of disengagement (e.g. media multitasking, mind wandering, elaborative thought). This change in probe methodology also provided us the opportunity to converge on a conclusion with different probes across studies. This is important because probe structure can influence participant responses, and dichotomous thought probes may not be the optimal way to characterize mental states (e.g. Mills, Raffaelli, Irving, Stan & Christoff, 2017; Mrazek, Smallwood, & Schooler, 2012; Seli, Beaty, Cheyne, Smilek & Schacter, 2018; Seli et al., 2013; Weinstein, 2017). Probes were presented up to 5 times per class ($M = 4.55$, $SD = 0.44$) for every lecture in the semester (19 lectures). The number of probes was variable to prevent participants from developing an expectation regarding the exact number of probes that would be presented. To elaborate, if, for example, the total number of probes was always four, after presentation of the third probe participants could be reasonably certain that another probe was to be presented, and this might impact their level of attentiveness; we wanted to avoid this possibility. The probes were presented in black text on a grey pop-up window in the bottom right corner of participants' laptop screens, and read as follows (manuscript shorthand in parentheses):

Please indicate below what you were thinking about JUST BEFORE this screen appeared:

- Paying attention to the present moment in the lecture (*On task*)
- Thinking about other material from this lecture or the rest of the course (*Elaboration*)
- Thinking about things related to your other courses (*School-related mind wandering*)
- Thinking about things unrelated to any of your courses (*Unrelated mind wandering*)
- Using your smartphone or laptop for activities unrelated to the lecture (*Media multitasking*)

Underneath was an additional button allowing participants to ‘Save answer’, and a button which read ‘I don’t want to respond right now’. In general, participants did not choose to opt out of many probes ($M = 0.979$ percent, $SD = 1.694$).

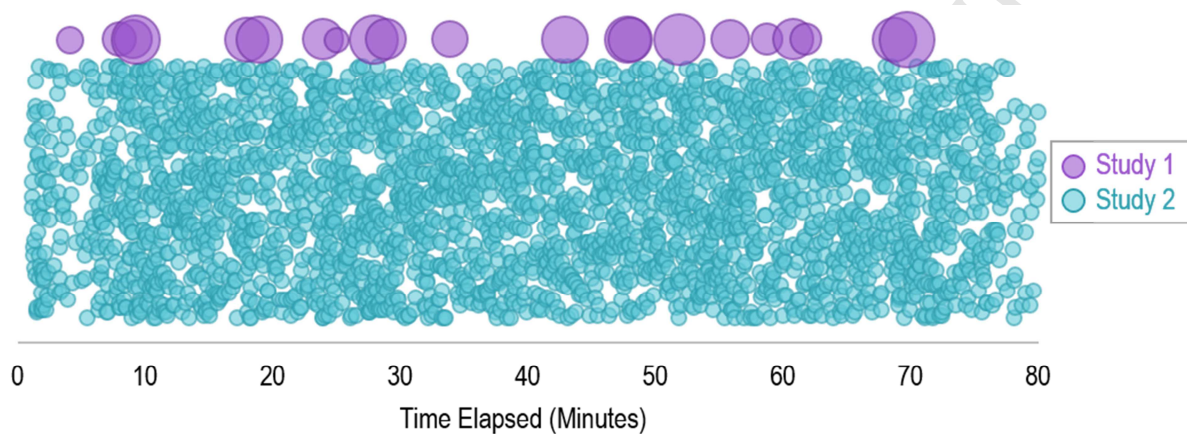


Figure 1. Probe presentation times in Study 1 (purple) and Study 2 (blue). In Study 1, each point represents many participants, but all participants were probed at the same set of times. In Study 2, each point contains a single participant, but due to independent randomization, our coverage of the time course is more complete. Note that the vertical axis has no meaning; the points were spread vertically to reduce overlap of the points.

2.3.3. Location Probes (Study 2 Only). For exploratory purposes, prior to each lecture in Study 2, participants were asked via the laptop application to indicate their approximate location in the lecture hall (Appendix C). The rationale for collecting student location information was to allow us to examine whether rates of media multitasking or mind wandering depended on the location in which the students sat. To collect information about seating location, participants were presented with a figure which divided a schematic diagram of the lecture hall into eight numbered regions (four wide, and two deep). They reported their location by selecting the number corresponding to their location.

2.3.4. Quiz questions. In both Study 1 and Study 2, three to five quiz questions were presented at the end of each lecture. Quiz questions were crafted by one of the authors (*authors omitted for blind review*) prior to each lecture, based on the slide deck for the upcoming lecture. To elaborate, these questions were written to target the content of a single slide or set of slides, and were roughly planned such that their source material was derived from a reasonable spread of time points in the lecture. Questions were designed to be multiple choice, with five possible response options (See Appendix D for sample questions). They were not however, written specifically based on slides surrounding planned probes, as we have done in prior work (*authors omitted for blind review*). Due to the unpredictable nature of live lecturing, and the variability in delivery time, the final deck of slides to be presented in an upcoming lecture was often not prepared until the evening prior. For this reason, it was not possible to write these questions collaboratively, or to pilot them. However, to ensure quality, the questions were subsequently reviewed and if necessary, tweaked slightly, by the instructor. Responses were provided by the students using their i>clicker remotes (in both Studies). The instructor would typically advance to the slides containing the quiz questions when there were approximately 5 minutes remaining in the lecture time. Sometimes, each quiz question and the options were read aloud, and students had 30 to 45 s to respond to each.

