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ORIGINAL RESEARCH ARTICLE

Patterns in students' usage of lecture recordings: a cluster analysis of self-report data

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Students' usage of lecture recordings can be characterised by usage frequency, repetitiveness and selectivity in watching, lecture attendance, and social context and location in which students watch the lecture recordings. At the University of Münster (Germany), the lecture recording service was evaluated over three semesters. The data were combined and used for a cluster analysis with the aim of being able to describe the students' distinct usage patterns. The cluster analysis was performed using partitioning around medoids with Gower distance. Five clusters of students were identified, which differed mainly on the amount of lecture recordings watched, whether the lecture recordings were watched completely or partially, whether the recordings were watched once or multiple times, and the number of lectures the students missed. The five clusters are interpreted as representing different ways of utilising lecture recordings. The clustering provides a basis for investigating the usage of lecture recordings in the context of different approaches to learning and learning strategies.

Keywords: lecture recording; lecture capture; approaches to learning; educational technology evaluation; self-regulated learning

Introduction

Lecture recording at universities has become more common (Edwards and Clinton 2018). However, whether lectures should be recorded or not is a controversial topic. Many students want lectures to be recorded (Dolch and Zawacki-Richter 2018) and report that having access to lecture recordings is useful for them (Bacro, Gebregziabher, and Fitzharris 2010). However, lecturers have many concerns about lecture recordings (Newland 2017), for example, that lecture attendance would decrease with the availability of lecture recordings (Draper, Gibbon, and Thomas 2018). Triggered by these controversial positions, many studies have been conducted about the effects of lecture recordings on student attendance and academic performance (see O'Callaghan *et al.* 2017 for a review of the recent literature).

These studies yielded mixed results, both with regard to the effects on lecture attendance and academic performance. For example, Walls *et al.* (2010) reported no

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correlation between using lecture podcasts and attendance, whereas Edwards and Clinton (2018) found a decrease in attendance when lecture recordings were available. Dommeyer (2017) reported that students who had access to lecture recordings had lower absentee rates compared to students who did not have access to such recordings. When the outcome is decrease in attendance, the question remains to what extent other learning resources contributed to the absences. Traphagan, Kucsera, and Kishi (2010), for example, found that the availability of the PowerPoint presentations of a lecture series had a greater negative impact on attendance than the availability of lecture recordings. Thus, whether and under which conditions the use of lecture recordings reduces lecture attendance remained an open question. Similarly, studies investigating the relationship between the use of lecture recordings and academic performance have also yielded mixed results. Some studies demonstrated that students' self-reported (e.g., Gosper *et al.* 2008) as well as their objectively measured academic performance increased when lecture recordings were available (e.g., Whitley-Grassi 2017). In contrast, Williams *et al.* (2016) found no learning gain even for students who attended the lectures and used the lecture recordings.

Actually, the effects of using lecture recordings on academic performance and attendance might be even more heterogeneous, as some studies demonstrated interaction effects. Kalnikaitė and Whittaker (2010), for example, found that students who watched the lecture recordings instead of attending the lecture performed worse than those who attended the live lectures. Traphagan, Kucsera, and Kishi (2010), however, stated that watching the recording of a lecture might nullify the negative effects occurring when students are unable to attend the lecture in the lecture hall. However, Nordmann *et al.* (2018) found that only high-performing students would be able to compensate for the negative effects of missing a lecture by watching its recording. Weaker students only benefit from the supplementary use of lecture recordings (Nordmann *et al.* 2018).

Summarised, evidence on how the availability of lecture recordings affects students' study behaviour and academic performance is largely unclear. We pursue the hypothesis that these diverse and partially inconsistent findings might be due to individual differences in *how* the lecture recordings are used and *how* they are embedded in the students' learning behaviour. Imagine, for example, a sample of students of which 80% simply view the existence of lecture recordings as a justification for not visiting the lecture, whereas 20% of them use the lecture recordings for deepening their understanding of the contents or for preparing exams. The effects on attendance and performance would be probably different if a sample is studied of which 80% see the recordings as a valuable resource for self-regulated learning and only 20% use the recording as a surrogate of the face-to-face contact in the lecture. Heterogeneity of the studied samples might explain diverging results. This assumption is corroborated by studies showing substantial variations in how students use lecture recordings. There is, for example, substantial variance in the number of lecture recordings watched (Elliott and Neal 2016). Some students watched only a few of the available recordings, while others watched most, if not all (Zupancic and Horz 2002). Furthermore, some students watched the same lecture recording multiple times (De Boer and Tolboom 2008), and a considerable variance has been found in the length of the lecture watching session (Mark and Vrijmoed 2017) and in terms of whether the recording was watched completely or in parts (Gosper *et al.* 2008). Introducing lecture recordings increases the flexibility of students' study routines because the time, location and social setting in which a lecture recording is watched can be freely chosen

