ABSTRACT

Introduction
An increasing number of courses within health science education allow students to access recorded lectures after class. The ability to save information, such as recorded lectures, could have benefits on students’ cognitive load. If cognitive load can be preserved during class, it may have learning benefits. However, knowledge of access to saved information may also reduce note taking, which can be important in the learning and encoding process. This study aims to elucidate the impact of access to recorded lectures on cognitive load and performance during restudy.

Methods
Seventy-eight participants were recruited and divided into two groups: access to recorded lecture and no access to recorded lecture. Participants viewed four lectures. For the first two lectures (i.e. the early lecture material), they were told whether they would or would not have access to the recorded lectures prior to their test one week later. They then watched an additional two videos (i.e. the late lecture material), for which they were told they would not have access to in the future. They were tested on all four lectures immediately after watching the videos and then tested again one week later. The primary outcome was test performance on the material contained in the second set of lectures following immediate testing. It was hypothesized that if participants were granted access to recordings of the early lecture material, they would have more cognitive resources (i.e. memory, attention) to devote to the late lecture material, resulting in better test performance on the content from the second set of videos.

Results
Performance did not differ when participants were told they have access to the lecture material. One week later, rewatching videos did improve performance (d=0.7). Participants in the no access condition forgot less information (d=0.42) over time compared to the access group (d=0.53) even though the access group wrote more notes.

Discussion
These finding suggest that there is no preservation of cognitive load when learners have knowledge of recorded lectures. Although test performance did not differ between the groups, the Access group had larger effect sizes for loss of material, suggesting that when participants knew they would not have access, they engaged in a stronger encoding during the learning phase. Participants who had diagrams in their notes performed better overall.
Introduction

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 lecture. In addition, students often listen to the instructor while taking notes on the subject and trying to process all of the information. This later processing, called consolidation, solidifies information into long-term memory. The simultaneous listening, note taking, and processing of material increases cognitive demands because it divides attention during encoding, which in turn has negative consequences for memory. 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. This off-loading can be in the form of granting students access to post-lecture recordings, which can reduce the amount of note taking and reallocate students’ cognitive effort and attention to consolidating the information presented to them. Additionally, the ability to off-load information could hypothetically reduce the difficulty in learning new information because of already existing information, otherwise known as proactive interference. This increase in attentional focus and reduction in proactive interference should have positive consequences on memory. These positive consequences have been seen when students are provided complete notes or slide sets both before and during class. In other words, offloading information (eg, students having complete note sets or saved PowerPoint slides) can help with memory by allowing students to focus solely on the lecture content and be more attentive. Reallocation of cognitive resources, such as memory, attention, and effort, can help students to better remember the content at hand, while other information is stored externally. Therefore, we postulate similar beneficial effects may be seen if students know they will have access to post-class lectures.

One reason that students prefer access to recorded lectures after class is that recorded lectures serve to externally store information and are available for later access. Pharmacy and other health profession schools often integrate new technologies into the classroom and one of these technologies has been lecture capture. Lecture capture allows one to record a class and make that recording available to students after class. Releasing recordings after the class session has its advantages and disadvantages, but it is difficult to assess how allowing students access to recorded lectures impacts their learning. Students favor recorded lectures for a variety of reasons, although this preference does not always align with the most educationally beneficial methods.

This study aimed to explore the impact of access to recorded lectures on learning within a classroom situation. In other words, 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 and processing the information at hand. Individuals externally store thoughts and memories regularly through ‘to do’ lists, calendars, contact lists, and smart devices. By storing information externally, we can minimize the mistakes of our own memory. Theoretically, if the instructional environment allows students to use a physical action (eg, saving the instructor’s PowerPoint© slides or having access to complete note sets) to off-load information, this can alter the information processing requirements of a task and can reduce the overall cognitive demand for students. The learner’s saved cognitive energy can then be reallocated for other tasks such as engaging in class activities and devoting more attention to novel course material, allowing for deeper processing of the information. This physical action or externalization of memory (eg, the making of a ‘to do’ list) is referred to as cognitive offloading. For example, Storm and Stone found that if participants could save material earlier in a list of things to be learned, they performed better on the later material. Based off this study, we expect students to perform...
better on late lecture material (i.e., material towards the end of class) if they are aware that the early lecture material will be recorded and available for later use.