2.3.5 A summary of the critical differences between studies.

2.3.5.1. Response Method. In Study 1 participants provided responses to thought probes using i>clickers, which they all possessed as part of the course requirements. In Study 2, they used an application downloaded onto their personal computers.

2.3.5.2. Sample Size. The sample size was smaller in Study 2 relative to Study 1, likely owing to the additional requirement of downloading the application in Study 2.

2.3.5.3. Probe Timing. Because of the differences in probing method, all students in Study 1 were probed at the same time, while probe presentation was independent and random for each student in Study 2 (see also Figure 1), allowing for more probes.

2.3.5.4. Probe Items. In Study 1, participants responded simply whether or not they were using their laptop or smartphone for things unrelated to the lecture, while in Study 2, they were asked to choose from five possible types of thought. In Study 2, we also added a 'location probe' (which was not present in Study 1) to get a measure of where students were located in the lecture hall.

2.3.5.5. Time of Day. The class for Study 1 was held later in the day (4:00 PM) relative to Study 2 (1:00 PM), and we collected data during fewer classes in Study 1 (half semester), relative to Study 2 (full semester).

3. Results

3.1. Overall response rates

3.1.1. Study 1. Participants were omitted from all analyses if they responded to fewer than 20% of the presented probes. This reduced the sample from 173 participants to 163. In this remaining sample, participants responded to a mean of 17.48 ($SD = 3.44$) of the 21 presented probes. Response rates were computed by dividing the number of media multitasking responses by the total number of responses provided. The proportion of these probes to which participants reported that they were media multitasking was 0.34 ($SD = 0.23$) of the time.

3.1.2. Study 2. To maintain an analogous standard to Experiment 1, participants were omitted if they responded to fewer than 20% of the maximum number of probes that any one participant responded to (i.e. 89). This resulted in a sample that was reduced from 76 to 70 participants. In this remaining sample, participants responded to a mean of 67.16 ($SD = 14.49$)

probes, and opted not to respond ('I don't want to respond right now' responses) to a mean of 1.57 probes ($SD = 1.10$). The mean proportion with which each probe response was endorsed was as follows: On task: 0.72 ($SD = 0.20$), Elaboration: 0.05 ($SD = 0.06$), School-related mind wandering: 0.03 ($SD = 0.05$), Unrelated mind-wandering: 0.06 ($SD = 0.07$), Media multitasking: 0.14 ($SD = 0.15$).

3.2. Trends over time

3.2.1. Study 1. The final five minutes of each lecture were reserved for quiz questions, so the remaining 75 minutes were divided into 4 equal quarters (18:45 each, as in previous work; *authors omitted for blind review*). Probes were placed into these quarters based on when they occurred in time, and a proportion was computed within each quarter by dividing the number of media multitasking responses by the number of probes responded to in that quarter. One participant could not be included in the analysis because they did not respond to any probes in the second quarter of the lecture. Where necessary, the Greenhouse-Geisser correction was used. A repeated-measures ANOVA revealed a significant main effect of Lecture Quarter on the proportion of media multitasking responses, $F(2.69, 432.52) = 3.10$, $MSE = .05$, $p = .031$, $\eta_p^2 = .02$, with a significant linear trend, $F(1, 161) = 4.46$, $MSE = .08$, $p = .036$, $\eta_p^2 = .03$. The most prominent difference among the pairwise comparisons was between the second and fourth quarter, which was just beyond the Bonferroni-corrected significance threshold ($p > .0083$), $t(161) = 2.67$, $SE = .03$, $d = .021$, $p = 0.0084$. All other comparisons failed to reach Bonferroni-corrected significance. See Figure 2 for the full pattern of results.