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(Woo *et al.* 2008). Thus, investigating the extent that students utilise these additional degrees of freedom can help us to understand under which conditions students might benefit from the availability of lecture recordings. Therefore, the aim of this study is to identify clusters of students who use lecture recordings in different ways. Our understanding of diverging and contradicting empirical findings would benefit, if we were able to distinguish different strategies in working with lecture recordings, as these different strategies might yield different effects on attendance and performance.

Based on the studies cited previously, use of lecture recordings can be characterised by assessing the variability of usage among students in the following six study behaviour variables:

- *Frequency of usage*: How many of the available lecture recordings of a lecture series are watched during the semester?
- *Repetitive watching*: Are lecture recordings or parts of the recordings watched multiple times?
- *Selectivity in watching*: Are the lecture recordings watched completely or in parts?
- *Lecture attendance*: How many of the lectures are attended in the lecture hall and how many are missed because lecture recordings are available?
- *Social context*: Are the lecture recordings watched alone or together with other students?
- *Location*: Where are lecture recordings watched?

In this study, these variables served as input variables in a cluster analysis to identify different strategies in using the lecture recordings.

Methods

Participants

In this survey, $N = 1079$ students enrolled at the University of Münster (Germany) answered questions on the lecture recording service (mean age: 22.32 years, $SD = 6.38$ years; 54.6% female, 42.9% male, 2.4% no gender was indicated). Each student attended at least one of $N = 47$ lecture series which were recorded by the university's central lecture recording service. The investigated lecture series referred to nine academic domains: economics (24 lecture series), law (9), theology (5), psychology (3), biology (1), history (1), sport sciences (1), pedagogy (1), political sciences (1), and philosophy (1). Table 1 shows the distribution of participants and lecture series across the three semesters of the evaluation period. In the following analyses, we included only those students who reported that they used the lecture recordings (right column in Table 1). The data re-analysis was consistent with the ethical guidelines of the American Psychological Association (American Psychological Association 2017) and the ethical meta code of the European Federation of Psychologists' Associations (European Federation of Psychologists' Associations 2005).

Procedure

The lecture capture service was evaluated by the local service operator and his staff, including the first author. The data used in this study were gathered during

Table 1. Number of lecture series and number of students by semester.

Semester	Lecture series	Students who completed the questionnaire	Students who completed the questionnaire and used the lecture recordings
Winter term 2016/17	6	198	188
Summer term 2017	13	370	344
Winter term 2017/18	28	511	491
Sum	47	1079	1023

this initial evaluation phase. The evaluations were conducted in the winter semester 2016/2017, summer semester 2017 and winter semester 2017/2018. At the end of each semester, all students who had access to the lecture recordings received a questionnaire via the learning platform with the request to participate in the evaluation. Students participated voluntarily. The online questionnaire was completed anonymously. Therefore, it was impossible to reconstruct who did or did not participate.

Materials

The online questionnaire (26 items in total) encompassed three types of items. The first type of items referred to how the participants used the lecture recordings. These variables except items with open response format were used as input variables for the cluster analysis (the corresponding items and response formats are described in Table 2).

The second set of items, which were used to gather additional information about the participants (age and gender), their experience with lecture recordings, their purposes of using lecture recordings and how they evaluated the lecture capture service, served as dependent variables. The identified clusters were analysed for differences on these variables. This analysis was expected to provide initial indications to which other variables usage patterns of lecture recordings may be related. The third set of items referred to technical aspects of using lecture recordings (how to access them, adequacy of the video format, quality of sound and picture). These variables were of specific interest for improving the service. However, the data were not included in the following analyses.

