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The Interrupted Learner: How Distractions during Live and Video Lectures Influence Learning Outcomes

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New instructional technologies have been increasingly incorporated into the medical school learning environment, including lecture video recordings as a substitute for live lecture attendance. The literature presents varying conclusions regarding how this alternative experience impacts students' academic success. Previously, a multi-year study of the first-year medical histology component at the University of Michigan found that live lecture attendance was positively correlated with learning success, while lecture video use was negatively correlated. Here, three cohorts of first-year medical students ($N = 439$ respondents, 86.6% response rate) were surveyed in greater detail regarding lecture attendance and video usage, focusing on study behaviors that may influence histology learning outcomes. Students who reported always attending lectures or viewing lecture videos had higher average histology scores than students who employed an inconsistent strategy (i.e., mixing live attendance and video lectures). Several behaviors were negatively associated with histology performance. Students who engaged in "non-lecture activities" (e.g., social media use), students who reported being interrupted while watching the lecture video, or feeling sleepy/losing focus had lower scores than their counterparts not engaging in these behaviors. This study suggests that interruptions and distractions during medical learning activities—whether live or recorded—can have an important impact on learning outcomes. Anat Sci Educ 11: 366–376. © 2017 American Association of Anatomists.

Key words: histology education; medical education; undergraduate education; study behaviors; interruptions; technology; lecture attendance; lecture videos; e-learning; self-directed learning

INTRODUCTION

The medical school classroom has ceased to be the major location where pre-clinical instruction takes place. At many institutions, students are taking advantage of the ability to view video podcasts of lectures remotely in lieu of live lecture attendance (Cardall et al., 2008; Lovell and Plantegenest, 2009; Traphagan et al., 2010). While convenience is a benefit to students, questions remain whether video-based lecture viewing affords students the same quality of education as in-person teaching, and if live lectures and active interactions with faculty hold the same value as they once did when fewer non-classroom learning modalities existed. At the University of Michigan Medical School (UMMS), students expressed strong preference for electronic learning resources over more traditional forms of instruction like live lectures (Holaday

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et al., 2013). However, literature reports on learning outcomes associated with various modes of lecture instruction present contradictory findings (Cook et al., 2008). Several studies have found superior learning success by lecture-goers compared to lecture video-watchers (McNulty et al., 2009; Williams et al., 2012; Ramlogan et al., 2014); others found the opposite (McKinney et al., 2009; Bhatti et al., 2011; Eisen et al., 2015); still others found the two modes of lecture consumption equally effective (Paegle et al., 1980; Solomon et al., 2004; Davis et al., 2008; Bacro et al., 2010; Beale et al., 2014; Vaccani et al., 2016). At UMMS, students' learning performance in medical histology was positively correlated with lecture attendance and negatively correlated with lecture video recording use (Selvig et al., 2015).

Differences in the lecture topic, the importance of the lecture component for the subject, and the quality of delivery may be factors affecting the effectiveness of lectures presented live versus as video podcasts. In addition, these divergent findings may also in part be explained by confounding students' study behaviors, forming the basis for this study. The relationship between the manner of lecture video usage (e.g., accelerated audio speed, concurrent use of the Internet or other distractions, reviewing/supplementing live lecture material) and academic success has not been studied in detail. The propensity of students to "multitask"—engaging in multiple competing activities—when using a computer and multitasking's limitations on learning are well-established (Naveh-Benjamin et al., 2007; Judd and Kennedy, 2011; Lee et al., 2012). Similarly, these behaviors may hinder optimal performance in the setting of e-learning (Lee et al., 2012).

This retrospective study using self-reported data primarily addresses students' learning behaviors in a first-year medical histology component. Histology, also known as microanatomy, by design requires students to employ visual abilities of analyzing and interpreting images (Hamilton et al., 2009; Helle et al., 2010). In this report, the academic performance in histology among lecture-goers was compared with lecture video-watchers while considering specifics related to how each form of content exposure was used. The conclusions from the data presented are aimed at making data-driven recommendations to educators and preclinical medical students regarding both modes of lecture delivery (live lecture and video podcast) and the manner of consumption for optimal educational value.

MATERIALS AND METHODS

Study Population: University of Michigan Medical School Student Body

Each year, approximately 170 students matriculate to the UMMS medical program. Each class includes 10–15 students pursuing the Medical Scientist Training Program (MSTP), an eight-year dual-degree program leading to an M.D./Ph.D. All 507 first-year UMMS students from 2014 to 2016 formed the sampling frame of this study.

Histology Lecture and Laboratory Curriculum

The two-year integrated preclinical curriculum at UMMS features histology in eight organ-system-based sequences from September through March of the first year (M1), with each sequence containing one to five traditional histology lectures and multiple faculty-guided laboratory sessions, typically taking place on the same afternoon as the lectures. In total, the M1 histology component offers 26 hours of lectures and 21 laboratory sessions. Lecture or laboratory attendance is not mandatory or documented.