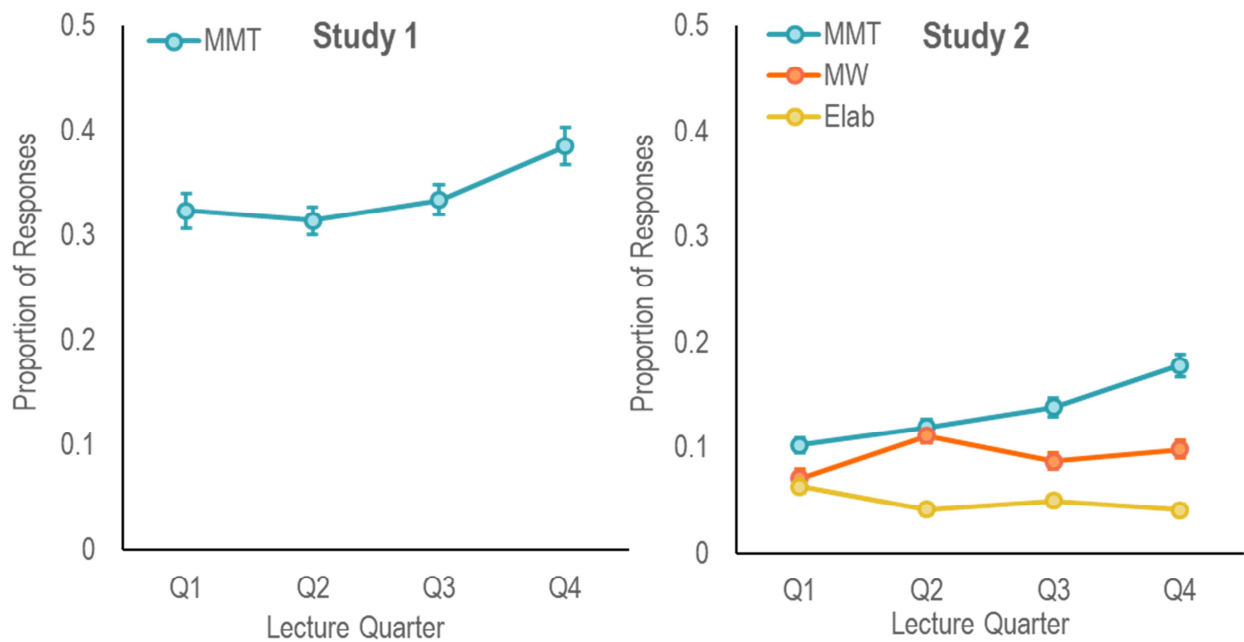


Figure 2. Proportion of probe responses in each quarter of the lecture in Study 1 and Study 2. Responses include media multitasking (MMT), mind wandering (MW; which contains both school-related, and unrelated mind wandering), and elaborative thought (Elab). Error bars are within-participant standard error bars (Cousineau, 2005), corrected for the participants' mean and the grand mean.

3.2.2. Study 2. Probes were divided into quarters as in Study 1. Due to their infrequency and similarity, responses of 'School-related mind wandering' and 'Unrelated mind wandering' were combined into one superordinate mind wandering measure, hereafter referred to simply as 'mind wandering'. Because our primary hypothesis was that media multitasking would increase while mind wandering would remain relatively stable, we directly compared these two linear trends, revealing a significant interaction between Lecture Quarter and Response, $F(2.723, 187.917) = 4.02$, $MSE = .01$, $p = .011$, $\eta_p^2 = .06$ ². We then conducted repeated-measures ANOVAs separately for each response

² An important caveat to this analysis is that these data could be described as being partially ipsative because our probe options were mutually exclusive (i.e., a forced choice situation). This structure necessitates that if one response category increases, another (or some combination of the others) must necessarily decrease (for a full discussion, see Seli, Wammes, Risko & Smilek, 2016). Because there were five, not just two response options, the finding reported here is unlikely to be seriously affected by this constraint. That is, an increase in media multi-tasking does not directly

category to clarify the interaction. As can be seen in Figure 1, there was a significant main effect of Lecture Quarter on the proportion of media multitasking reports, $F(2.568, 177.205) = 10.57$, $MSE = .01$, $p < .001$, $\eta_p^2 = .13$, with a significant linear trend, $F(1, 69) = 28.52$, $MSE = .01$, $p < .001$, $\eta_p^2 = .29$. Specifically, there were significant increases from the first to the third, $t(69) = 3.00$, $SE = .01$, $d = 0.40$, $p = 0.004$, from the second to the fourth, $t(69) = 3.82$, $SE = .02$, $d = 0.48$, $p < 0.001$, and from the first to the fourth quarter, $t(69) = 5.03$, $SE = .02$, $d = 0.69$, $p < 0.001$. While there was also a significant main effect of Lecture Quarter in the proportion of mind wandering³ reports, $F(2.857, 197.132) = 3.60$, $MSE = .01$, $p < .001$, $\eta_p^2 = .05$, there was no evidence for a linear trend, $F(1, 69) = 1.63$, $MSE = .01$, $p = .21$, $\eta_p^2 = .02$, and the only significant increase was from the first to the second quarter, $t(69) = 3.44$, $SE = .01$, $d = 0.42$, $p = 0.001$. We also conducted a separate repeated measures ANOVA for elaborative responses, which revealed no significant differences, $F(2.480, 171.090) = 2.58$, $MSE = .004$, $p = .07$, $\eta_p^2 = .04$.

3.3. Quiz and Test Performance

Recall that we aimed to explore whether both media multitasking and mind wandering would be associated with poorer learning, and moreover, whether the impact of media multitasking on learning would be stronger than that of mind wandering. We focus first here on the relation between reports of media multitasking, and memory for material presented in the lectures, as measured by later quiz questions, and by tests (detailed in the Overall Quiz and Test Performance section). All correlations reported in-text are Spearman's rho, but Pearson correlations are

necessitate a decrease in mind wandering. In fact, it is more likely that increased media multitasking is associated with decreased on-task thought, as can be seen from the mean proportion of on-task responses by quarter of lecture ($M_s = 0.76, 0.73, 0.72, 0.68$, respectively). Similarly, rates of mind wandering and media multitasking are *not* correlated with each other during any quarter of the lecture ($r_s = 0.17, 0.01, -0.11, 0.04$, $p_s > 0.25$), while both mind wandering ($r_s = -0.53, -0.56, -0.44, -0.51$, $p_s < 0.001$) and media multitasking reports ($r_s = -0.70, -0.63, -0.71, -0.73$, $p_s < 0.001$) are negatively correlated with on-task reports at *every* quarter.

³ We note that there was no evidence of a linear effect in either of the mind wandering response categories when separated either, and the same interaction with media multitasking occurred in either case.

additionally reported in Tables 1 and 2. While quiz questions were not explicitly written based on specific slides, participants were sometimes probed during a quizzed slide just by happenstance. To be thorough, we also report accuracy on those quiz questions that were based on the slides in close temporal proximity to the presentation of a probe, where possible (detailed in the Slide-Based Performance section).