Data analyses

To identify the patterns of using lecture recordings, a cluster analysis was conducted using the variables listed in Table 2 as input variables. The responses to these items provided information about how students utilised the recordings in their learning behaviour. In a cluster analysis, a set of data points, in this study the students, are grouped by similarity in the input variables with the aim of identifying groups that are internally as homogeneous as possible but differ from each other as much as possible. The clustering algorithm we used in this study (Partitioning Around Medoids; PAM; Kaufman and Rousseeuw 1990) aims at grouping the data points by similarity to other data points chosen as the centres of their clusters. Similarity is determined by a distance measure (Gower distance; Gower 1971), which is suitable to determine the distance between data points that contain categorical as well as numerical values. PAM requires the number of clusters k to be manually determined. We determined k based on the average silhouette

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Table 2. Items describing how students used the lecture recordings (input variables for the cluster analysis).

No.	Question	Possible answers	Coding
1	How many of the lecture recordings, of the lecture you attended, did you watch?	No answer	Missing
		A few	1
		About half	2
		Most	3
		Almost all	4
2	Did you watch some lecture recordings multiple times?	No answer	1
		Yes	2
		No	3
3	How did you use the lecture recordings?	No answer	1
		I usually watched the lecture recordings completely	2
		I usually only watch parts of a lecture recording	3
4	How many lectures did you not attend because you could expect to be able to watch the lecture recording?	No answer	Missing
		None	1
		A fewAbout half	2
		Most	3
		Almost all	4
			5
5	How did you use the lecture recordings?	No answer	Missing
		Always alone	1
		Mostly alone	2
		Mostly together with other people	3
		Always together with other people	4
6	Where did you usually watch the lecture recordings?	No answer	1
		On the go	2
		At home	3
		In the university	4

coefficient (Rousseeuw 1987), which is a measure of consistency of clustering that ranges from −1 to +1 with higher values indicating a higher quality of clustering (more internally consistent clusters). We calculated the average silhouette coefficients between $k = 2$ and $k = 10$. The average silhouette coefficient was highest at $k = 3$ and $k = 5$, with an average silhouette coefficient of 0.48 for both solutions. The five-cluster solution was more differentiated because one of the clusters represented students who missed most of the live lectures – a phenomenon previously reported in the literature (e.g., O'Callaghan *et al.* 2017). Therefore, five clusters were extracted.

Following the identification of the clusters, we tested whether the differences between the clusters were significant on the input variables as well as on the dependent variables. The Kruskal–Wallis rank sum test (Kruskal and Wallis 1952) was performed for continuous variables, and for significant test results, the Conover–Iman test of multiple comparisons using rank sums (Conover and Iman 1979) was performed as a post-hoc test to determine which pairwise comparisons were significant. For the categorical variables, Pearson's chi-square test for count data with Monte Carlo simulation (Hope 1968) was employed (8,000 iterations as recommended by Mundform et al. 2011). Post-hoc analyses for significant results were conducted based on the standardised residuals of the Pearson's chi-square test (Beasley and Schumacker 1995). For post-hoc analyses, Bonferroni corrections (Dunn 1961) were applied to the p values.

Results

In the following, the extracted clusters are described in terms of the differences revealed on the input variables listed in Table 2. Significant differences were found on the input variables 1 to 5 but not on input variable 6. Thus, all clusters have in common that lecture recordings were mainly watched at home. Table 3 shows the statistics of the input variables for each cluster.

Cluster 1 – Frequent repetition (N = 291): Cluster 1 students watched most of the lecture recordings, usually completely and some of them even multiple times. Although the students knew that the lecture recordings would be available, they missed only a few live lectures, but they missed more lectures than the students in the Clusters 2, 3 and 4. Summarised, we interpret this pattern as an attempt to repeat the content of nearly all lectures of a series.

Cluster 2 – Selective repetition (N = 296): The students of this cluster also seem to repeat complete lectures by watching the lecture recordings, but less consistently than Cluster 1. Cluster 2 students watched only about half of the lecture recordings, and they watched them only once and not repeatedly. Although these students knew that the lecture recordings would be available, they missed only a few live lectures.

