RESEARCH

Recorded Lectures as a Source of Cognitive Off-loading

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Objective. To assess and elucidate the impact of student pharmacists' knowledge of future access to recorded lectures on their ability to remember information presented during lecture.

Methods. Pharmacy students viewed 50 minutes of videotaped lecture in a simulated class period. For the early lecture material, participants were instructed as to whether or not they would have future access to the recorded lectures for restudy prior to their test one week later. For the late lecture material, participants were instructed they would not have future access to lecture material. Participants were tested immediately following the lectures and again one week later. The primary outcome was the participants' performance on the examination administered immediately following presentation of the late lecture material. If participants had preserved cognitive resources (eg, memory, attention) because of knowledge they would have future access to recorded lectures, performance was expected to be higher on the late lecture material.

Results. Overall performance on the examinations did not differ between participants who knew they would have access to the lecture material for later restudy and those who did not. There was, however, loss of knowledge over time. Participants with knowledge of future access to recorded lectures wrote more notes, which correlated with better performance on the examination.

Conclusion. These findings suggest knowledge of future access to recorded lectures did not enhance the ability of participants to remember other information and therefore, may not free-up cognitive resources that could be used for other tasks within the classroom.

Keywords: recorded classes, cognitive off-loading, desirable difficulties, note-taking, memory

INTRODUCTION

Imagine the following scenario. Wendy's significant other gives her a written grocery list of 10 items to pick up on the way home. On the way to the grocery store, Wendy receives a call from her significant other asking her to run five additional errands. Across town, Stefanie's significant other calls her and verbally asks her to pick up 10 items from the grocery store on the way home. Stefanie keeps rehearsing this list in her head so she will not forget it. On the way to the store, Stefanie receives a second call from her significant other asking her to run five additional errands. Who is more likely to remember the five errands they are supposed to run, Wendy or Stefanie? One might guess Wendy because all she had to do was memorize the five errands. Her grocery list was already written down, so she did not have to devote any mental effort to remembering it.

This is an example of the benefits of cognitive off-loading, ie, using external storage (in this case a written shopping list) to free up cognitive resources which can then be used for future events such as remembering other information. Related to cognitive off-loading is saving-enhanced memory, or the consequences of saving certain information on one's ability to learn and remember other information. In pharmacy education courses, digitally recorded lectures may serve as a "shopping list," allowing students to externalize information and preserve cognitive resources for future learning events. This was one of the theories explored in the current study. Specifically, if students are aware that lecture recordings will be available, will this knowledge allow them to save their cognitive resources to use towards remembering other material?

Memory formation can be broken down into three processes: encoding, consolidation, and retrieval. The first process, encoding, converts sensory perceptions into meaningful representations within the brain. Within a typical classroom setting, these sensory perceptions could be listening to the instructor during a lecture and viewing

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the PowerPoint slides presented. In addition, as students listen to the instructor, they will be taking notes and trying to process all the information. This later processing, known as consolidation, solidifies information into long-term memory. Retrieval involves accessing the information from long-term storage, reprocessing the information within a new context, and consolidating that new context into long-term memory. Once in long-term memory, forgetting occurs over time but the extent of forgetting may depend on the strength of the initial encoding and learning.¹⁰ Because the initial encoding strength may dictate the rate or extent of forgetting, instructional techniques that focus on deep processing of information (eg, active learning) can be used to strengthen that initial encoding.

During a class session, the simultaneous actions of listening, note-taking, and processing material increase cognitive demands because they divide the listener's attention during encoding, which in turn has negative consequences for memory.^{1,2} These negative consequences may be abated if students can off-load some of the information, allowing them to focus on listening to and comprehending the lecture content.⁷ By storing information externally in to-do lists, calendars, contact lists, and smart devices, students can minimize the mistakes of their own memory.^{3,4} In the classroom, for example, when students are provided with complete notes or slide sets before class and then see and hear the information presented during class, they may retain more information.^{5,6} The reason why offloading may improve learning is because information allows students to focus solely on the lecture content and be more attentive, as well as decrease proactive interference (ie, the difficulty in learning new information because of already existing information in memory).^{3,7-9} Therefore, we postulated that similar benefits would be seen if students knew they would have access to lectures after the class ended for future restudy, ie, providing future access to recorded lectures would be a form of externalizing information which, in turn, would allow students to free up cognitive resources.