This study also serves to investigate whether knowledge of access to recorded lectures impacts the quantity of notes taken during the learning period. While access to recorded lectures may free cognitive resources for deeper processing of content, recorded lecture availability may also change the process underlying note taking. When participants take notes, participants shift from merely transcribing the content to clarifying or elaborating on lecture content. This elaboration might reflect deeper processing and have positive consequences for memory.\textsuperscript{10,11} From this perspective, positive consequences may come from note taking because it reflects deeper processing. Therefore, note taking may be an important mediator in learning.

While note taking is one mediating factor, retention length is another important factor to consider. We tested participants on their knowledge immediately and after a delay. When studying memory and retention, it is important to examine both immediate and delayed testing because improvements in performance due to an educational intervention can sometimes be seen in delayed tests rather than immediate tests.\textsuperscript{19} 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.\textsuperscript{13,14} Cramming, or reviewing videos immediately prior to an exam, increases the accessibility 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 summary, the purpose of this study is to investigate if knowledge of future access to recorded lectures serves to enhance students’ ability to learn other information. We hypothesize that if learners know they will have access to the early lecture material in the future, they should perform better on the late lecture material as a result of having more attention to devote to that content.

**METHODS**

An *apriori* 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.\textsuperscript{5} The needed sample size was 32 participants per group (G*Power 3.1, Universität Kiel, Germany). Participants were recruited from the School of Pharmacy and were offered either extra credit in certain courses or a $25 gift card. Participants were recruited from all professional classes. In general, each professional year has the same admissions criteria. Student pharmacists were similar in age (M = 22, range 18 – 51) and educational background (86% with a college degree, mean GPA = 3.5, mean Pharmacy College Admission Test score = 88%).

Lectures were emulated with publicly available video lectures. The video lectures were independent of pharmacy content in order to reduce the effect of prior knowledge on study outcomes. Each video was 10-12 minutes in length and the content related to astronomy (\textit{Crash Course on Astronomy} series (YouTube®)), physics, or earth science. A total of eight videos were used in the study but each participant only viewed four of these. The lectures watched were counterbalanced across conditions to reduce any content related effects (e.g., easier or harder content areas).
Learning was assessed through a test on each of the video lectures watched. Each video was tested with 10 questions with a mixture of question types to parallel authentic exams (6 short-answer or fill in the blank, 2 multiple-choice, and 2 true/false). These questions were either knowledge or concept based (i.e., lower levels of Bloom’s Cognitive Taxonomy).

The study was a parallel arm study with the conditions being (1) students instructed they will have access to recorded lectures of the early lecture material (i.e. the first two lectures watched) to restudy before their final assessment at 1 week (Access Group); (2) students instructed they would not have access to recorded lectures of the early lecture material for restudy before their final assessment at 1 week (No Access Group). This study design consisted of 6 total phases (Figure 1) and was a 2 (Recording Access: Access or No Access) x 2 (Time: immediate test at 10 minutes or delayed test at 1 week) design. Access to recorded lectures was the only between subjects’ variable; all other variables were within-subjects. The dependent variables were the number of words and diagrams in the notes taken during the lecture (note-taking behavior) and percentage of questions correct on the assessments (test behavior).

In Phase I, participants were randomized to watch two lectures and received their instructions. Half the participants were informed that in 1 week they would have a chance to review the early lecture videos (i.e., the first two lectures) and the other half were told they would not have access. They were instructed to behave as if they were in a real classroom setting. For each lecture, participants had blank paper and a pen for notes. Phase 1 content represents the early content within a lecture (i.e., first 25-30 minutes of a lecture).