Cluster 3 – Frequent consultation (N = 107): Students in Cluster 3 watched most of the lecture recordings and some even multiple times. However, they usually watched only parts of a lecture recording. Thus, we interpret this pattern as an attempt to immerse oneself into specific topics. This interpretation is consistent with the observation that students of this cluster consulted only specific passages of a lecture recording and refrained from watching them completely compared to Clusters 1 and 2. In line with this idea, Cluster 3 students missed only a few lectures in the lecture hall.

Cluster 4 – Selective consultation (N = 158): Cluster 4 students also watched lecture recordings only partially but less frequently than Cluster 3 and usually only once and not multiple times. Although they knew the lecture recordings would be available, they missed only a few live lectures.

Cluster 5 – Increased absenteeism (N = 171): In contrast to all other clusters, these students missed most of the lectures in the lecture hall and instead watched almost all lecture recordings, usually completely but only once. We interpret this pattern as the attempt to substitute attending the live lectures by watching the recordings.

Table 4 shows the extent to which the cluster size varies across the semesters of the evaluation period. Although the number of participants varied across the three semesters of the evaluation period, the proportions of the clusters within each semester did not, χ^2 (8, N = 1023) = 9.25, p = .32. In each semester, the clusters of (frequent and selective) repeaters (Clusters 1 and 2) were larger than Clusters 3 and 4 representing students who mainly used the lecture recordings for the deeper consideration of specific topics. Across semesters, the relative sizes of the clusters varied within narrow boundaries. The largest cluster (Cluster 2), for example, ranged from 25.58% (of the total semester N) to 30.85%; the smallest cluster (Cluster 3) ranged from 9.01% to 11.41%. The stability of the clusters in their relative size is remarkable because in each semester, different samples of students and lecture series were studied.

We further explored whether the clusters differed on additional variables describing the participants and specific aspects of their study behaviour. For means, standard deviations and frequencies of the clusters on these variables, see Tables 5 and 6. These additional variables have the status of dependent variables because they were not included in identifying the clusters.

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Table 3. Differences between clusters on the input variables.

Input variables	Clusters					
	Frequent repetition	Selective repetition	Frequent consultation	Selective consultation	Increased absenteeism	*p*
(1). How many of the lecture recordings, of the lecture you attended, did you watch?	*Most* *M* = 3.44 *SD* = 0.92	*About half* *M* = 2.11 *SD* = 1.1	*Most* *M* = 2.68 *SD* = 1.03	*About half* *M* = 1.73 *SD* = 0.91	*Almost all* *M* = 3.63 *SD* = 0.67	<0.001[1]
(2). Did you watch some recordings multiple times?	*Yes* 97.9%	*No* 95.9%	*Yes* 98.1%	*No* 97.5%	*No* 100%	<0.001[2]
(3). How did you use the lecture recordings?	*Completely* 99.7%	*Completely* 100%	*Partially* 96.3%	*Partially* 98.1%	*Completely* 99.4%	<0.001[3]
(4). How many lectures did you not attend because you could expect to be able to watch the lecture recording?	*A few* *M* = 2.28 *SD* = 1.51	*A few* *M* = 1.51 *SD* = 0.66	*A few* *M* = 1.87 *SD* = 1.37	*A few* *M* = 1.56 *SD* = 1.05	*Most* *M* = 4.02 *SD* = 0.96	<0.001[4]
(5). How did you use the lecture recordings?	*Always alone* *M* = 1.16 *SD* = 0.38	*Always alone* *M* = 1.04 *SD* = 0.21	*Always alone* *M* = 1.14 *SD* = 0.38	*Always alone* *M* = 1.11 *SD* = 0.34	*Always alone* *M* = 1.09 *SD* = 0.28	<0.001[5]
(6). Where did you usually watch the lecture recordings?	*At home* 93.5%	*At home* 90.9%	*At home* 91.6%	*At home* 91.8%	*At home* 90.1%	0.438[6]

Note: The label in each cluster column (in italics) refers either to the most frequently chosen response or the category in which the mean was located. [1] *Kruskal–Wallis rank sum test:* H (4, *N* = 1012) = 386.26; [2] *Pearson's chi-squared test for count data:* χ^2 (8, *N* = 1023) = 1008.5; [3] *Pearson's chi-squared test for count data:* χ^2 (8, *N* = 1023) = 1016.4; [4] *Kruskal–Wallis rank sum test:* H (4, *N* = 974) = 329.55; [5] *Kruskal–Wallis rank sum test:* H (4, *N* = 1020) = 24.398; [6] *Pearson's chi-squared test for count data:* χ^2 (12, *N* = 1023) = 12.099.