Students often prefer to have access to recorded lectures as these recordings serve to externally store information and are available for later access.^{10,11} Many pharmacy and other health professions schools now have lecture capture technology in the classroom. Lecture capture allows professors to record a class and make that recording available online to students almost immediately after the class session has concluded (or whenever they wish to restudy the lecture). While releasing lecture recordings after the class session has logistical advantages and disadvantages, assessing how doing so affects learn-

ing is more difficult. While students favor recorded lectures for a variety of reasons,¹¹ this preference does not always align with the most educationally beneficial results. Thus, the goal of this study is to better understand how recorded lectures influence the learning process.

The first question we addressed was "does knowing that a lecture will be available online for review in the future allow students to prospectively save memory?" Imagine a situation where a student has back-to-back classes and the first class provides lecture notes to students but the second class does not. If students know they have notes from the first class, will they save their mental energy for the later class? In this study, we asked the question, "If students know they have access to externally stored information in the form of recorded lectures, does that allow them to focus more on learning future content?" Storm and Stone found that if participants could save material presented to them first in a list of things to be learned, they performed better when tested on material presented to them later.³ The authors referred to this as "saving-enhanced memory." Based on the results from this study, we theorized that if students knew they would have access to early lecture material in the form of recorded lectures, they would perform better on late lecture material because they have "saving-enhanced memory." We investigated this scenario within a simulated classroom to help eliminate confounding variables.

This study also investigated whether knowledge of access to recorded lectures after class impacted the quantity of notes students took during the class. As we suggested above, listening to a lecture and taking notes at the same time may divide students' attention and decrease their learning. Thus, knowing they have access to recorded lectures may reduce students' need to take notes and thus free cognitive resources for deeper processing of content. However, when students take quality notes, they shift from merely transcribing lecture content (or externalizing the content) to clarifying or elaborating on lecture content for themselves. This elaboration might reflect deeper processing and have positive consequences for memory.^{12,13} As a result, taking fewer notes in class could lead to lower performance. Lower performance was noted in a study examining medical student learning which found that there was an observed correlation between increased video watching and lower performance.¹⁴ As such, note-taking may be an important mediator in learning either by facilitating deeper encoding or dividing attention.

While note-taking is one mediating issue, retention length is another important factor to consider regarding student performance. In this study, participants were

tested on their knowledge immediately after watching a lecture and again after a delay. When studying memory and retention, examining the effects of both immediate and delayed testing is important because improvements in performance resulting from an educational intervention can sometimes be seen in delayed tests rather than immediate tests.²⁰ The delayed test also represents a more realistic classroom setting. Immediate test performance or perceptions of the usefulness of recorded lectures are outcomes that are often studied but have limited utility in a practical setting. For example, cramming (massed study) promotes high performance on immediate tests of memory, but results in much poorer performance for tests of long-term retention.^{15,16} Cramming, or reviewing videos immediately prior to an examination, increases the accessibility (or retrievability) of information. This often allows students to perform better on an immediate test, but that benefit may not persist to a later test because of the lack of deep processing involved. In other words, any benefit from a more difficult encoding situation, such as not having access to lectures, might only appear on a delayed test.

In this study, we addressed two main questions. The first question was does knowing a class is being recorded positively impact students' learning of material presented at a later time (ie, under these circumstances, would students save memory to use for other purposes)? The second question was does knowledge of future access to recorded lectures impact students' note-taking behavior and is this associated with their performance? These two questions were explored in a simulated classroom environment in which participants were told before a lecture whether they would have access to a recording prior to being tested. We examined students' immediate performance, length of notes taken, and delayed performance (one week after the initial lecture).

METHODS

This study was a parallel arm study. Students in arm 1, referred to hereafter as the "access group," were informed that they would have access to recorded lectures of the early material from a simulated classroom environment to restudy before their final assessment at one week. Students in arm 2, referred to hereafter as the "no access group," were instructed that they would not have access to recorded lectures of the early material from a simulated classroom environment for restudy before their final assessment at one week (no access group). This study design consisted of five total phases (Figure 1) and had a 2X2 design: (recording access instructions: access or no access) x (immediate test at 10 minutes or delayed test at one week). Knowledge of recording access was the only be-

Figure 1. Diagram of Study Design. In Phase 1, participants were instructed if they would or would not have access to recordings for restudy. In Phase 2, participants were instructed they would not have future access for restudy. Performance on Phase 2 content was the primary outcome as a function if participants were instructed whether they would have the ability to save earlier content. Phase 1 through 4 occurred within a single, 50-minute class period.

tween subjects variable; all other variables were within subjects. For the note-taking objective, the dependent variables were the number of words and drawings in the notes taken during the lecture (note-taking behavior) and percentage of questions correct on the assessments (test behavior).