3.3.1. Overall Quiz and Test Performance.⁴

3.3.1.1. Study 1. There were three students whose test scores were unavailable, so the average of five multiple imputations was used to fill in these missing values with probable values based on the available data. The proportion of thought probes to which participants responded that they were media multitasking was negatively associated with both in-class quiz performance, $r(161) = -0.22, p = .005$, and later test performance, $r(161) = -0.21, p = .007$.

3.3.1.2. Study 2. The proportion of thought probes to which participants responded that they were media multitasking was again negatively associated in-class quiz performance, $r(68) = -0.27, p = .022$. There was no relation between quiz performance and the proportion of either mind wandering, $r(68) = 0.07, p = .554$, or elaborative responses, $r(68) = 0.09, p = .483$. Critically, a Williams test revealed that the correlation with quiz performance was higher for media multitasking than that with mind wandering reports, $t(67) = 2.27, p = .027$. In this study however, the relation between media multitasking and later test performance did not reach significance, $r(68) = -0.10, p = .393$.

⁴ Quiz performance did not differ between Study 1 ($M = 0.589, SD = 0.138$) and Study 2 ($M = 0.628, SD = 0.150$), $t(231) = 1.845, SE = 0.021, p = 0.0663$. Although metrics of internal consistency are not often reported in the literature, we report that Cronbach's Alpha was 0.62 for Study 1, and 0.89 for Study 2.

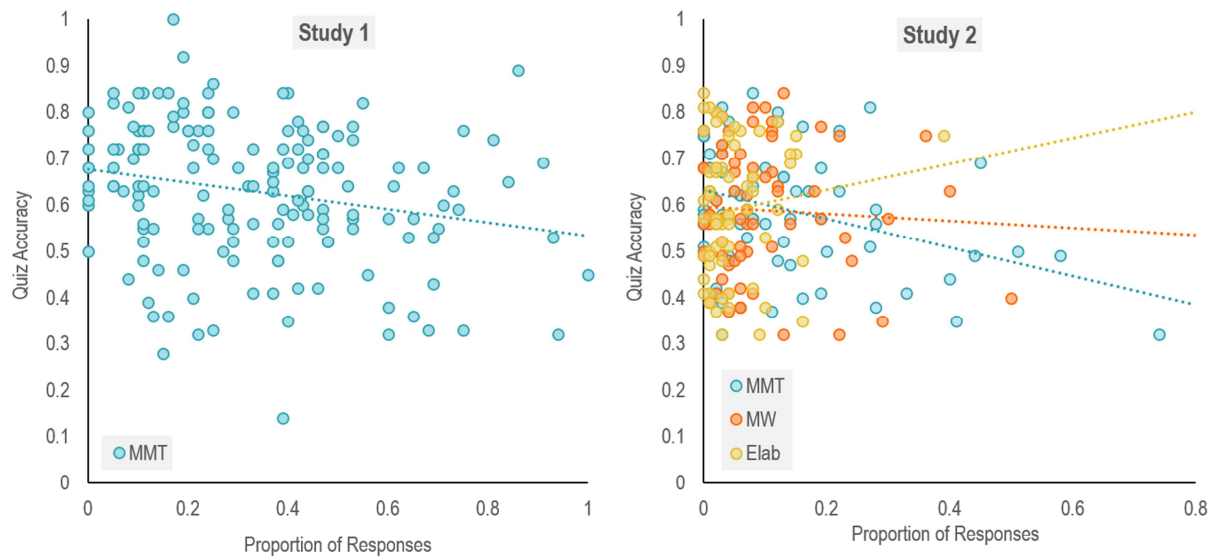


Figure 3. Correlations between quiz accuracy and the proportion of probes to which participants responded they were media multitasking (MMT) in Studies 1 and 2, and to which they responded they were mind wandering (MW) or engaging in elaborative thought (Elab) in Study 2.

3.3.2. Slide-Based Performance.

3.3.2.1. Study 1. Unfortunately, because quiz questions in Study 1 were not written purposefully based on material adjacent to thought probes, there were very few total questions based on slides preceding thought probes ($M = 6.72$, $SD = 1.43$), so we refrain from analyzing these data in detail⁵.

3.3.2.2. Study 2. In Study 2, since probe presentations were independently random for each participant, quiz questions were not locked directly to thought probes⁶. However, we were able to filter the data to include only the probes that occurred either during, or up to two slides after, slides

⁵ For the interested reader, collapsed across participant, questions about material presented just prior to ‘media multitasking’ and ‘on task’ responses were answered correctly 68.53%, and 66.23% of the time, respectively. In the subset of participants who answered at least 3 quiz questions associated with each response type, the correct percentage was 55.48% for media multitasking ($SD = 29.35\%$) and 63.66% for on task thought ($SD = 28.24\%$). However, because only 31 of the participants met these criteria, it is difficult to derive any conclusions from these numbers.

⁶ By response category and collapsed across participant, the proportion of correct quiz question responses associated with each response category were as follows: On task: 0.64, Elaboration: 0.73, School-related mind wandering: 0.62, Unrelated mind-wandering: 0.61, Media multitasking: 0.52.

that were later quizzed (yielding 2343 data points). We then fit the data using a multilevel regression model conducted in R, using *lme4*; Bates, Maechler, Bolker & Walker, 2015), with participant as a random variable, and possible probe responses (i.e. mind wandering, media multitasking, elaborative thought) were each dummy-coded as a predictor variable. In this analysis, a media multitasking response, for example, is coded as 1 for the media multitasking variable, and 0 for all other predictors. Thus, on-task thought is treated as the baseline and a beta estimate is derived for the contribution of each response to later quiz accuracy. In this model, the intercept (or the accuracy for on-task responses) was 0.65 (CI₉₅ = 0.61, 0.68), and only media multitasking emerged as a negative predictor of quiz performance, -0.10 (CI₉₅ = -0.16, -0.04). The estimate for mind wandering responses was -0.06 (CI₉₅ = -0.13, 0.01), and for elaborative responses was 0.04 (CI₉₅ = -0.06, 0.13), but neither were significant. This analysis converges with the findings from the presented correlation analysis.