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Table 4. Proportion of the clusters by semester.

	Clusters					Sum
	Frequent repetition	Selective repetition	Frequent consultation	Selective consultation	Increased absenteeism	
Winter term 2016/2017, N (%)	54 (28.72)	58 (30.85)	20 (10.64)	21 (11.17)	35 (18.62)	188
Summer term 2017, N (%)	108 (31.40)	88 (25.58)	31 (9.01)	62 (18.02)	55 (15.99)	344
Winter term 2017/2018, N (%)	129 (26.27)	150 (30.55)	56 (11.41)	75 (15.27)	81 (16.50)	491
Sum, N	291	296	107	158	171	1023

No significant gender differences were found among the five clusters. All clusters contained slightly more women than men. The self-reported experience in using lecture recordings also did not differ between the clusters. Between 66.9% and 75.5% of the students per cluster reported to have no prior experience with lecture recordings.

Although the mean age of the clusters varied only between 21.64 and 22.97 years, Cluster 1 was significantly older than Cluster 2 ($p = 0.006$) and Cluster 4 ($p = 0.002$), and the latter was also significantly different to Cluster 5 ($p = 0.027$). A significant difference between the clusters was also found on the item that addressed whether the lecture recordings were used as the only resource or in addition to attending the lectures. In Clusters 1 and 5, more students than expected stated to have used the lecture recordings solely (Cluster 1: $p < 0.001$; Cluster 5: $p < 0.001$), whereas more students than expected stated to have used the lecture recordings parallel to the lectures in Clusters 2 ($p < 0.001$) and Cluster 4 ($p < 0.001$). This result is consistent with the interpretation that Clusters 2 and 4 used the lecture recordings selectively for repeating or revisiting lecture contents, which makes sense when students attended the lecture and were familiar with its contents.

The item that assessed the extent that students were satisfied with the lecture capture service at their university was answered positively and the cluster means ranged between *satisfied* and *very satisfied*. Nevertheless, Cluster 4 was significantly less satisfied than Clusters 1 ($p < 0.001$), 2 ($p = 0.046$) and 5 ($p < 0.001$), which might be related to the observation that Cluster 4 used the recording less intensively than all other clusters.

Table 6 presents three responses given by students from the five clusters to the item that assessed the purpose for which the students used the lecture recordings. The distribution of answers varied substantially across the clusters on each variable. The lecture recordings were used to review the lectures more often than expected by the students in Cluster 1 ($p = 0.023$) and less often than expected in Cluster 4 ($p = 0.031$). As a reference the lecture recordings were used more frequently than expected in Clusters 1, 3 and 5 ($p = 0.004$, $p < 0.001$, $p = 0.047$) and less frequently than expected in Cluster 2 ($p < 0.001$). Using the lecture recordings to prepare for the exam was reported to have occurred more often than expected by the students in Clusters 1 ($p < 0.001$) and 3 ($p = 0.020$) and less often than expected in Clusters 2 ($p < 0.001$) and Cluster 4 ($p = 0.048$).

Discussion

The most important result is that we found a clear and meaningful cluster structure. The participants could be clearly grouped according to their usage of the lecture

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Table 5. Differences between clusters on variables characterising the students and their study behaviour.