Laboratory sessions typically last up to three hours. They begin with a 30-minute lecture-style introduction to the relevant virtual slide material, followed by independent or group-based completion of laboratory assignments as laid out by the Michigan Histology website (UMMS, 2017). Histology faculty are available for the duration of laboratory sessions to answer students' questions and to guide them through the assignments. The Michigan Histology website with virtual slides can also be accessed remotely by students to view without faculty guidance (UMMS, 2017). Students attending laboratory sessions have also access to light microscopes with glass slides and poster-size labeled electron micrographs. Lecture slides, laboratory introduction slides, and a collection of electronic review materials created by the UMMS histology faculty are available for download by UMMS students from a password-protected server. Students are encouraged, but not required, to supplement lecture and laboratory material with a histology textbook.

Lecture Video Recording System

At UMMS, all lectures are video-recorded and videos are made available for streaming and download shortly following the lecture hour. The MediaSite playback software, version 7.0.23 (Sonic Foundry Inc., Madison, WI) allows students to view, simultaneously and side-by-side, a high-quality screen capture of the desktop (usually PowerPoint slides), as well as a video feed, directed either toward the lecturer or the projector screen to capture image features indicated by the lecturer's laser pointer. During the lecture, a medical student member of the class manages the equipment and toggles between the camera views and microphone recording of the presenter or the audience. Students have access to the current year's video recordings, but may opt to view the previous year's recordings to stay on pace or ahead of pace with lecture-goers. To the understanding of the authors, those students who do not attend histology lectures typically do not attend the laboratory session, and employ self-directed learning for the laboratory component.

Assessment of Student Knowledge

During the first two years of the four-year M.D. program at UMMS, students are graded on a Satisfactory/Unsatisfactory scale. Satisfactory performance in part requires earning an overall score of at least 75% in longitudinal disciplines throughout the first year, which include histology, gross anatomy, physiology, and biochemistry.

First year medical students at UMMS take weekly online quizzes and an end-of-sequence final examination. Histology multiple-choice questions covering lecture and laboratory session material—with or without an accompanying virtual microscopy slide or other reference image—are interwoven into these weekly assessments. In total, roughly 180 histology questions are administered during the M1 academic year. Cumulative histology scores (i.e., percent correct out of ~180 questions) are used as the primary outcome measure for the

M1 histology component and were used for assessing histology performance in this manuscript.

Survey and Data Collection

At the conclusion of the M1 histology component, a link to an online survey was provided by email to UMMS classes in 2014, 2015, and 2016. The survey items were initially drafted by the histology course director (M.H.). The survey then underwent a careful review and editing process. The involvement of two medical students (A.H.Z. and J.B.R.), who provided significant input as peers of the target audience, was key to this process. Further, a faculty member with significant expertise in survey research methodology (J.A.P.) also contributed to the review and editing process. Participation was voluntary and incentivized by three $70 cash prizes (or four cash prizes if the class response rate exceeded 90%) awarded each year by random drawing from the survey participants. The survey was constructed using the Qualtrics online survey software (Qualtrics, 2017) and consisted of 20 questions, some of which had multiple components (see Supporting Information Material 1).

The first group of survey questions focused on educational background, inquiring if the student worked in a basic science laboratory in the last five years, had any prior experience in histology and/or pathology, was colorblind, or was enrolled in the MSTP program. The second group of survey questions used a five-point Likert scale to assess preferences for live lectures versus video podcasting, and learning or study strategies employed. The third group of survey questions quantified the amount of time students reported studying per lecture hour, group versus individual study behaviors, and perception of histology difficulty. Respondents were also asked if these factors changed from early in the academic year to its conclusion. Finally, the last group of survey questions asked students to reflect on their prioritization of histology in relation to other subjects taught simultaneously in the M1 curriculum, satisfaction with their final histology score, and perceived relevance of histology to their future career. Many of the survey items are not analyzed or further discussed in this manuscript. The original survey is available as Supporting Information Material 1.

Some survey questions (frequency of lecture attendance and video usage) were identical to those assessed in a prior study surveying UMMS M1 classes in 2011–2013 (Selvig et al., 2015), and for those items responses were pooled to form a larger study sample size. Response rates varied by year and ranged from 79.4% to 95.3%. Prior to data analysis, a study contributor (J.A.P), who was not personally involved in teaching the M1 histology component, linked survey responses with the overall cumulative histology examination results and de-identified all responses. The project was exempted by the University of Michigan Institutional Review Board (application number HUM00085761).

Statistical Analysis

Descriptive statistics including percentages, means, and standard deviations were calculated to summarize student response patterns for the survey items (IBM SPSS Statistics, version 19, IBM Corp., Armonk, NY). ANOVA was used to test for difference in group means, to determine whether students grouped by varying survey responses differed in their mean cumulative histology score. To mitigate the increased potential for Type I error inherent in applying multiple statistical tests, a Bonferroni adjustment was applied to post-hoc tests comparing pairs of groups. Multiple linear regression analysis was performed to determine whether the bivariate associations examined with ANOVA persisted after controlling for students' self-reported motivation to learn histology. The threshold for statistical significance was set at 0.05.