Phase II was similar to Phase I, but with two additional, different videos. All participants were instructed they would not have access to these videos for later re-study. This content represents the late material within the lecture (i.e., 30-50 minutes of lecture). Performance on this content was the primary outcome for the study.

Phase III consisted of each group completing a filler task for approximately 10 minutes. Phase IV consisted of a 40-question assessment on all 4 lectures. However, the primary outcome was test performance on the questions on content from the later two videos only. Phase V and VI occurred 1 week after the initial lecture. Participants were randomized to review one of the two videos they had watched initially. After participants restudied the lecture content, they were given a filler-task, just as they were earlier and then took the same assessment as before on all four videos.

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 (7 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. A secondary outcome was performance on lecture 1-4 (early lecture content) with and without review conditions. We conducted a paired t-test for review condition at 1 week (Review or No Review) and to assess changes over time (i.e., 10-minute delay vs. 1-week delay). An additional secondary outcome was the cost-effect analysis with cost being the additional time to restudy the video and effect being the learning gains or deficits (delayed recall – immediate recall).

Multiple linear regression was performed to examine the impact of lecture behavior on performance. Predictor variables were centered prior to analysis and a Stepwise approach was used. The p-value was set at p<0.05 except for 3 or more comparisons, for which it was
adjusted using the Holm-Bonferroni correction (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp). This study was approved by the University of North Carolina Institutional Review Board.

RESULTS

A total of 78 participants completed the study with 39 participants in each group. In this study, we attempted to determine whether external storage of certain information, such as the ability to access recorded lectures, allowed students to conserve memory for other information. There was no difference in performance between the Access and No Access group, (d=0.17, p=0.47) suggesting there is no beneficial effect on memory when a learner knows he/she will have access to offloaded information in the form of a recorded lecture (Table 2). This lack of difference was also noted during delayed recall (i.e., 1-week retention interval) (d=0.05, p=0.83). However, for this late lecture content, both the Access group (d=0.62, p<0.001) and the No Access group (d=0.48, p<0.001) showed a significant decrease in test performance over time (Table 2).

We also examined performance on the early lecture material (first two videos) in order to assess the implications of students having knowledge of future access (or no access). At the 10-minute retention interval, the Access and No Access group demonstrated no significant difference (d=0.13, p=0.452).

Re-watching lectures helped students learning performance. Participants watched one of the two early lecture videos prior to their test at the 1-week retention interval. Within both Access and No Access groups, reviewing the video improved performance (d= 0.72, p<0.001; d=0.73, p<0.001, respectively) (Figure 2). When videos were not re-watched, both groups had significant decrease in performance over time (d=0.42)(p<0.001; d=0.53, p<0.001) (Figure 2). In other words, participants forgot material under all conditions except for when they re-watched the video prior to the final examination. Based on effect size differences, there is some indication the No Access group gained less by re-watching (d=0.41 vs. d=0.34) and lost less knowledge over time (d=053 vs d=0.42).

One potential mediating factor of retention of learned material is note-taking behavior. Participant’s access to recorded lectures was associated with note-taking quantity (Table 3). The Access group also wrote longer notes and made more diagrams when compared to the No Access group (Table 3). Correlation analysis reveals a moderate association between note quantity and performance by condition (Table 3). Compared to the Access condition, participants 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=0.10) and diagrams (d = .82 vs. d=.28) and performance.

DISCUSSION

This study investigated the impact of access to recorded lectures on the preservation of memory in a classroom setting. When participants were told they would have access to recorded lectures, there was no significant effect for the preservation of memory or cognitive load 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 of learners knowing they have access to recorded class sessions in a lecture-based environment. This also may apply to engaged classrooms (eg, active learning or flipped class), in which students are involved in higher-order learning that often requires more cognitive resources.