An additional concern introduced by the use of a computer-based application is that probe presentation itself might foster distraction from lecture content, thus leading to impairment in performance. However, when comparing performance on quiz questions that occurred up to two slides following a thought probe ($M = 0.609$, $SD = 0.158$) with overall quiz performance ($M = 0.595$, $SD = 0.138$), there was no significant difference, $t(67) = 1.61$, $SE = .009$, $d = 0.204$, $p = 0.113$, and if anything, performance trended in the direction of being slightly better on material immediately following probes.

3.4. Individual Differences

We collected several self-report measures during the pre-term questionnaire, all of which are reported in Tables 1 and 2. However, below we unpack in more detail the correlations which we believe to be most noteworthy, especially those that are consistent across studies. Note that the

correlations between probe responses and quiz accuracy are reported above, and are simply duplicated in the table for the ease of the reader (See Tables 1 and 2). In Study 2, three students had incomplete questionnaires, so the average of five multiple imputations was used to fill in missing values with probable values.

Table 1

Pearson (Above Diagonal) and Spearman (Below Diagonal) Correlation Among Measured Variables in Study 1

	MMT	Quiz	Test	pMMT	pMW	Mot	Know	Read
MMT probes		-0.22	-0.21	0.43	0.28	-0.19	0.04	0.01
Quiz accuracy	-0.22		0.28	-0.10	-0.09	0.03	0.15	-0.01
Test scores	-0.21	0.31		-0.20	-0.23	0.09	0.34	-0.01
Prospective	0.45	-0.11	-0.20		0.60	-0.33	0.15	-0.21
MMT								
Prospective MW	0.26	-0.12	-0.23	0.61		-0.41	0.11	-0.27
Motivation	-0.21	0.03	0.12	-0.33	-0.37		0.03	0.17
Knowledge	0.05	0.14	0.34	0.15	0.10	0.08		-0.15
Reading	-0.02	0.03	-0.01	-0.22	-0.26	0.17	-0.15	

Note. $n = 163$, coefficients in bold are conventionally significant, MMT = media multitasking, MW = mind wandering, p = prospective, Mot = pre-term motivation to learn, Know = self-reported pre-term knowledge of subject matter, Read = pre-term likelihood of doing the assigned reading before class.

Table 2

Pearson (Above Diagonal) and Spearman (Below Diagonal) Correlation Among Measured Variables in Study 2

	MMT	MW	Elab	Quiz	Test	MWS	MWD	Grit	Mot	Know	Read	Int
MMT probes		0.03	-0.08	-0.34	-0.13*	0.33	0.18	-0.25	0.02*	0.00	-0.13	-0.37
MW probes	0.15		0.39	-0.05	-0.21	0.29	-0.12	-0.14	-0.13	-0.04	-0.06	-0.04
Elab probes	-0.11	0.29		0.12	-0.01	0.21	0.09	-0.22	-0.08	-0.11	-0.09	-0.13
Quiz accuracy	-0.29	0.07	0.08		0.42	-0.01	0.12	0.00	0.20	0.18	0.09	0.20
Test scores	-0.10*	-0.18	-0.04	0.39		-0.21	0.04	0.12	0.04	0.39	0.01	0.14
MW-Spontaneous	0.27	0.13	0.18	-0.02	-0.22		0.26	-0.56	0.08	-0.21	-0.11	-0.20
MW-Deliberate	0.17	-0.02	0.09	0.10	0.03	0.22		-0.32	0.04	-0.30	-0.27	-0.23
Grit scale	-0.15	-0.05	-0.21	-0.01	0.19	-0.47	-0.26		0.16	0.36	0.22	0.37
Motivation	-0.10*	-0.13	-0.01	0.27	0.11	0.04	0.01	0.26		-0.01	0.16*	0.45
Knowledge	-0.01	-0.01	-0.12	0.17	0.39	-0.22	-0.25	0.35	0.05		0.12*	0.23
Reading	-0.17	-0.07	-0.07	0.06	-0.02	-0.04	-0.30	0.24	0.17*	0.08*		0.41
Interest	-0.27	-0.13	-0.16	0.18	0.12	-0.10	-0.17	0.34	0.37	0.17	0.42	

Note. $n = 70$, coefficients in bold are conventionally significant, * = significant in only Study 1 (i.e. did not replicate), MMT = media multitasking, MW = mind wandering, S = spontaneous, D = deliberate, Grit = 8-item grit scale, Mot = pre-term motivation to learn,

Know = self-reported pre-term knowledge of subject matter, Read = pre-term likelihood of doing the assigned reading before class, Int = pre-term self-reported interest in the subject matter.