An *a priori* sample size calculation was performed based on the previous literature from a controlled laboratory experiment and assumed an effect size of 0.72, alpha of 0.5, and beta of 0.8.³ We determined that the necessary sample size was 32 participants per group. Sample size was calculated using G*Power 3.1 (Universität Kiel, Germany).

Participants for the study were recruited from the UNC Eshelman School of Pharmacy. The study results would be directly impacting future school policies and course design. Students were recruited from all professional classes. In general, each professional year had the same admission criteria. Students were similar in age ($M=22$ years, range 18-51 years) and educational background (86% with a college degree, mean grade point average=3.5, mean Pharmacy College Admission Test score=88%). Students were offered either extra credit in certain courses or a \$25 gift card as an incentive to participate.

As an overview, participants were scheduled in small cohorts depending on participant availability (eg, 5-15 participants at a time) to simulate a classroom environment. An instructor (portrayed by the study investigator) was present at each class session (50-minute period) to provide overall instructions to the participants and manage the lecture videos.

This study had five phases (Figure 1); the first four of these phases occurred during the first of two class sessions. In phase 1, participants were randomized into one of two groups to watch the two video lectures. Half the participants were informed that in one week they would have a chance to review the first two lecture videos; the other half were told they would not have any future access to the videos. They were instructed to behave as if they were in a real classroom setting. In both settings, participants were given blank paper and a pen for notes. Phase 1 content represented the early content within a lecture (ie, during the first 25-30 minutes of a lecture).

Phase 2 occurred immediately after phase 1 and participants viewed two additional video lectures that were different from the lectures viewed in phase 1. This time, all participants were told they would not have access to the video lectures for later restudy. This content represented the material presented later in a lecture (ie, during the last 30-50 minutes of a lecture). After students finished the final two videos, participants completed a filler task (eg, solving a math puzzle) for approximately 10 minutes. Participants then completed a 40-question assessment on all four videos (described later). Performance on this assessment was the primary outcome for the study.

One week after the first session, all participants returned to the simulated classroom and completed the same assessment as they did on the first study day. There was no restudying of material regardless of condition.

The overall study was outlined above and details of each part follow. Publicly available video lectures were used in the study. The video lectures were independent of pharmacy content to reduce the effect of prior knowledge on study outcomes. Videos were used instead of live lectures to maintain consistency across study days. Each video was 10-12 minutes in length and the content was related to astronomy, physics, or earth science. Eight different videos were used in the study, but each participant only viewed four of these. The lectures watched were counterbalanced, randomized, and blocked across conditions. That is, cohorts studied on different days watched a different set of videos to reduce the effects of content and content difficulty.

Learning was assessed by a test on the content of each of the video lectures watched. Ten questions were created on the content of each of the eight videos, and a

mixture of question types were used to parallel an authentic examination (six short-answer or fill in the blank items, two multiple-choice items, and two true/false items). These questions were knowledge- or concept-based (ie, they tested lower cognitive levels of Bloom's Taxonomy of Learning).

Students completed a filler task in between watching lectures and taking the test in order to better assess long-term memory instead of immediate recall. This material consisted of visuospatial brainteasers (eg, Sudoku) or math problems and was administered in paper-and-pencil format.

The primary outcome was immediate recall test performance on the late lecture material (the last two videos watched). Performance on the same, late lecture material during delayed recall (seven days later) was a secondary outcome. We conducted a *t* test for treatment (access or no access) and a paired *t* test for time (immediate test vs delayed test). Pearson correlations were used for the associations between performance and notes.

The *p* value was set at $p < .05$ except for three or more comparisons, for which it was adjusted using the Holm-Bonferroni correction (calculated using SPSS Statistics for Windows, Version 22.0, IBM Corp, Armonk, NY). This study was approved by the University of North Carolina Institutional Review Board.

RESULTS

Seventy-eight participants completed the study, with 39 participants randomly assigned to the access group and 39 to the no access group (Table 1). Each group was balanced except the no access group had more third year students.