Prior laboratory-based studies found large effects on learning when information could be stored externally.9 One possible reason there was not a larger effect in the current investigation is that the participants within the study are 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 in a lecture style class and have shown they can perform well in this environment. Therefore, it is not surprising that when the participants were exposed to novel content (astronomy and astrophysics), they performed well, as displayed 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. Since there was no difference in performance between the two groups, our hypothesis that learning would be enhanced with the ability to offload information was rejected. It is possible that if higher memory loads were placed on the students, there may be noticeable effects (eg, longer class periods, more dense lectures, etc.).

As one would expect, there was a statistical difference when students had a chance to review the video before their final assessment. Medical students state that one of the reasons they review lectures is that through reviewing lectures, they can reinforce concepts and fill in gaps in their comprehension.1, 2 Further research is necessary in order to determine if re-watching a video differs than other approaches such as restudying from notes or taking a practice test. However, there may be some differences in the magnitude of effect that re-watching videos has if students know they would have future access. Based on a cost-effect analysis (Figure 3), spending time to re-watch an entire class over again resulted in increasing performance by 25% compared to no restudy; other study strategies can be compared to re-watching lectures by considering time investment and outcome, especially for measures of long-term retention.

Regarding the early lecture content where the instructions had direct implications (i.e., they would or would not have access to these videos), participant performance did not differ between the Access and No Access groups. There was, however, some indication that the Access group had larger effect sizes for loss of material. This finding may suggest that when participants knew they would not have access, they engaged in a stronger encoding during the learning phase.

Participants who had diagrams in their notes, potentially representing deeper processing, performed better overall, but this was especially impactful for the participants that were instructed they would not have access to recorded lectures.

It is remarkable that participants with access to externally stored information (i.e., lecture recordings) took more notes than the group without access to externally stored information. We hypothesized that having access to recorded lectures would free up cognitive resources and reduce note taking. However, despite having the ability to offload information, those students reallocated their efforts into more note-taking. Conversely, the findings also suggests that participants without access to externally stored information invested their attentional 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 would take more notes, but it may be related to changes in metacognition during cognitive offloading.5,15 For example, one study showed participants were more likely to take notes when they anticipated more things to remember despite no differences in accuracy 16. Another potential explanation is motivation and gender.17 In one study, results indicated that females recorded significantly more
information in notes than males and performed significantly better on measures of handwriting speed, working memory, language comprehension, and conscientiousness.\textsuperscript{17} Within the current study each group was balanced in gender but it does not rule out hand-writing speed, working memory, or personality. Regardless, the differences in note taking in this study did appear to impact performance or retention.

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. Another strength is that learning was assessed through a variety of question types, both immediately and after a one-week delay. A potential downside is that simulated lecture style classroom may not accurately represent the true nature of a professional curriculum: face-to-face instruction, active learning, or the repeated demands on memory. Further investigations are needed in authentic environments with potentially higher cognitive demands. With the use of more realistic aspects of a 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 access to recorded lectures. In addition, the use of laptops to take notes versus hand-written notes may be influential, since typing notes may lead to transcribing and may take less cognitive demand than hand written notes.\textsuperscript{18}

However, some of the trends and findings of this study do reflect what is observed in the classroom. For example, the knowledge of access to recorded lectures resulted in poorer performance on long-term retention, consistent with classroom studies that have found students who access recordings more frequently perform poorer on exams.\textsuperscript{12} Also, when participants knew they had later access, there was a small effect increase in performance on later lecture material, suggesting there may have been more cognitive space to be used in more engaged learning or mind-wandering; the latter has been noted in the literature.\textsuperscript{5,20}