RESULTS

Participants

Overall, 439 of 507 first year UMMS students participated in the survey distributed to three M1 classes from 2014 to 2016 (86.6% overall response rate). For several questions analyzing histology lecture attendance and lecture video usage, this data set was pooled with responses from an earlier survey from 2011 to 2013 (Selvig et al., 2015), yielding 888 participants (87.7% overall response rate). Several students did not answer all questions, resulting in different counts for some questions.

Histology Lecture Attendance Patterns

Figure 1 illustrates overall trends in histology live lecture attendance and lecture video usage by curricular year between 2010 and 2016. Reported lecture attendance decreased during the period of this study, with concomitant increases in video podcast usage. Specifically, 69.9% of students reported "always" or "frequently" attending live lectures during the 2010–2011 academic year, compared with only 20.7% of students during the 2015–2016 academic year. The association between survey year and frequency of live lecture attendance was statistically significant (χ^2[20, $N = 888$] = 131.8, $P < 0.001$).

In contrast, histology lecture video usage increased in a complementary pattern: 27.4% of students reported "always" or "frequently" relying on videos for lecture material in the 2010–2011 academic year, compared with 67.4% of students in the 2015–2016 academic year. Similarly, the association between survey year and frequency of watching histology lecture videos was statistically significant (χ^2[20, $N = 888$] = 73.3, $P < 0.001$).

Histology Performance: Lecture Attendance versus Video Usage

Table 1 presents a matrix of histology performance among first-year medical students enrolled during the 2010–2016 academic years stratified by lecture consumption medium ($N = 878$). Frequency of attending lectures in person was associated with histology cumulative examination score (ANOVA F[4, 874] = 8.43, $P < 0.001$), and those who attended "always" had the highest mean score. Frequency of viewing histology lecture videos online was also associated with histology cumulative examination score (ANOVA F[4, 873] = 8.02, $P < 0.001$), but in this case those students who viewed videos online least often had the highest mean score.

The relationship between lecture consumption modality usage and performance as ascertained by ANOVA analysis was curvilinear, as seen in Figure 2. Students "always" attending live lectures outperformed those "never" attending

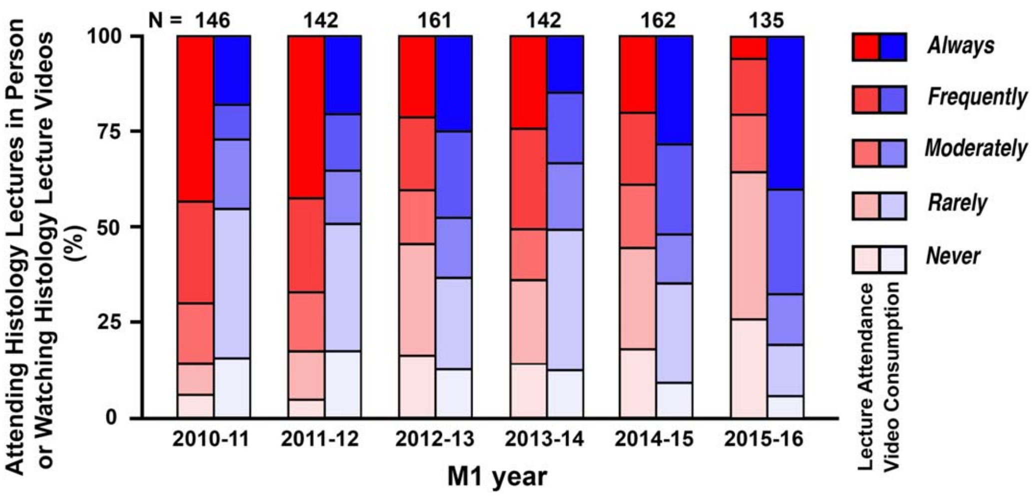

Figure 1.

Live histology lecture attendance (red bars) and histology lecture video usage (blue bars) from 2010 to 2016 annually reported by first-year University of Michigan Medical School (UMMS) students following the completion of each year's histology component, demonstrating a decline in lecture attendance over the observed time period with a concomitant increase in lecture video usage.

live lectures (difference 2.2%, $P < 0.001$), yet the nadir of performance occurred for those attending lectures "moderately." Similarly, students "never" watching video lectures performed better than those "always" watching videos (difference 2.0%, $P = 0.003$), yet the nadir again was for those viewing video lectures "moderately." Generally, students with a more consistent lecture usage strategy, especially those attending lectures in person, performed the best in histology.

In multiple linear regression analysis, these tendencies were confirmed even after statistically controlling for a measure of students' motivation to learn histology. When

Table 1.

