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Dividing attention in the classroom reduces exam performance

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ABSTRACT

The intrusion of internet-enabled electronic devices (laptop, tablet, and cell phone) has transformed the modern college lecture into a divided attention task. This study measured the effect of using an electronic device for a non-academic purpose during class on subsequent exam performance. In a two-section college course, electronic devices were permitted in half the lectures, so the effect of the devices was assessed in a within-student, within-item counterbalanced experimental design. Dividing attention between an electronic device and the classroom lecture did *not* reduce comprehension of the lecture, as measured by within-class quiz questions. Instead, divided attention reduced long-term *retention* of the classroom lecture, which impaired subsequent unit exam and final exam performance. Students self-reported whether they had used an electronic device in each class. Exam performance was significantly worse than the no-device control condition both for students who did and did not use electronic devices during that class.

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instruction; long-term
retention; social distraction;
exam performance

Introduction

The senior author can remember when etiquette at all levels of schooling required students to devote full attention to the teacher. Regardless of class size, dividing ones attention between a lecture and some other activity, such as doing homework for another course, was not a possibility. This cultural prohibition was beneficial because 60 years of laboratory studies have found that when a person divides attention between two tasks they remember less from at least one of them (Cherry, 1953; Wood & Cowan, 1995). However, technological advances have changed cultural norms. The intrusion of electronic devices (laptop, tablet, and cell phone) allows students to divide attention between the classroom and unrelated activities, for example, texting, watching a movie, playing a game, and shopping. Recent laboratory studies in which one of the tasks requires using an electronic device on the internet have replicated this finding (Grace-Martin & Gay, 2001; Hembrooke & Gay, 2003; Sana, Weston, & Cepeda,

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2013). So, when students divide attention between an electronic device and the classroom lesson they should be learning less. In fact, several classroom studies have found a negative correlation between the amount of time spent using an electronic device for non-academic purposes during class and subsequent exam performance using both self-report measures of electronic device use (Fried, 2008; Jacobsen & Forste, 2011; Junco, 2012; Ravizza, Hambrick, & Fenn, 2014) and direct electronic monitoring (Kraushaar & Novak, 2010; Ravizza, Uitvlugt, & Fenn, 2017).

Unfortunately, all of these informative studies are correlational. They only establish that students who divide attention in class do worse on exams. They do not establish that it is the division of attention in class that causes the poorer performance. These results (Fried, 2008; Jacobsen & Forste, 2011; Junco, 2012; Kraushaar & Novak, 2010; Ravizza et al., 2014, 2017) cannot rule out the plausible hypothesis that the students who are more likely to divide attention between academic and non-academic tasks in class are also more likely to do so out of class. So generally, less attention to study both in and out of class ultimately reduces exam performance rather than a specific effect of divided attention on classroom learning.

A recent experimental classroom study (Carter, Greenberg, & Walker, 2016) partly fills this gap. In some course sections, electronic devices were forbidden in the classroom but in other sections, they were not. There was poorer final exam performance for those sections in which electronic devices were permitted. Since the students had no control over their assignment to a course section, it may be inferred that the exam performance was an effect of assignment to either an electronic devices allowed or electronic devices not allowed section. Hence, this study does show an ultimate effect of divided attention in class on final exam performance.

However, the study (Carter et al., 2016) did not address important questions about how divided attention affects exam performance. Laboratory studies have shown at least three distinct costs of divided attention. The first effect is the *selection effect*. For example, when more than one person is speaking, while listening to one person speak a listener hears nothing of what the other speaker is saying (Cherry, 1953; Wood & Cowan, 1995). The second effect is the *switching effect*. When two tasks are being performed, there is a switching time between tasks when neither task is being performed (Jersild, 1927; Rogers & Monsell, 1995; Ruthruff, Pashler, & Klaassen, 2001; Spector & Biederman, 1976). Both selection and switching immediately degrade performance on at least one, and usually both tasks, causing an immediate effect of divided attention. However, there is a third, delayed effect of divided attention on *retention*. When attention is divided between two tasks, fewer targets of a study task are subsequently remembered (Mulligan & Picklesimer, 2016). Even when there is little or no selection or switching effect, divided attention reduces retention of the targets for both tasks.