Variables	Clusters					
	Frequent repetition	Selective repetition	Frequent consultation	Selective consultation	Increased absenteeism	*p*
What is your gender?	*Female* 54.0% *Male* 43.3%	*Female* 54.6% *Male* 43.6%	*Female* 48.6% *Male* 46.7%	*Female* 58.2% *Male* 41.1%	*Female* 56.3% *Male* 41.9%	0.502[1]
How old are you?	*M* = 22.97 *SD* = 7.59	*M* = 21.89 *SD* = 5.87	*M* = 22.15 *SD* = 5.09	*M* = 21.64 *SD* = 5.89	*M* = 21.99 *SD* = 3.00	<0.001[2]
Did you use the lecture recordings provided for the lecture that you attended?	*Parallel to the lectures* 57.7% *Solely used the lecture recordings* 42.3%	*Parallel to the lectures* 87.2% *Solely used the lecture recordings* 12.8%	*Parallel to the lectures* 79.4% *Solely used the lecture recordings* 20.6%	*Parallel to the lectures* 84.8% *Solely used the lecture recordings* 15.2%	*Parallel to the lectures* 26.9% *Solely used the lecture recordings* 73.1%	<0.001[3]
Did you have any experience using lecture recordings before this semester?	*Yes* 32.1% *No* 66.9%	*Yes* 24.1% *No* 75.5%	*Yes* 28.0% *No* 72.0%	*Yes* 26.1% *No* 73.2%	*Yes* 29.8% *No* 70.2%	0.382[4]
How satisfied are you, all in all, with the lecture recordings?	*M* = 4.53 *SD* = 0.72	*M* = 4.39 *SD* = 0.78	*M* = 4.35 *SD* = 0.78	*M* = 4.19 *SD* = 0.86	*M* = 4.53 *SD* = 0.69	<0.001[5]

Note: The label in each cell (in italics) refers to either the most frequently chosen response or the category in which the mean was located. [1] *Pearson's chi-squared test for count data:* χ^2 (8, *N* = 1012) = 7.3906; [2] *Kruskal–Wallis rank sum test:* H (4, *N* = 1002) = 21.607; [3] *Pearson's chi-squared test for count data:* χ^2 (4, *N* = 1023) = 222; [4] *Pearson's chi-squared test for count data:* χ^2 (8, *N* = 1019) = 8.6138; [5] *Kruskal–Wallis rank sum test:* H (4, *N* = 1015) = 27.838.

Table 6. Differences between clusters on the question 'Which role did the lecture recordings have in your learning process?'.

Variables	Clusters					
	Frequent repetition	Selective repetition	Frequent consultation	Selective consultation	Increased absenteeism	*p*
To review the lecture	89.0	82.4	90.7	75.3	78.4	<0.001[1]
As a reference, e.g. during exercises	39.5	16.2	52.3	40.5	22.2	<0.001[2]
To prepare for the exam	88.7	54.7	84.1	62.0	71.3	<0.001[3]

Note: Values are percent of students per cluster who chose the respective response. Multiple responses were possible.
[1] *Pearson's chi-squared test for count data:* χ^2 (4, N = 1023) = 21.44; [2] *Pearson's chi-squared test for count data:* χ^2 (4, N = 1023) = 75.157; [3] *Pearson's chi-squared test for count data:* χ^2 (4, N = 1023) = 97.917.

recordings, and the proportions of the clusters remained stable across the three semesters, although this comparison involved different samples and different lecture series. Thus, we hypothesise that this cluster structure represents strategies in using lecture recordings that have some potential for generalisation.

The five clusters we identified can be interpreted as a hierarchical structure: Some students used the recordings in lieu of attending the lectures (Cluster 5), while others used them to supplement and enrich the lecture (Clusters 1–4). The students in the latter clusters either aimed at repeating the content presented in the recorded lecture (Clusters 1 and 2) or used the recordings for deepening their knowledge concerning specific topics (Clusters 3 and 4). The repetition clusters have in common that they usually watched complete lecture recordings although the frequent repeaters (Cluster 1) watched lecture recordings multiple times, whereas the selective repeaters did not (Cluster 2). The consultation clusters have in common that they usually watched only parts of the lecture recordings. The main difference between these clusters is that the frequent consulters (Cluster 3) watched lecture recordings multiple times, whereas selective consulters (Cluster 4) did not. Furthermore, there is a striking similarity between the frequent (Clusters 1 and 3) and the selective variants (Clusters 2 and 4). Students in the frequent cluster variants watched most of the lecture recordings (many of them multiple times), whereas students in the selective variants watched only about half of the lecture recordings and usually only once.

Whereas the clusters did not differ with regard to gender and experience in using lecture recordings, they pursued different goals. Across all clusters, reviewing lectures was the most frequently mentioned goal, especially in Clusters 1 (frequent repetition) and 3 (frequent consultation). The same clusters also often reported that preparing for an exam was the goal of viewing the lecture recordings. Using the lecture recordings as a reference, for example, during exercises, was most often reported by Cluster 3 (frequent consultation) but least frequently in Cluster 5 (increased absenteeism).