Students' Reported Frequency of Attending Live Histology Lectures in Person and Viewing Histology Lecture Videos with Corresponding Average Cumulative Histology Scores

		Viewing Histology Lecture Videos Average of Cumulative Histology Score (±SD) *N*					
		Never	**Rarely**	**Moderately**	**Frequently**	**Always**	**Total**
Attending Histology Lectures in Person	**Never**	89.2 (±5.0) 11	87.7 (±4.5) 10	82.4 (±5.4) 10	87.6 (±4.8) 11	87.7 (±5.4) 79	87.4 (±5.4) 121
	Rarely	93.1 (±1.2) 2	82.5 (±4.6) 12	84.9 (±4.0) 11	86.9 (±5.8) 79	87.7 (±5.7) 98	87.0 (±5.8) 202
	Moderately	86 (±17.3) 3	85.1 (±5.1) 10	87 (±5.1) 51	86.9 (±6.5) 50	86.3 (±6.2) 17	86.7 (±6.1) 131
	Frequently	85.5 (±6.6) 3	88.4 (±5.9) 104	86.8 (±5.1) 50	86.0 (±6.2) 25	87.5 (±6.4) 9	87.6 (±5.8) 191
	Always	90 (±5.2) 89	89.9 (±5.9) 120	85.7 (±5.5) 8	85.1 (±4.8) 5	89.6 (±6.3) 11	89.6 (±5.7) 233
	Total	89.7 (±5.7) 108	88.6 (±6.0) 256	86.3 (±5.1) 130	86.8 (±6.0) 170	87.7 (±5.7) 214	87.8 (±5.8) 878

Data source: six academic years, starting in 2010 and ending in 2016.

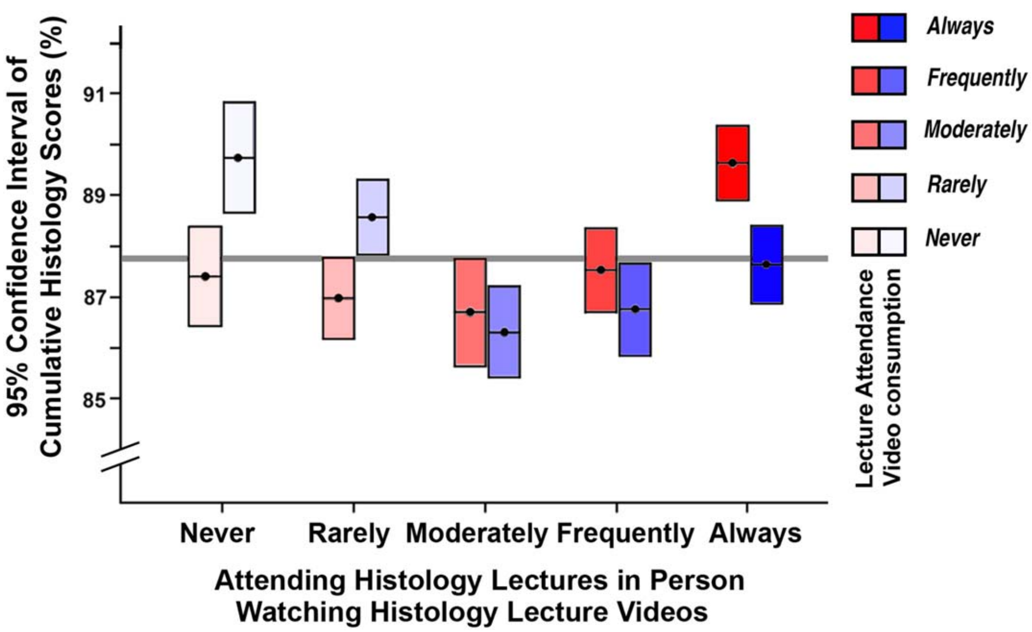

Figure 2.

Cumulative histology course performance stratified by live lecture attendance and lecture video usage from 2010 to 2016 among first-year University of Michigan Medical School (UMMS) medical students. The colored bars indicate the 95% confidence intervals of average cumulative histology performance for live attendees (red bars) and video viewers (blue bars), with the horizontal grey line denoting the average cumulative histology performance for all respondents. Both lecture viewing modalities exhibit a U-shape curve with the histology performance lowest for students "moderately" attending the lecture in person or watching the lecture video.

accounting for students' answers to a question about the relevance of histology to their future career as a physician, a proxy for motivation to learn histology that has been used in other settings (Shin et al., 2017), frequency of lecture attendance continued to show a statistically significant positive association with histology cumulative examination scores (Beta = 0.121, t = 3.64, $P < 0.001$), while frequency of lecture video watching showed a negative association with histology cumulative examination scores (Beta = −0.109, t = −3.27, $P < 0.001$).