The effect of divided attention on retention is one example of a more general effect of limiting the amount of time available for study when the study material is initially presented. There are two ways to limit study time. One way is to present the study material rapidly. The other way is to require the performance of a secondary task that occurs either simultaneously or immediately after the study material. The effect of reducing the time available for study is to reduce the robustness of the memory of the study material so that it more rapidly degrades from the perception of similar

material and so is rapidly forgotten. When study time is completely eliminated, forgetting is immediate. For example, Rundus and Atkinson (1970) found that when a serially presented list of words is presented, long-term retention is determined by the number of distributed rehearsals (Modigliani, 1980) that each word receives. The beginning of the list is remembered better (the primacy effect) because early list members receive more distributed rehearsals. When the rate of presentation is increased, the number of rehearsals is reduced, consequently reducing both primacy and overall recall. In the limit, Potter (1975, 1976) found that when a list of words or pictures is presented at a rate of 114 milliseconds per item, everything is recognised and nothing, except for a single target item that elicits a response, is remembered.

Similarly, when Müller and Pilzecker (1900) had participants study two lists in succession, long-term recall of the first list was impaired when the second list was presented immediately after the first, hence eliminating continued rehearsal of the first list. When the performance of a secondary distracter task was both required and immediate, Brown (1958) and Peterson and Peterson (1959) found that recall of the study item was immediately impaired. However, when the secondary task was less demanding and so more similar to the effect of the voluntary division of attention studied here, only an effect on delayed retention was found (Mulligan & Picklesimer, 2016).

The well-established dual-system description of mammalian memory (Yin & Knowlton, 2006) provides an explanation of the essential role of study in long-term retention. According to the dual system hypothesis, two distinct systems comprise the mammalian memory system. The instrumental system, which includes the posterior hippocampus and surrounding medial temporal region, encodes the perceptual representations of novel inputs that are subsequently used for navigation and recognition. The habit system, which includes the caudate nucleus, the surrounding basal ganglia structures, and the anterior hippocampus, encodes sequences of actions (Woolley et al., 2013).

Packard and McGaugh (1996) found that when a perceptual target and a successful response are repeated, a more robust, hence much-longer-retained representation is preserved in the habit system than is initially encoded by the instrumental system. Despite the fact that it encodes sequences of actions, the habit system is also involved in the long-term retention of perceptual sequences, which are encoded as response–effect sequences (Ziessler & Nattkemper, 2001). Because the dual-system hypothesis directly predicts that long-term retention is *not* a consequence of repeated perception, but of repeated responses to the same perceptual or semantic target, it directly predicts the testing effect, that long-term retention of semantic material is increased by question-answering when compared with reading or listening, a prediction confirmed by both laboratory (Karpicke & Roediger, 2007, 2008) and classroom studies (Glass, Brill, & Ingate, 2008; McDermott, Agarwal, D’Antonio, Roediger, & McDaniel, 2014). More specifically, the dual-system hypothesis predicts an interaction such that question-answering does not increase performance on immediate or short-term but only on long-term retention because its effect is mnemonic. It does not facilitate learning but long-term retention. The specific effect on only long-term retention has been

confirmed by both laboratory (Karpicke & Roediger, 2007, 2008) and classroom studies (Glass, Ingate, & Sinha, 2013).

Similarly, the dual-system hypothesis directly predicts that divided attention will impair long-term retention because of reduced opportunity for mnemonic activities, e.g. rehearsal, that increase long-term retention. The specific effect of divided attention on long-term retention has been confirmed in at least one laboratory study (Mulligan & Picklesimer, 2016) and is tested by this classroom study for the first time.

If selection and/or switching contribute to the ultimate impairment of exam performance then engaging in these mental activities must interfere with the comprehension of the material presented during the lecture. An immediate question during class should reveal the impaired comprehension. However, if the entire effect of divided attention is on retention then immediate comprehension, as measured by classroom questions, may be unimpaired and only delayed comprehension may be impaired, as found in the laboratory by Mulligan and Picklesimer (2016).

Selection, switching and retention effects are all effects of an individual dividing attention on the individual's own performance. When considered in the context of a classroom, allowing students to divide attention between an electronic device for a non-academic purpose and the classroom may also have the social effect of distracting other students who are not trying to divide attention. The social effect of distraction was tested in a laboratory simulation in which all students took notes on a lecture and some students also had to perform internet tasks on laptops in addition to the note-taking (Sana et al., 2013). Both the students performing the internet tasks and the students who sat near them performed worse on a subsequent exam on the content of the lecture.