There was no difference in performance between the access and no access group ($d = .17$, $p = .47$), suggesting there is no beneficial effect on memory when learners know they have access to offloaded information in the form of a recorded lecture (Table 2). This lack of difference was also noted during delayed recall (ie, one-week retention interval) ($d = .05$, $p = .83$). For the late lecture content, both the access group ($d = .62$, $p < .001$) and the no access group ($d = .48$, $p < .001$) showed a significant decrease in test performance over time (Table 2).

One potential mediating factor for retention of learned material was note-taking behavior. Whether the participants were told they would or would not have access to recorded lectures was associated with the quantity of notes they took (Table 3). The access group wrote longer notes and made more diagrams than the no access group did (Table 3).

Correlation analysis revealed a moderate association between note quantity and performance by condition (Table 3). Compared to the access condition, participants

Table 1. Summary of Participants (N=78). Self-reported physics knowledge was collected because the lecture videos had physics and astronomy content

Characteristic		Total, No.	Access Group, No.	No Access Group, No.
Sex	Male	23	11	12
	Female	55	27	28
Year	First	66	35	31
	Second	6	4	2
	Third	6	0	6*
	Total	78	39	39
Self-reported Physics Knowledge	Minimal	48	23	25
	Moderate	26	13	13
	Good	4	3	1

$p < .05$, Fisher Exact Test

with no access had a lower association between notes ($d=0.98$ vs $d=0.49$), diagrams, ($d=1.2$ vs $d=.45$), and performance during immediate recall. These effects were more pronounced during delayed recall, with the no access group having smaller effects for notes and performance ($d=.63$ vs $d=.10$) and diagrams and performance ($d=.82$ vs $d=.28$).

DISCUSSION

This study investigated the impact of access to recorded lectures on pharmacy students' preservation of memory and its effects on later class material (ie, material in phase 2). When participants were told they would have access to recorded lectures, there was no significant effect for the preservation of memory in terms of enhanced performance on learning later course material. However, the current study was powered to detect moderate to large differences. Thus, it is possible that smaller effects exist, but it is unclear whether these effects would be educationally significant. Within a classroom setting, this finding would suggest there is no beneficial effect to learners knowing they have access to recorded class sessions in a lecture-based environment.

Prior laboratory-based studies found large effects on learning when information could be stored externally.³ One possible reason there was not a larger effect in the

current investigation is that the participants within the study were accustomed to having large amounts of information presented to them and successfully remembering that information. Student pharmacists are often in classes for several hours a day and have shown they can perform well in this environment. Therefore, not surprisingly, when the participants were exposed to novel content (ie, astronomy and astrophysics), they performed well as evidenced by the relatively high average scores on the initial tests. The late lecture content served as the primary outcome because a preservation of memory would impact performance primarily on this set of material. Because there was no difference in performance between the two groups, our hypothesis that learning would be enhanced by the ability to offload information was rejected. If higher memory loads had been placed on the students, there may have been noticeable effects. These higher memory loads may be the result of longer class periods, more dense lectures, more complex material, or possibly, active-learning assignments.

Remarkably, participants who were assured they would have future access to externally stored early lecture material wrote more notes than participants who were told they would not have future access to that same material. We had hypothesized that students having access to recorded lectures would free up cognitive resources and reduce note-taking. However, for late lecture material, neither group had access to future recordings, thus we did not expect any differences in note taking. Despite this, those students reallocated their efforts into more note-taking for the later lecture material. Conversely, the findings also suggest that participants without access to externally stored information invested their attention and cognitive resources to processing information rather than externalizing the information in note form. It is unclear why participants with access to externally stored information took more notes on the late lecture material, but it may have been related to changes in metacognition during

Table 2. Summary of Quiz Scores for Each Time (Immediate Recall at 10 minutes vs Delayed Recall at 1-week Post Lecture), and Participant's Instructions on Access to Recordings for Re-study (Access vs No Access). Data presented as mean and standard deviation

Condition	Immediate Recall, % Correct	Delayed Recall % Correct
Access (n=39)	60 (16)	49 (19) ^a
No access (n=39)	57 (18)	48 (19) ^a

^a $p < .001$ vs 10 minute (paired t test)

Table 3. Summary of Note Characteristics Based on Access to Recorded Videos. Summary includes number of words written and number of diagrams within the notes. Data shown for each group (Access vs No Access) and at each testing point (Immediate recall at 10 minutes after lecture and at 1-week after lecture)