Student Behaviors during Live Lectures and Histology Performance

Students were asked detailed questions regarding their behaviors during lecture consumption, ranging from note-taking habits to potential distractors. Table 2 shows the average cumulative histology scores for students with different frequencies of reported behaviors during live lectures from 2013 to 2016. Approximately 30% of students primarily took handwritten paper notes, about 50% of students primarily took notes electronically, and close to 10% of students usually did not take any notes, yet none of these groups significantly differed in their average histology performance.

Students who reported engaging in non-lecture activities using an electronic device during live lectures (e.g., Facebook, email) overall performed worse than their peers who did not; scores decreased monotonically among those "never" engaging in non-lecture activities when compared to those students "always" engaging in these behaviors. Notably, approximately 30% of students "moderately," "frequently," or "always" engaged in non-lecture activities during live lectures. In post-hoc analysis using Bonferroni correction no significant pairwise differences were observed.

Other reported behaviors for which significant negative correlations between groups ($P < 0.05$) were observed on ANOVA analysis were feeling sleepy or losing focus and following the lecture with the slides on a computer/tablet. For the former case, no significant pairwise differences were observed on Bonferroni post-hoc analysis, while in the latter case, "moderately" differed significantly from "never" (difference 4.8%). Otherwise, no significant differences between groups were observed.

Interestingly, watching the lecture video in part or whole again after attending the lecture in person was not associated with an improved histology examination score (Table 2).

Student Behaviors during Lecture Video-Casting and Histology Performance

Students were asked about a range of behaviors during their lecture video podcast usage. Table 3 summarizes the average cumulative histology performance for students with different frequencies of reported behaviors during video-casting for the 2013–2016 academic years, including ANOVA analysis and Bonferroni post-hoc analysis for categories with significant P-values. Several student behaviors showed statistically significant heterogeneity in performance: video-casting in the school's computer laboratory, getting interrupted during

Table 2.

Statistical Analysis of First-year Medical Students' Reported Behaviors when Attending Histology Lectures in Person and Their Corresponding Average Cumulative Histology Scores.

When attending histology lectures in person	Mean (±SD) *N* Never	Rarely	Moderately	Frequently	Always	ANOVA Analysis	Bonferroni Post-Hoc Tests *Alpha* = 0.05
I took handwritten notes on paper	86.8 (±5.6) 241	86.2 (±5.3) 28	87.6 (±5.0) 17	87.1 (±6.3) 22	87.5 (±5.9) 88	$F = 0.42$, $P = 0.795$	n/a
I took notes on my computer/tablet	87.8 (±5.5) 143	87.3 (±5.1) 31	85.8 (±5.2) 33	85.4 (±5.5) 39	86.8 (±5.8) 149	$F = 2.13$, $P = 0.076$	n/a
I did not take any notes	87.0 (±5.7) 308	86.3 (±5.9) 36	84.6 (±4.2) 10	87.6 (±5.6) 19	87.5 (±5.7) 21	$F = 0.66$, $P = 0.618$	n/a
I followed the lecture slides on my computer/tablet	87.8 (±5.7) 138	86.6 (±5.9) 27	83.0 (±6.0) 14	86.1 (±5.0) 33	86.7 (±5.5) 180	$F = 2.73$, $P = 0.029$	Moderately differed significantly from Never
I used my computer/tablet/phone for non-lecture activities (e.g., Facebook, email)	87.8 (±5.4) 151	87.1 (±5.8) 123	86.3 (±5.5) 75	85.0 (±5.1) 34	84.3 (±7.4) 12	$F = 2.73$, $P = 0.029$	No significant pairwise differences
I felt sleepy, fell asleep, or lost focus	87.9 (±5.2) 70	87.8 (±5.6) 143	86.0 (±5.5) 119	86.0 (±6.2) 51	84.9 (±5.8) 10	$F = 2.84$, $P = 0.024$	No significant pairwise differences
I watched the lecture (in part or whole) again on video after attending the lecture in person	87.4 (±5.6) 231	86.8 (±5.3) 98	86.6 (±6.2) 39	86.6 (±6.2) 13	83.1 (±5.1) 13	$F = 2.04$, $P = 0.088$	n/a

Data source: three academic years, starting in 2013 and ending in 2016.

lecture consumption, feeling sleepy/losing focus, engaging in non-lecture activities, and simultaneously using the Internet for clarification. Increased frequency of these behaviors was associated with lower histology performance. For example, students who reported "never" being interrupted while watching the lecture video had a 3.6% higher average score when compared with students who reported they were "frequently" interrupted. In post-hoc analysis, "never" differed significantly from "moderately" and "frequently" in this category.

Likewise, as with live lectures, engaging in non-lecture activities (e.g., Facebook, email, text messaging) while watching lecture videos was a negative predictor of histology performance, with students reporting "never" engaging in these activities scoring an average of 2.2% higher when compared to students who reported to "moderately" engage in these behaviors. In post-hoc analysis, "never" differed significantly from "moderately."