A critical gap in the ability to devise an instructional strategy to respond to the intrusion of electronic devices into the classroom for recreational, non-academic purposes has been the lack of understanding of the effect of divided attention by some students in classroom on the comprehension and retention of the lesson by all of the students in the classroom. To fill the gap in the understanding of the effect of classroom divided attention on academic performance, the study reported here embedded a within-subject, within-item experimental design in an actual multi-section college lecture course in which tight control was maintained over the teaching of each section in order to obtain the full power of an analysis of variance. The purpose of the study was to measure the effect of attention to electronic devices for content and/or tasks unrelated to the immediate classroom activity on both classroom and subsequent exam performance within the framework of an experimental design that would permit a causal attribution of the effect of divided attention on both classroom and exam performance.

During the course of the semester, students answered 126 questions in class on just-presented content using personal response software which allowed them to use any electronic device. Each of these questions was paired with another question that appeared on both a unit exam and the final exam. The same principle or fact statement implied both the answer to the classroom question and the answer to the exam question. The primary purpose of the classroom questioning was as an instructional methodology to ensure long-term retention of the course material. However, it also

provided precise information about the level of student knowledge during the class lesson.

Two sections received exactly the same 25 lessons and questions back-to-back. During the first two lessons, during the first week of class, the rules for the use of electronic devices during the remainder of the course were repeatedly explained to the students. For the remaining 23 lessons, the classes were identical except for when electronic devices were permitted. Except during the brief time periods when used to answer a question, a proctor ensured that students did not have a laptop or cell phone open for the odd-numbered lessons for section 1 and for the even-numbered lessons for section 2. For the other lessons, students were permitted to have laptops and cell phones open. As a consequence of the within-subject, within-item design, item difficulty was counterbalanced across the condition in which electronic device use was not allowed (Not Allow condition) and the condition in which electronic device use was allowed (Allow condition).

Method

Participants

A total of 118 students, attending one of two sections of an upper-level college cognitive psychology course taught by the same instructor in an identical manner and scheduled during successive class periods in the same lecture hall, participated in the experiment. They were 39% Caucasian, 31% Asian, 13% Latino, 6% African, 4% Mixed Race, and 7% Other. There were 72 students in one section and 46 students in the other. There were 34 males, 82 females, and 2 no responses. There were 114 students between the ages of 18 and 24 and 4 students between the ages of 24 and 36. There was no factor that would have influenced the selection of one identical section over the other. The university was a flagship state university in the United States.

Materials

A total of 126 pairs of five-alternative multiple-choice questions were selected from the question sets accompanying the course textbook (Glass, 2016). The principles and statements implying the answers to all of these questions could be found within the text. One question from each pair was asked in class and the other question appeared on the unit exam and final exam.

Procedure

Two sections of a college course on cognitive psychology were taught by the same instructor back-to-back. Both sections received the same Tuesday and Thursday 80-minute lectures, quizzes, and exams during 28 back-to-back class sessions. There were three unit exams during the class sessions of the semester and a cumulative 3-hour final exam during finals week. The first two classes of the course were not included in the experimental design and three classes were devoted to unit exams. This left 23 lecture classes included in the experimental design. There was complete redundancy

between the textbook and the 23 classroom lectures so that the answer to every exam question was presented both in the textbook and on a PowerPoint slide presented during the lecture by the instructor. All of the lecture slides were available to the students on the course website at the beginning of the semester.

During the course of the semester, students answered 126 multiple-choice questions in class on just-presented content on the previous slide using personal response software which allowed them to use any electronic device. The question appeared on a slide. The instructor read the question from the slide once and then activated a 10-second countdown, visible on the slide, during which students could respond with any (properly registered) electronic device. At the conclusion of the countdown, the percent of students who made each response was presented. Next, a checkmark indicated the correct answer. Finally, the instructor asked if there were any questions about why that response was correct.

Sections 1 and 2 received exactly the same 23 lessons and questions back-to-back. However, as was stated on the syllabus and at the start of each class, the students were only allowed to use electronic devices for half of the lectures and this prohibition was enforced by a proctor that only attended classes for which dividing attention to electronic devices was forbidden. Except during the brief periods when used to answer a question, a proctor ensured that students did not have a laptop or a cell phone open for the odd-numbered lessons for section 1 (held on Tuesday) and for the even-numbered lessons for section 2 (held on Thursday). When electronic devices were not allowed, students were told to leave them closed on the arm extensions of their seats and to touch them only to answer questions. The lecture hall had arena style seating in which each row of seats is above its predecessor. So, a proctor at the back of the lecture hall had a good view of the electronic devices on the arm extensions below. When the proctor noticed an open electronic device, the proctor approached the student and instructed that it be closed. Students always complied immediately. After the first three weeks, the prohibition became routine and was no longer violated, though the proctor continued to attend until the end of the semester. For the other lessons, students were permitted to have laptops and cell phones open.