Metric	10-min		1-week	
	Access Group	No Access Group	Access Group	No Access Group
Word count (SD)	106 (50) ^a	35 (46)	—	—
Diagram count (SD)	1.5 (1.9) ^a	0.6 (1.1)	—	—
With notes, No. (%)	39 (100) ^a	19 (49)	—	—
With diagrams, No. (%)	19 (51)	10 (26)	—	—
Note to quiz correlation	r=.44 ^b	r=.24	r=.30	r=.05
Diagram to quiz correlation	r=.51 ^b	r=.22	r=.38 ^b	r=.14

^a $p < .05$ vs No Access (t test or chi square)

^b $p < .05$ for the correlation

cognitive offloading.^{9,17} For example, one study showed participants were more likely to take notes when they anticipated they would have more things to remember despite no differences in accuracy as measured by test performance.¹⁸ This is similar to the labor-in-vain effect where increasing effort does not lead to increased performance.¹⁹ Another potential explanation is motivation and gender.²⁰ In one study, results indicated that female students recorded significantly more information in notes than male students did and performed significantly better on measures of handwriting speed, working memory, language comprehension, and conscientiousness.¹⁸ Within the current study, each group was balanced in terms of participants' gender but it does not rule out differences between genders in hand-writing speed, working memory, or personality. Regardless, the differences in note-taking in this study did appear to impact students' performance on the examination and therefore, their retention of information.

One of the strengths of this study is that it assessed the impact of knowledge of access to recorded lectures by using a simulated classroom environment with novel lecture content. An additional strength was that participant learning was assessed through a variety of question types, both immediately after watching a video lecture and one week later. A potential limitation of this study was that the simulated lecture-style classroom may not have accurately represented a professional curriculum, ie, face-to-face instruction, active learning, longer class times, or the repeated demands on students' memory. Further investigations in authentic environments with potentially higher cognitive demands are needed. Another possible downside was that the videos did not include explicit learning objectives, nor were learning objectives provided to the students. The videos generally had overviews of what would be presented later in the video. While students

not having explicit learning outcomes would not have impacted the overall results, it could have impacted test performance or note taking behaviors provided students followed the learning objectives as guides for note-taking or studying for an examination. Students were not provided links to the videos but they were searchable and attainable on the web. Thus, we could not rule out the possibility that students reviewed the lectures on their own prior to taking the examination. However, this was unlikely given that most of the students found very little interest in the videos. Finally, each participant took the immediate test and this test could have strengthened memory through the testing effect.^{21,22} If the immediate test had not been completed as part of the study, differences may have been seen in students' performance on the delayed test.

This study provokes some intriguing questions. First, what would be the impact of using pharmacy content in a similar scenario? In this study we used non-pharmacy content to minimize the impact of prior knowledge. Using pharmacy content could increase students' motivation to learn, which in turn may impact memory. To study this effect, it may be important to limit subjects to a certain academic year so that the content included could be future material rather than content they had already covered. For example, limiting the subject pool to first-year Doctor of Pharmacy (PharmD) students who are taking mostly foundational science courses would allow investigators to use pharmacotherapy content that occurs during the second or third year. Alternatively, investigators could use future course content and study the impact in earlier sections of the course. Second, how would this impact change in an authentic class setting? With the use of a more realistic classroom setting, such as active learning, longer class periods, denser content, and use of laptops to take notes, the results could differ. In this situation, it

would be important to minimize content effects to study the impact of having access to recorded lectures. In addition, the use of laptops to take notes versus hand-written notes may be influential as typing notes may lead to transcribing and may take less cognitive demand than hand-written notes.²³ This study could be extended to look at back-to-back classes in which the instructor in one course records and releases lectures while the instructor in the subsequent course does not. In such a scenario, if the cognitive off-loading theory held true, students would do better in the latter course. To further extend this idea, does the idea of cognitive off-loading impact pre-class preparation. If students are studying from video to learn the foundational content, does this have the same consequences on memory as it would have in class?

CONCLUSION

Allowing students access to recorded lectures after class does not appear to preserve cognitive resources and does not result in better performance on late lecture material. Therefore, offloading of information does not seem to conserve memory in this setting. However, having access to recorded lectures resulted in students taking more notes. Although smaller effects may have existed between groups that were not detected by this study, the significance of such effects is unclear. There is no clear advantage or disadvantage to students of having access to recorded lectures in terms of test performance or retention of learning, a concept which is often debated among pharmacy school administrators. Further work is needed to examine the impact of recorded lectures on learning and to help inform instructors on the context in which recorded lectures benefit or hinder student learning.

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