The reported frequencies of behaviors while watching lecture videos that were associated with deleterious histology performance was notable. For example, summing the "moderately," "frequently," and "always" categories together, 41.2% (174/422) of students reported getting interrupted, 43.9% (185/421) reported feeling sleepy or losing focus, and 41.7% (176/422) reported using the Internet simultaneously for concept clarification or additional information.

Influence of Lecture Video Speed on Histology Performance

Students watching the lecture video had an option to select and shift between 0.5x, 1x, 1.4x, 1.6x, and 2x of the speed at which the lecturer spoke in real life. The survey asked students at which speed they "most often" watched histology lecture podcasts. No students reported using 0.5x speed as their preferred video speed, and the most preferred setting used by students was 1.6x (38% of the 424 respondents). ANOVA and Bonferroni post-hoc analyses revealed no significant differences in histology performance for students using different viewing speeds.

DISCUSSION

In this report, the relationship between lecture consumption modality (live vs. video) and histology learning outcomes was investigated in a large cohort of first-year medical students. Several distractors and student behaviors were associated with lower histology performance, both among lecture

Table 3.

Statistical Analysis of First-year Medical Students' Reported Behaviors when Watching Histology Lecture Videos and Their Corresponding Average Cumulative Histology Scores.

	Mean (±SD) N						
When streaming histology lecture videos	**Never**	**Rarely**	**Moderately**	**Frequently**	**Always**	**ANOVA Analysis**	**Bonferroni Post-Hoc Tests *Alpha* = 0.05**
I was in the computer laboratory in school	88.1 (±5.9) 139	87.4 (±5.6) 104	86.0 (±5.4) 90	87.2 (±5.4) 73	84.0 (±5.4) 15	$F = 3.13$, $P = 0.015$	No significant pairwise differences
I was at home	87.2 (±6.1) 43	87.7 (±5.4) 69	87.0 (±5.6) 97	86.7 (±5.4) 141	88.0 (±6.1) 72	$F = 0.89$, $P = 0.472$	n/a
I only watched certain segments of the lecture video	87.3 (±5.7) 296	87.1 (±5.1) 89	85.3 (±6.5) 22	89.8 (±4.8) 11	87.3 (±6.5) 4	$F = 1.23$, $P = 0.296$	n/a
I viewed parts (or all) of the lecture video multiple times	87.8 (±5.7) 142	87.2 (±5.5) 163	86.1 (±6.1) 64	86.3 (±5.5) 35	88.3 (±5.0) 18	$F = 1.35$, $P = 0.252$	n/a
I often got interrupted (by people, messages, etc.)	89.4 (±5.3) 67	87.5 (±5.4) 181	86.1 (±5.6) 110	85.8 (±5.6) 55	86.5 (±7.7) 9	$F = 4.90$, $P = 0.001$	Never differs significantly from Moderately and Frequently
I felt sleepy, fell asleep, or lost focus	88.5 (±5.4) 66	88.2 (±5.4) 170	85.6 (±5.8) 128	85.9 (±4.9) 51	89.1 (±8.3) 6	$F = 5.98$, $P < 0.001$	Never differs significantly from Moderately; Rarely differs significantly from Moderately
I engaged in non-lecture activities (e.g., Facebook, e-mails, texting)	88.3 (±5.3) 83	87.8 (±5.6) 132	86.1 (±5.8) 148	86.4 (±5.3) 48	88.9 (±6.4) 10	$F = 2.96$, $P = 0.02$	Never differs significantly from Moderately
I paused the video to take notes	89.1 (±5.6) 40	86.7 (±5.0) 40	87.4 (±5.9) 116	86.8 (±5.5) 142	87.0 (±5.9) 82	$F = 1.46$, $P = 0.214$	n/a
I simultaneously used the Internet for clarification or more information	88.2 (±5.9) 89	87.9 (±5.3) 157	86.0 (±5.7) 104	86.3 (±5.3) 58	85.2 (±7.1) 14	$F = 3.33$, $P = 0.011$	No significant pairwise differences

Data source: three academic years, starting in 2013 and ending in 2016.

attendees and video watchers. Several of these factors have in common that they represent learning distractions or interruptions. However, as they are independent study behaviors of students, no assumption was made that they are causally linked or correlated.

Declining Lecture Attendance and Increased Video Podcasting

Over the six-year period for which histology lecture consumption at the UMMS was investigated, a clear trend of declining lecture attendance with increasing video podcasting was observed. Similar observations were made at other medical schools after the introduction of a lecture video recording system (Lovell and Plantegenest, 2009; Traphagan et al., 2010). This change in lecture consumption modality by students was largely complementary, with an apparent shift from lecture attendance to video podcasting, with a smaller number of students combining the strategies and very few students ($N = 11$) using neither modality (Table 1). This finding contrasts with several shorter-term studies that found no significant decline of lecture attendance one to two years after the introduction of lecture podcasts (Copley, 2007; Gysbers et al., 2011). From informal observations of lecture attendance for other subjects, the observed switch from attending lectures in person to lecture video podcasts reflects a school-wide rather than a histology-specific trend. Histology lecturer ratings at UMMS are high (above school average for all M1 lecturers) and did not decline over the six-year period and the histology curriculum did not substantively change over the study period, arguing against either factor having a significant influence on histology lecture attendance.