At the end of each class at which electronic devices were permitted, the students answered the following question: During class today, did you look at your laptop or cell phone? (It was made clear that this was for a use other than answering a question.)

The interval between a classroom lecture and unit exam varied from 5 d to 28 d. The interval between a unit exam and the final exam varied from 5 d to 3.5 months.

Since nothing was done in this course that was not also done in other courses throughout the university; the only difference being that the effects of divergent, widely used, classroom decorum rules were being systematically evaluated, the method received an exemption from additional informed consent requirements from the Institutional Review Board.

Results

Divided attention in the classroom did not affect classroom performance but did affect subsequent exam performance. Exam performance was poorer for material taught in

classes that permitted electronic device use both for students who did and did not direct attention to an electronic device for a non-academic purpose during those classes.

Responses to the classroom quizzes, unit exams, and final exam were analysed in a 3×2 within-subject, within item-design in which the independent variables were Question (class quiz, unit exam, and final exam) and Electronic Device Use (Allowed, Not Allowed) and the dependent variable was percent correct on the classroom and exam questions. The results are shown in Figure 1. The effects of both Question $F(2, 234) = 140.5, p < .01$ (partial eta-squared = 0.10) and Electronic Device Use $F(1, 117) = 12.8, p < .01$ (partial eta-squared = 0.55) and their interaction $F(2, 234) = 12.4, p < .01$ (partial eta-squared = 0.10) were significant. Post hoc comparisons confirmed that the difference between Allowed and Not Allowed was not significant for classroom questions, $F(1, 117) = 0.7, p = .40$ (partial eta-squared = 0.03), but was significant for the unit exam, $F(1, 117) = 5.9, p = .02$ (partial eta-squared = 0.17), and the final exam, $F(1, 117) = 56.5, p < .01$ (partial eta-squared = 0.15), questions.

We excluded from further analysis those students who reported whether they used electronic devices only once. Among the remaining students, a total of 79 students reported that they used electronic devices in more than half of the lectures in which they were allowed and among these 43 reported always using electronic devices. A total of 30 students reported that they did not use an electronic device in more than half of the lectures in which they were allowed and among these six reported never using an electronic device. To assess the performance of students who did use electronic devices versus those who did not use electronic devices when they were allowed, two analyses were performed. Every response of every student was included in at least one of these two analyses.

A between-subjects analysis was performed in which a student was assigned to the Use group if the student reported using an electronic device in the majority of the classes in which it was allowed and a student was assigned to the Not Use group if the student reported not using an electronic device in the majority of the classes in which it was allowed. If a student was in the Use group then any responses made in

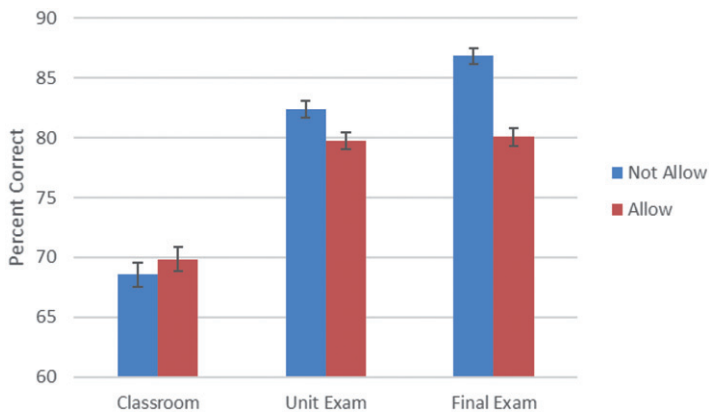


Figure 1. The effect of allowing electronic devices in the classroom on percent correct on classroom quizzes and a subsequent unit exam and the final exam.