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First, in both studies, quiz accuracy was significantly positively correlated with performance on later tests, indicating that these quiz questions were a reasonable measure of one's immediate memory for material presented in the course. Performance on tests was also positively associated with participants' self-reported knowledge of the subject area on the pre-term questionnaire in both studies. Participants' predictions about the extent to which they would disengage were also correlated with their actual measured levels of disengagement as measured by the thought probes, indicating that our probe methodology was effective. In Study 1, prospective judgments of mind wandering and media multitasking during the course were positively correlated with the measured tendency to media multitask in class (Table 1), providing further evidence of the validity of the probing method. In Study 2, scores on the Spontaneous Mind Wandering (MW-S) questionnaire were positively correlated with media multitasking and mind wandering in class (Table 2).

In addition, grit was negatively associated with both MW-S and Deliberate Mind Wandering (MW-D) questionnaire scores, as well as media multitasking probe responses (Table 2). In our previous work, grit was more closely associated with MW-S than with MW-D (Ralph et al., 2017). While this difference was not significant in the present data, $t(67) = 1.53, p = .130$, the pattern trends in the same direction. In Study 2, those who reported being more interested in the subject matter, were also grittier, less likely to media multitask during lectures, more motivated to learn, and more likely to do the reading before class.

3.5. Exploratory spatial analysis

In Study 2, prior to the beginning of each class we asked participants using the app to indicate in which of eight regions of the lecture hall they were seated. This was largely an exploratory measure, as we did not introduce assigned seating as a manipulation, and had few strong predictions, except that inattention would be higher in regions of the classroom which were farther away from

the instructor. To this end, we collapsed the regions into the front and back of the lecture hall, and examined responses provided when participants were seated in these regions. Figure 4 shows the data pattern, collapsed across participants, but *not* collapsed across the front and back of the lecture hall. Students who most frequently sat in the back of the lecture hall tended to media multitask more than those who most frequently sat in the front, $t(67) = 2.69$, $SE = .04$, $d = .069$, $p = 0.009$. The differences between groups for other response categories and quiz performance failed to reach significance, though there was a numerical tendency toward worse quiz performance for those in the back of the room compared to those in the front of the room. A conservative within-participant analysis was conducted, comparing only the thirty-seven students who sat in the front and the back of the lecture hall for at least two probes each. The analysis revealed no evidence that seating location influenced media multitasking, mind wandering or quiz performance, though it is noteworthy that the numerical trends did mimic the between-participant analysis. We remind the reader that these analyses were exploratory and our goal was only to present the forgoing preliminary analyses to guide future work.

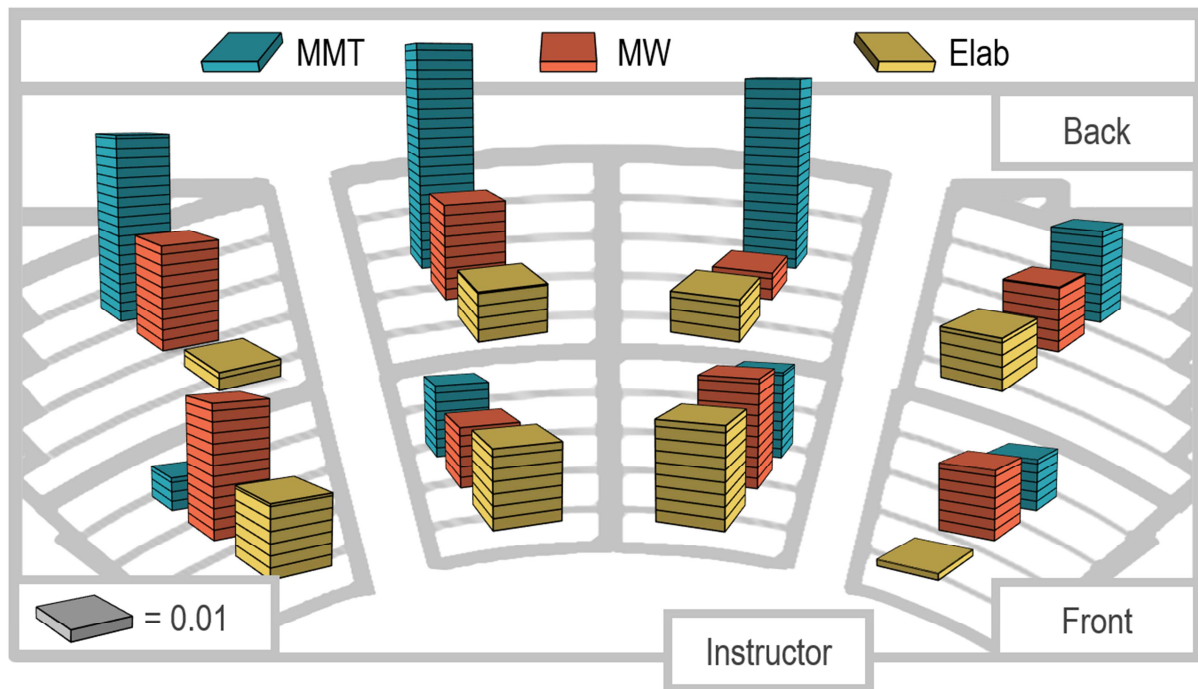


Figure 4. In each of eight regions in the lecture hall, the proportion of probes to which media multitasking (MMT), mind wandering (MW) and elaborative (Elab) responses were given, collapsed across participant. Each layer (i.e., tile) represents an additional proportion of 0.01 (or 1% of responses). The front and back of the lecture hall is noted, as well as the location of the podium where the Instructor typically began the lecture and returned frequently.