**Conclusion**

Allowing students access to recorded lectures after class does not appear to preserve cognitive resources for students during class. The offloading of certain information in the form of recorded lectures did not result in improved learning performance on other information for students. Having access to recorded lectures does, however, impact note-taking behavior and results in students taking more notes. Although it remains possible that smaller effects exist between groups and were not detected by this study, the significance of these effects is unclear. There is no clear advantage or disadvantage of students having access to recorded lectures in terms of test performance or retention of learning. There is some indication that not having access to recorded lectures resulted in a stronger memory trace with less decline over time. Finally, re-watching lectures improved exam performance but it is unclear if other study methods would be more or less helpful.
Table 1. Participant Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Access</th>
<th>No Access</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>23</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td><strong>Year</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>66</td>
<td>35</td>
<td>31</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>6</td>
<td>0</td>
<td>6*</td>
</tr>
<tr>
<td>Total</td>
<td>78</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td><strong>Self-reported Physics Knowledge</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Minimal</td>
<td>48</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>Moderate</td>
<td>26</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Good</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

*p<0.05 (Fisher Exact Test)*
TABLE 2: Summary of quiz scores for each time (Immediate recall at 10 min vs. delayed recall at 1 week), timing of delivery of content (early vs late lecture), participant's instructions on access to recordings for re-study (Access vs No Access) and whether the early lecture material was reviewed on re-study at 1 week (Yes or No).

<table>
<thead>
<tr>
<th>Lecture Content</th>
<th>Reviewed</th>
<th>10 minutes</th>
<th>1-week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Access</td>
<td>No Access</td>
<td>Access</td>
</tr>
<tr>
<td>Early (n=39)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>.57 (.14)</td>
<td>.55 (.17)</td>
<td>---</td>
</tr>
<tr>
<td>Yes</td>
<td>.55 (.21)</td>
<td>.55 (.23)</td>
<td>.64 (.22) a,c</td>
</tr>
<tr>
<td>No</td>
<td>.60 (.21)</td>
<td>.55 (.20)</td>
<td>.48 (.24) a</td>
</tr>
<tr>
<td>Late (n=39)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>.60 (.16)</td>
<td>.57 (.18)</td>
<td>.49 (.19) a</td>
</tr>
</tbody>
</table>

a p<0.001 vs 10 minute  
b p<0.05 vs 10 minute  
c p<0.001 vs Not Reviewed
TABLE 3: Summary of note characteristics based on access to recorded videos and position in lecture.

<table>
<thead>
<tr>
<th>Count</th>
<th>10-min Access</th>
<th>10-min No Access</th>
<th>1-week Access</th>
<th>1-week No Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word Count (SD)</td>
<td>106 (50) a</td>
<td>35 (46)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Diagram Count (SD)</td>
<td>1.5 (1.9) a</td>
<td>0.6 (1.1)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td># with Notes (%)</td>
<td>39 (100%) a</td>
<td>19 (49%)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td># with Diagrams (%)</td>
<td>19 (51%)</td>
<td>10 (26%)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Note to Quiz correlation</td>
<td>r=.44 c</td>
<td>r=.24</td>
<td>r=.30</td>
<td>r=.050</td>
</tr>
<tr>
<td>Diagram to Quiz correlation</td>
<td>r=.51 c</td>
<td>r=.22</td>
<td>r=.38 c</td>
<td>r=.14</td>
</tr>
</tbody>
</table>

a p<0.05 vs. No Access (t-test or Chi Square)
c p<0.05 for the correlation
FIGURE 1: Diagram of study design

Access (Experimental)
Lecture 1&2 (12-15 min each)

No Access (control)
Lecture 1&2 (12-15 min each)

Phase 1
25-30 minutes

Phase 2
25-30 minutes

Phase 3

Phase 4

Phase 5

1 week

Phase 6

Lecture

Filler Task

Test

Lecture 1 Restudied

Filler Task

Lecture 2 Not Restudied

Test
FIGURE 2: Impact of retention time (10 min or 1 week) and review (Review vs No Review) for (A) Access only; (B) No Access Only; (C) Confidence intervals for the effect sizes related to the time (10-minute vs 1-week)

A) Access Only

B) No Access Only

C) Confidence intervals for the effect sizes for time-effects
Figure 3. Cost-effect relationship between time spent re-watching and gain in performance.
References