the Allow condition when the student reported not using an electronic device were not included in the analysis. Similarly, if a student was in the Not Use group then any responses made in the Allow condition when the student reported using an electronic device were not included in the analysis. Then, a $2 \times 3 \times 2$ between-subject analysis of variance was performed in which the independent variables were Group (Use, Not Use), Question (class quiz, unit exam, and final exam), and Electronic Device Use (Allowed, Not Allowed), and the dependent variable was the percent of correct responses in the classroom and exam questions. The results of this analysis are shown in Figure 2. Neither the effect of Group, $F(1, 107) = 2.1, p = .15$ (partial eta-squared = 0.02), nor any of its interactions were significant; however, the effects of both Question $F(2, 214) = 114.5, p < .01$ (partial eta-squared = 0.52) and Electronic Device Use $F(1, 107) = 0.8, p < .01$ (partial eta-squared = 0.15) and their interaction $F(2, 214) = 10.4, p < .01$ (partial eta-squared = 0.09) were significant. As shown in Figure 2, the significant interaction was the same for both the Use and Not Use groups and replicated the interaction shown in Figure 1. Post hoc comparisons confirmed that the difference between Allow and Not Allow was not significant for classroom questions, $F(1, 108) = 0.58, p = .45$ (partial eta-squared = 0.05), and was not significant for the unit exam, $F(1, 108) = 2.65, p = .11$ (partial eta-squared = 0.02), but was significant for the final exam, $F(1, 108) = 50.06, p < .01$ (partial eta-squared = 0.32), questions. There were no significant differences for Not Use versus Use.

Since the group size of Not Use and Use was unequal, we also did a correlation and an ANCOVA test to demonstrate there were no differences for Not Use versus Use. The correlation between the number of classes students reported using electronic device and the percent correct was not significant for classroom questions (Pearson $r = 0.03, p = .74$), for the unit exam (Pearson $r = 0.09, p = .37$), nor for the final exam (Pearson $r = 0.12, p = .21$).

If we added the number of classes as a covariate, the results were the same as the between-subjects analysis we did above. The effects of both Question $F(2, 214) = 16.2, p < .01$ (partial eta-squared = 0.13) and Electronic Device Use $F(1, 107) = 0.03, p = .04$

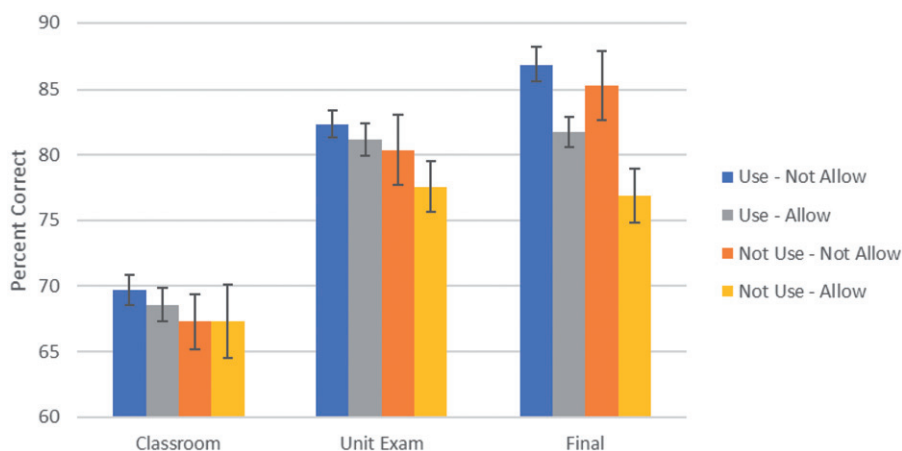


Figure 2. The results of a between-student analysis of the effects of allowing and using electronic devices in the classroom on percent correct on classroom quizzes and a subsequent unit exam and the final exam.

(partial eta-squared = 0.04) and their interaction $F(2, 214) = 11.8, p < .01$ (partial eta-squared = 0.10) were significant.