4. General Discussion

Across two studies, spanning a semester and a half of live university lectures, we aimed to explore four primary predictions. We measured temporal trends in off-task behavior during lectures, and explored whether (a) media multitasking rates would increase over time during a live university lecture, while (b) mind wandering rates would remain relatively stable. We also tested whether (c) both media multitasking and mind wandering would negatively impact learning, but that (d) media multitasking would hinder learning to a greater extent than mind wandering. Our data yielded the following observations: First, we found that media multitasking reliably increased over time in an average live lecture. In addition, we replicated previous work showing that mind wandering tends to

remain relatively stable over time. We found that media multitasking, but not mind wandering, was negatively associated with learning outcomes, and correspondingly, that media multitasking was reliably associated with poorer learning than was mind wandering. Importantly, the present findings lead us to reconsider an inference we made in our prior work (*authors omitted for blind review*). Across our prior studies, mind wandering rates remained rather stable over time during live university lectures, despite differences between studies in lecture length and in probing methodology. Based on those prior findings, we proposed that increases in attentional disengagement during live lectures are not a necessary outcome of extended time on task (*authors omitted for blind review*). Although the current work replicated the finding that mind wandering does not change over time, rates of media multitasking increased. This provides evidence that disengagement does increase over extended periods of time on task in live lectures, though seemingly due to media multitasking rather than mind wandering.

The present results harmonize with mounting evidence from prior studies, demonstrating that the manner in which engagement changes over time during a lecture depends on whether the study is conducted in live university lectures with enrolled students, or in lectures staged for non-students in the laboratory (Varao Sousa & Kingstone, 2015; Wammes & Smilek, 2017). As previously mentioned, it is common in laboratory-based lecture studies for rates of mind wandering to increase as time elapses (e.g. Farley et al., 2013; Risko et al., 2012; 2013; Seli et al., 2015). For instance, Risko et al. (2012) found that mind wandering rates increased from 35% to 52% from the first to the second half of a video lecture. However, as replicated here, mind wandering during live lectures is quite stable over time on task (Wammes & Smilek, 2017, Wammes et al., 2016a; 2016b).

The present findings suggest that media availability is an important factor which might contribute to the aforementioned discrepant patterns found between laboratory and live lecture

studies. In live lecture settings, because of the ubiquity of external distractions, attention disengagement over time on tasks manifests primarily as a progressive increase in *external* engagement with class-unrelated media (i.e., media multitasking). In contrast, in the laboratory, participants are often not afforded the opportunity to use their smartphone or laptop, limiting the availability of salient external distractions. Accordingly, while viewing lecture videos in this laboratory setting, a decrease in engagement over time primarily manifests as an increased tendency to *internally* engage with task-unrelated thoughts (i.e., mind wandering). It may be the case that mind wandering and media multitasking operate as competing forms of disengagement, though future work will be necessary to flesh out this relation, and to target the tradeoff between these varieties of off-task thought more systematically. It will be important to determine, for example, whether mind wandering rates will increase when access to media (e.g. smartphones and laptops) is restricted versus freely available (c.f. Kane et al., 2017).

Of course, there are other factors that likely play a role in attentional engagement in lectures as well. In fact, one factor that likely influences engagement levels over time, and one that is relevant for considering the discrepant mind wandering patterns across laboratory and live lecture contexts, is one's motivation to attend. Indeed, motivation has emerged as a powerful predictor of mind wandering behavior (e.g. Kurzban, Duckworth, Kable & Myers, 2013; Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Seli et al., 2016; Unsworth & McMillan, 2013; 2017). In the actual classroom, students are required to learn and retain the presented material in order to achieve a passing grade, which may provide sufficient motivation to remain engaged throughout the lecture. By contrast, naïve participants in laboratory studies stand to gain little (if anything) from remembering what was presented in the lecture, and may therefore be less motivated to remain attentive.

Turning to the link between attentional disengagement and performance, our findings here demonstrated clearly that media multitasking was negatively associated with quiz performance in both studies, and was negatively associated with test performance in Study 1, but not 2. These findings are in line with the well-documented performance costs associated with media use during lectures that is unrelated to the presented content (Fried, 2006; Mueller & Oppenheimer, 2014; Ravizza et al., 2014; 2017; Risko et al., 2013; Sana et al., 2013; Wood et al., 2012; but see Unsworth & McMillan, 2017). We additionally demonstrated that media-multitasking was *more* detrimental to quiz performance than mind wandering in university lecture settings. Why this is the case remains an interesting puzzle. One possibility is that entertaining internal digressions and external task focus (i.e. on the lecture content) simultaneously may be simpler than simultaneously engaging in two external tasks. The possibility that one can allocate partial resources to mind wandering without incurring costs to learning is in line with the resource control theory, which suggests that given a relatively undemanding task, one can titrate his or her mind wandering in such a way that external task performance does not suffer (Thomson, Besner & Smilek, 2013; 2015). Moreover, in previous work, we demonstrated that performance on quiz questions decreases according to the depth, or degree to which one was mind wandering (*authors omitted for blind review*). In other words, students were often able to partially mind wander without totally undermining learning⁷. It appears that, compared to mind wandering, media multitasking may be a more insidious form of disengagement that captures attention more completely, undermines one's ability to balance off-task behavior and focal task demands, and ultimately results in greater impairments in performance.