Lecture video-casting provides more scheduling flexibility for students to meet the high demands on their time, while also offering a perceived time savings by viewing lectures at speeds greater than real-time (Cardall et al., 2008). These factors may have led to a student preference for non-scheduled over scheduled learning opportunities (Holaday et al., 2013). Anecdotal information obtained over several years at UMMS indicate that lecture attendance further declines from the M1 to the M2 year, a phenomenon that has been reported by other researchers (Gupta and Saks, 2013).

The described student behavior may also be partially influenced by the pass/fail system of the M1/M2 curriculum at UMMS where most students score well above the requisite passing cut-point of 75% (Hortsch and Mangrulkar, 2015).

Nonlinear Relationship between Lecture Attendance and Performance

Consistent with prior work (Selvig et al., 2015), always attending histology lectures was associated with higher performance by UMMS M1 students (Fig. 2). A "U-shape" curve for performance was observed, with the nadir in performance for students who "moderately" attended lectures. This finding suggests that choosing a consistent strategy (e.g., always attending lecture or watching the lecture video and not changing between the two) may be related to better performance. This parallels the findings in a recent publication by Husmann et al. (2016) who reported that changing study behaviors and strategy negatively correlated with academic performance. Similarly, medical students who change their general study approaches in gross anatomy do not score as well on examinations when compared to students, who use a consistent approach (Ward, 2011). As this study was retrospective and cross-sectional, it is unclear whether the reported observations reflect causal relationships. For example, as attending lectures at a fixed time requires more effort than viewing online videos at leisure, it may be that those who choose to always attend lectures have a more disciplined approach to learning. Likewise, those who "moderately" attended lectures and appeared to score lower than their peers may have had other demands on them that related both to performance and their ability to commit to a consistent learning strategy. Further analysis of the nonlinear relationship observed in this large study is warranted.

Paper and Electronic Note-Taking Strategies Have Similar Performance Outcomes

Note-taking during lectures is an important, cognitively demanding task that can help learners process the lecture material and prepare them for subsequent tests and examinations (Piolat et al., 2005; Kobayashi, 2006). A majority of students attending histology lectures in person took notes using a laptop computer or computer tablet, but no significant difference in histology academic performance was found between students using different note-taking media or not taking notes. This finding contradicts a recent report by Mueller and Oppenheimer (2014) that demonstrated a significant advantage in higher conceptual understanding for students taking longhand written notes compared to students using a laptop for note-taking. However, that study did not analyze note-taking during hour-long academic lectures, but rather for shorter non-science presentations. In addition, the impact of note-taking and note-taking strategies on student performance is lessened at higher academic levels such as medical school (Kobayashi, 2006). The reported findings suggest that medical school histology students should use the note taking approach that appeals to them most.

Accelerated Lecture Video Replay Speed Is Not Associated with Students' Learning Success

In this study, lecture video viewing speed was not associated with differences in academic performance, suggesting that students are able to comprehend histology lecture content at up to double speed without significant negative consequences for their learning success. These findings are consistent with several studies reporting that a moderate (up to 50%) compression of audio or digital video delivery, especially when accompanied by corresponding visual information, has no significant impact on the cognitive load and conceptual understanding of most learners (Ritzhaupt and Barron, 2008; Pastore, 2012; Ritzhaupt et al., 2015). Moreover, many learners appear to prefer a moderately accelerated lecture replay speed (Ritzhaupt et al., 2008), and may feel that accelerated replay increases their efficiency of knowledge acquisition (Cardall et al., 2008). Ritzhaupt and Barron (2008) estimated that a typical learner's ability to comprehend verbal information declines when the presentation speed exceeds 300 words per minute, which is roughly twice the average rate of speech of 150 words per minute (NCVS, 2017). Additional modifying factors, such as the normal verbal speed of the lecturer and whether the lecturer is a native speaker of the language in which the lecture is delivered (Shaw and Molnar, 2011), likely affect learner comprehension.

Distractions and Interruptions Threaten Both Live Lectures and Video-Casting

This study identified several student behaviors that were negatively associated with histology performance. Frequent use of a computer/tablet/phone for non-lecture activities (e.g., Facebook, email) was linked to lower histology performance for both live lecture attendees and those who watched video podcasts. In the study cohort, engaging in non-lecture activities was highly prevalent among both lecture attendees and video viewers. The negative association between overall histology performance and engaging in non-lecture activities, getting interrupted during lecture video consumption, or feeling sleepy/losing focus is consistent with the literature that indicates multitasking and task-switching behaviors are deleterious to content retention (Edwards and Gronlund, 1998; Naveh-Benjamin et al., 2007; Kraushaar and Novak, 2010; Lee et al., 2012), with social technologies like Facebook being particularly harmful (Kirschner and Karpinski, 2010; Junco, 2012; Judd, 2014). The prevalence of these behaviors among medical students was surprising. Use of smartphones for easy access to the Internet, social media apps, and other distractions is likely a broader reality that is unlikely to diminish, and such distractions have been observed in other medical student populations (Judd and Kennedy, 2011). The findings reported in this study suggest that medical education programs and their learning support staff should advise students on the potential negative impact of such distractions and interruptions on their learning performance, and consider interventions to minimize such behaviors.