Also, a within-subjects analysis was carried out on the performance of the 39 students who sometimes did and sometimes did not use an electronic device when it was allowed. A 3×3 within-subject analysis was performed in which the independent variables were Question (class quiz, unit exam, and final exam) and Electronic Device Use (Used, Not Used, and Not Allowed) and the dependent variable was percent correct on the classroom and exam questions. The results of this analysis are shown in Figure 3. The effect of Question was significant, $F(2, 76) = 23.7, p < .01$ (partial eta-squared = 0.38). The effect of Electronic Device Use was not significant, $F(2, 76) = 1.3, p = .27$ (partial eta-squared = 0.03). However, their interaction $F(4, 152) = 3.3, p = .01$ (partial eta-squared = 0.08) was significant, which replicated the between-subjects interaction of Figures 1 and 2 with this within-subjects interaction shown in Figure 3. Post hoc comparisons found that classroom performance was actually better in the Allow condition, $F(1, 38) = 5.1, p = .03$ (partial eta-squared = 0.07), but again performance was better in the Not Allow condition for the unit exam, $F(1, 38) = 4.6, p = .01$ (partial eta-squared = 0.01), and was significant for the final exam, $F(1, 38) = 16.8, p < .01$ (partial eta-squared = 0.11), questions. There were no significant differences for Not Use versus Use.

Discussion

Divided attention had no effect on performance of the classroom lesson questions. However, following the lessons in which cell phones and laptops were allowed, performance was poorer on the unit exam and final exam questions. This finding demonstrates for the first time that the main effect of divided attention in the classroom is not an immediate effect of selection or switching on comprehension but a long-term effect of divided attention on retention. Hence, the effect on long-term retention was

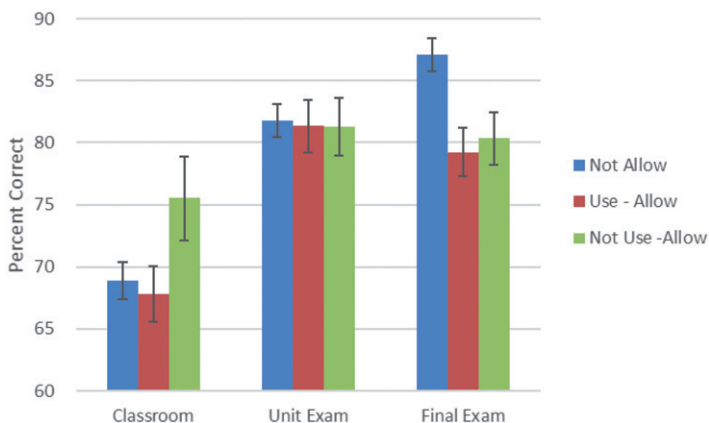


Figure 3. The results of a within-student analysis of the effects of allowing and using electronic devices in the classroom on percent correct on classroom quizzes and a subsequent unit exam and the final exam.

obtained in the absence of an immediate effect on comprehension and the effect on retention was largest at the largest retention interval, on the final exam.

Furthermore, when the use of electronic devices was allowed in class, performance on the unit exams and final exams was poorer for students who did not use electronic devices during the class as well as for the students who did use an electronic device. This is the first-ever finding in an actual classroom of the social effect of classroom distraction on subsequent exam performance. The effect of classroom distraction on exam performance confirms the laboratory finding of the social effect of distraction (Sana et al., 2013).

Obviously, the effect of allowing electronic devices on those students who chose not to divide attention was the result of a large majority of the students (87) choosing to use devices in most classes while only six students never used them at all. This ubiquitous use certainly changed the social character of the class from an occasion for joint attention to more like a group of individuals in a waiting room occasionally looking up. It meant that for the few students who tried to direct attention to the instructor there was distracting activity on both sides and in front of them. The instructor often noticed two students giggling as they together viewed an image on a laptop. It seemed that such behaviour would be distracting to individuals around them.

Confirmation of dual-system hypothesis

The specific effect of distraction on long-term retention is further confirmation that the dual-system model of mammalian memory extends to humans. Within the framework of the dual-system model, long-term retention is a consequence of voluntary action within the habit system. Consequently, any distraction that reduces mnemonic activities reduces long-term retention.

The severity of the effect of classroom divided attention on exam performance

Divided attention to a laptop or cell phone during a classroom lesson clearly impaired long-term retention of the lesson, as demonstrated by the poorer performance on the corresponding review, unit exam, and final exam questions. The magnitude of the effect, a 5% decrease, was a meaningful amount, about half a letter grade in conventional scoring systems.

However, the design of the experiment minimised the effect of divided attention during a lesson. First, all of the course material was presented redundantly. Students who failed to retain material presented in the classroom could have learned it from the textbook and the online lecture slides. In a course in which redundant presentation of the course material may be less systematic and comprehensive, there may be less opportunity to compensate for divided attention or distraction in the classroom. Thus, the resulting long-term effect of the inattention would be greater.