We also presented some purely exploratory findings regarding whether inattention during lectures was associated with the seating location of students in the classroom. We asked participants

⁷ However, we note that this trend may also be driven by students opting to partially mind wander during the presentation of content that they are already familiar with.

prior to each lecture to indicate where they were sitting, and predicted that those in the back of the lecture hall would be more prone to inattention (mind wandering and/or through media multitasking). Our results confirmed this case for media multitasking, as those who spent more time seated at the back of the classroom were also more likely to media multitask at a higher rate. There was no clear spatial trend in mind wandering, though the general distribution (Figure 4) is suggestive that mind wandering was highest at the left side of the room – opposite the instructor’s podium. For the subset of the participants who sat in both the front and back of the classroom on enough occasions to derive an estimate, there was no clear within-participants effect, though media multitasking was numerically higher when one was seated in the back, as compared to the front of the room. With the current data, we are unable to distinguish whether the sort of students who sit in the back are also the sort of students who are more likely to media multitask, or whether sitting in the back is somehow causally tied to multitasking. Future assigned-seating studies will be required to adjudicate between these possibilities more directly.

Lastly, it is important to address the temporal trends and consequences, or lack thereof, associated with elaborative thought in our Study 2. Previous work reported that some thoughts that would fall under the broad category of not explicitly being ‘on task,’ can actually be beneficial to later performance. Namely, elaborative thought about the content being presented in the lecture can be associated with better retention (Kane et al., 2017). Our findings here are less conclusive. While the correlation between elaborative probe responses and quiz accuracy was indeed positive in Study 2, it was quite weak and not statistically significant. There were also no notable trends in elaborative thought over time in an average lecture. So, while our findings do not conflict with previous work, they do not strongly confirm previous work either. It is possible that the endorsement rate of the ‘elaborative thought’ option was far too low (only ~ 5%) to observe any notable effects. It also could be the case that many potential ‘elaborative’ responses were classified by the students in our

sample as being 'on task' thought. In any case, there is not enough evidence to make any substantive claims in this response class.

4.1. Limitations

One shortcoming of the current approach was that we could only include a relatively small number of thought probes per class. We opted to keep the number of thought probes low in order to minimally distract students with probes during the lecture and interfere with their learning. During staged or laboratory lectures, probes can be placed at a much higher frequency as the consequences of disruption are less severe. That being said, we circumvented the problem of having few probes per class by collecting relatively large sample sizes and collecting data across multiple lectures and multiple samples.

Another possible concern is that the base rate of media multitasking was different across the two studies (i.e., it was lower in Study 2 than in Study 1). While we cannot be certain about the reason for this discrepancy, it is possible that the samples simply differed because they were collected using different cohorts of students in different academic semesters. An alternate explanation worth discussing, however, is that the phrasing and response options included in the probe impacted response rates, as has been documented in prior work (e.g., Weinstein, 2017; Weinstein, De Lima, van der Zee, 2018). Recall that in Study 1, participants were only asked about whether or not they were media multitasking, while in Study 2, participants were asked to choose which of five options characterized what they were thinking about. It could be the case that students' experiences were best captured by a combination of responses, yet they were required to choose the most appropriate among the available options. For example, a student may have *mostly* been listening to the lecturer, but also allocating some attention to using his or her laptop for unrelated activities. In Study 1, the appropriate response when probed would be to report 'Yes'

(media multitasking), since he or she was indeed using his or her smartphone for things unrelated to the lecture, and since the sole alternative response was 'No' (not media multitasking). In Study 2 on the other hand, the most appropriate response would be 'On task', because *most* of the student's attention was allocated to the lecture. To address this issue future work may allow students to select multiple response options for a single probe. In any case, differences in response rates (i.e. as a main effect) across samples with different probe methodology are difficult to interpret.

Finally, we note that because our studies were conducted in ecologically valid lectures, we had to concede a modicum of experimental control. For example, we did not have direct control over the timing of the presentation of the course material since student interest and questions influenced how quickly a topic was completed in the class. This meant that breakpoints between topics did not always occur at the end of a class but sometimes occurred in the middle of a class. As another example, occasionally the lecture went longer than intended and this reduced the number of quiz questions that were presented in those lectures. Furthermore, we had no direct control over whether and how much students were studying or reviewing material outside of the lecture hall, factors that likely heavily influenced their test performance. For all of these and many other reasons, the data collected during live classes can often be noisier than those collected during laboratory studies. However, that we find replicable patterns despite these limitations affords us some confidence in our conclusions.

5. Summary and Conclusions

Across two studies, we demonstrated that media multitasking increases as students spend more time in actual live university lectures. Interestingly, media multitasking was also associated with costs to learning, as measured by later accuracy on both quizzes and course tests. In contrast, mind wandering rates remained relatively stable, and had a less severe impact on retention of material

presented in the lecture. We also present preliminary findings that students seated in the back of a lecture hall are more likely to engage in media multitasking than those who sit in the front, pointing toward potential targets for future empirical and applied research. The relative temporal dynamics of media multitasking and mind wandering suggest that student engagement decreases over time as a lecture unfolds, but that this increased disengagement takes on a specific form in live lectures. Specifically, participants are turning their attention to external distractions (i.e. their smartphones and laptops) more frequently in the latter part of lectures rather than to internal distractions/off-task thought. Given the severe costs of such disengagement to learning, this finding has broad implications for the general practice of electronic device usage in the classroom.

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Highlights

- Measured media multitasking and mind wandering during live university lectures
- Media multitasking rates were high and increased over time within a lecture
- Mind wandering rates remained stable over time, consistent with prior work
- Media multitasking more negatively associated with learning than mind wandering
- Exploratory findings suggest media multitasking is higher in the back of the room