Lecture video consumption, which can take place in any setting with access to the Internet, provides a less standardized environment compared to live lecture attendance and therefore may be more prone to distractions than a traditional lecture classroom setting. Moreover, when watching a recorded lecture, students are by design connected to the Internet, which may make it more tempting to be distracted online. These factors potentially explain the increased rate of distractions and interruptions reported by video podcast viewers. However, many students probably deliberately choose a low-distraction environment and avoid multitasking activities when watching the lecture videos.

Several potential benefits of video-casting were not borne out in this study. While many students did pause video lectures to take notes—a suggested mechanism for improved learning through self-pacing (Mayer, 2009)—pausing was not associated with improved histology performance. Likewise, the ability to use the Internet during lecture video viewing to clarify or obtain additional information may be a potential benefit of video-casting over live lecture attendance, but was associated with lower histology performance. A possible explanation for this finding may be that such behaviors create disjointed lecture content that support detailed fact learning, but not a general understanding of concepts and connections.

A negative association with viewing videos in the school's computer laboratory was also observed. One explanation may be that students in the school's computer laboratory are more prone to distractions from peers in their immediate vicinity.

Overall, the findings reported in this study suggest that the learning environment and choices made by students have a significant influence on learning outcomes (Gordon et al., 2000; Bierer and Dannefer, 2016), regardless of lecture consumption modality.

Study Limitations

This study was based on student recall of their live lecture attendance and lecture video usage following completion of the M1 histology component, as well as their self-assessed frequency of engaging in various behaviors while studying. The survey did not specify definitions for the categorical scale items (e.g., "moderately" vs. "frequently") and actual attendance at histology lectures was not formally assessed. However, an occasional head count by the histology course director (M.H.) during lectures throughout several academic years showed rough agreement with student-reported attendance. It is also possible that students who scored lower in histology may have been predisposed to justifying their performance with particular lecture behaviors (e.g., engaging in non-lecture activities) that carry a connotation of what might be expected to adversely influence learning.

There were other limitations to the internal validity of this work. First, variables such as students' Medical College Admission Test scores or overall test-taking skills that might have confounded the relationship between observed behaviors and course performance outcomes were unavailable for analysis. Additionally, the differences observed in this study, while statistically significant, represent small effect sizes of a few percentage points, which may not be "clinically" significant at the level of individual students. However, these are significant effects that appear to play an important role at the class level.

It should also be noted that although the findings reported here are broadly applicable to other health sciences programs, the UMMS curriculum and learning environment have unique elements. Specifically, student attitudes regarding lecture attendance may vary depending on mandatory lecture attendance requirements, lecture and video recording quality, and other cultural and professional factors (Johnson et al., 2015). This manuscript only investigates learning outcomes for a medical histology course and care should be used in extrapolating these results to other subjects and student populations. Additionally, one should be cognizant that effective academic advising is best tailored to an individual's learning style (Newble and Entwistle, 1986), and thus caution should be exercised before applying the reported findings to all students without consideration of their specific needs.

CONCLUSIONS

Medical students' histology performance is influenced by many factors (Selvig et al., 2015). Here, several student behaviors while attending live lectures or viewing lecture video podcasts were correlated with histology course performance. Some behaviors, such as engaging in non-lecture activities like Facebook or email, were identified to have deleterious consequences on histology performance, regardless of whether content was consumed live or via video. These findings suggest that while live lectures and recorded video lectures each have their respective advantages and disadvantages, an important factor for student learning outcomes may ultimately depend on individual learners' choices regarding how they use each modality.

Preliminary evidence also suggests that choosing a consistent method for obtaining lecture information (i.e., always attending live lectures or always watching videos) may be associated with improved learning outcomes across multiple subject areas. Consistency in the longitudinal use of various learning modalities may be linked to greater academic success, a premise that will require further validation.

The reported data show a six-year trend at UMMS of switching from high lecture attendance to high video podcast usage in a first-year medical histology component. Other studies (Lovell and Plantegenest, 2009; Traphagan et al., 2010) corroborate a general trend towards increased video podcast usage among students, contributing to calls for new educational models using video-based lectures (Prober and Heath, 2012; Prober and Khan, 2013). The current study provides insight into potential implications of such shifts and thus should be useful to others assessing outcomes and student study strategies. Taken together, these findings highlight the need for continued study of learning outcomes related to live versus video recorded lectures, as well as study behaviors that may enable or threaten students' learning success.

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