Second, in this experiment, immediately after a fact was presented in lecture the students had to answer a multiple-choice question that tested immediate retention. Requiring students to answer a question reduces the effect of divided attention on retention compared with a similar condition without question-answering (Mulligan &

Picklesimer, 2016). Furthermore, answering the question increases long-term retention of the answer and the testing effect alone causes a meaningful increase in classroom performance (Glass, 2009; Glass & Sinha, 2013; Roediger, Agarwal, McDaniel, & McDermott, 2011). If a question had not followed the presentation of the fact statement, but merely passive listening was required, then there would have been a much greater reduction in retention of the content being presented. Hence, the results of this study represent the minimum reduction in exam performance as the result of divided attention and distraction in class.

Third, notice that the insidious nature of the retention deficit complicates the task of what to study for a subsequent exam. One possible strategy is to subsequently study those items previously gotten wrong on a quiz or exam. However, the effect of divided attention is rapid forgetting of those items answered correctly. So, a student would not only have to study to learn what she did not already know but also what she was about to forget.

Failure to find an immediate effect of divided attention on performance

The finding of an effect of divided attention on long-term performance does not preclude an additional immediate effect on classroom performance. As mentioned above, such immediate effects of divided attention are well-known from laboratory studies. Why then was such an effect not found in the classroom?

Divided attention has an immediate effect when the demands of two tasks create an irreconcilable conflict between which of two competing responses should be made. When a participant can schedule when to respond to each task and gives one task priority, no decrement in the performance of that task is observed (Schumacher et al., 2001). This is the situation in the classroom. A student momentarily being entertained by cell phone content or distracted by the student in the adjacent seat can nevertheless focus on each question when it is asked in class. Consequently, as measured in this study, there was no decrement in immediate memory when a student was asked a question about a just-presented slide. Students had good reason to prioritise answering classroom questions because their responses influenced their grades. Laboratory studies that produced an immediate effect of divided attention on retention (e.g. Risko, Buchanan, Medimorec, & Kingstone, 2013) are not comparable, because they did not provide a similarly strong incentive to prioritise the immediate memory test in the presence of distraction. Furthermore, students watched a video of a lecture in the laboratory studies. Wammes and Smilek (2017) found that less attention is directed to a video of a lecture than to a live classroom lecture; so, a video lecture is more susceptible to an immediate effect of distraction.

Multi-tasker awareness of the effect of divided attention on performance

The finding that divided attention affected exam performance through its long-term effect on retention rather than through an immediate effect of selection or task switching on comprehension may explain why students who are experienced at multi-tasking are unaware of any negative effect it has on their performance (Ophir,

Nass, & Wagner, 2009; Sana et al., 2013). In a real-life multi-tasking situation, the multi-tasker may be aware of any immediate error on one of the tasks. However, when an error has not been made or noticed, there is no reason for a multi-tasker to suspect that long-term retention of the current experience is being compromised.

Social interaction and classroom learning

Given the comprehensive redundancy of the course, it is notable that merely dividing attention in the classroom had any effect on subsequent performance on an exam weeks later. After all, besides attending class, students often study the course material immediately prior to taking an exam. This is why the performance was greater on the final exam than on the unit exams. Why does not this post-class, pre-exam studying completely overwhelm and eliminate the effect of classroom attention?

The post-class study may be inherently inferior to classroom instruction for many individuals because *human cognitive capabilities* evolved to support *human social abilities* (Dunbar & Sutcliffe, 2013) and for many humans, learning occurs more in a social context than an asocial context. Consequently, most humans of all ages, from infants (Kuhl, Tsao, & Liu, 2003), to young children (Nussenbaum & Amso, 2016; Roseberry, Hirsh-Pasek, & Golinkoff, 2014), to college students (Keefe, 2003), retain more from face-to-face social *interactions* than they do from nearly equivalent instructional situations (e.g. involving video or other online instruction) that do not involve social interaction. Also, how much is learned in the classroom may influence the quality of post-class study.

Policy implication

The finding that divided classroom attention ultimately reduces exam performance suggests a re-calculation of the risk/benefit ratio of technology that disables devices and applications not for educational engagement. While laboratory studies of learning are essential, it is only through experimental studies conducted in the classroom measuring actual exam performance that the effects of learning variables on classroom study and exam performance can be determined.

Disclosure statement

No potential conflict of interest was reported by the authors.

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