These results demonstrate that the students used lecture recordings in different ways pursuing different goals. Whatever strategy they employed, the students were highly satisfied with the lecture capture service, which increased their degrees of freedom in organising their studies – including the opportunity not to visit the lecture. Whereas lecturers may be concerned about this option, students may benefit from the increased flexibility in their study schedule, especially in challenging situations such as time conflicts between different lectures or between lectures and job or child care. In our sample, only about 17% of the students chose the Cluster 5 option and were

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consistently absent (with low variance across semesters). In many types of lectures, this percentage of absent students can be tolerated – particularly taking into account that at least a part of them would not participate anyway, for example, when time conflicts are the reason why they do not visit the lecture.

Our results also help to reconcile and interpret seemingly contradicting results from studies investigating the effects of lecture recording availability on lecture attendance (Dommeyer 2017; Edwards and Clinton 2018; Walls *et al.* 2010). A positive correlation between the usage of lecture recordings and absenteeism may emerge from fundamentally different situations. If, for example, all students of a lecture series sometimes watch the video and sometimes skip a lecture, a moderate positive correlation could be the result. A similar correlation could result when some students consistently watch the videos and do not visit the lecture, whereas many other students sporadically use the lecture recordings and sometimes miss a live lecture. Our results corroborate the second interpretation. In our sample, a smaller number of students substituted nearly every lecture by watching the recording (around 17%), whereas a larger number of students nearly always used the recording as a supplement to attending the live lecture. Thus, mean absenteeism rates may be misleading because of the large heterogeneity in user behaviour. However, this interpretation requires differentiating between different strategies of using lecture recordings as proposed in this study.

Similarly, considering different subgroups of students who consistently show different usage behaviour may also help to understand that the availability of lecture recordings may or may not help to increase academic performance. The consultation clusters, for example, used the recordings to deepen their understanding, which could enhance performance (Wiese and Newton 2013). A comparable effect for students who primarily replace attendance in the live lecture by viewing the recording is less probable, although this hypothesis still needs to be tested.

Limitations

An important limitation of this study was that the data were gathered for evaluating the lecture capture service. Consequently, not all data were related to the students' usage behaviour but they were also related to the technical and organisational aspects of the lecture capture service. Interactions between these different types of questions cannot be excluded. Furthermore, the available data were all self-reported. Methods using log or tracking data can be more reliable, especially in the context of study behaviour (e.g., Gyllen *et al.* 2019). Similarly, testing the potential relations between strategically using lecture recordings and academic performance would require reliable measures of performance, which were unavailable in the context of this study.

Another limitation is related to an organisational problem of the evaluation procedure. In the summer semester 2017 and the winter semester 2017/2018, some students could have attended other recorded lecture series and thus might have evaluated more than one recorded lecture.

Future research perspectives

Our results demonstrate that students use lecture recordings in diverse ways, which we interpret to be related to the students' learning strategies. This view is corroborated by two studies exploring different approaches to learning (Marton and Säljö

1976). For example, Vajoczki *et al.* (2011) found that students following a deep learning approach used lecture recordings more often to review a lecture and to prepare for exams than surface learning students, which could apply to our Clusters 1 and 3. Students following a more surface-oriented approach were more likely to use the lecture recordings as a substitute for the lectures, which is consistent with the behaviour of our Cluster 5 students. Another example for relations between the way students use lecture recordings and approaches to learning was reported by Wiese and Newton (2013). They found that deep learners compared to surface learners watched more lecture recordings and were more likely to watch them completely, which is consistent with our Cluster 1 but also with Cluster 5 students who demonstrated absenteeism. These examples show that for future research, a more differentiated analysis of students' usage of (digital) learning resources is needed to explore how the availability of lecture recordings affects strategic learning behaviour. Exploring these relationships may help to understand how learning situations can incorporate new technical options, such as lecture recordings or interactive videos, to augment self-directed study behaviour.

Data and materials

The data that the results are based on are available in the Open Science Framework at https://doi.org/10.17605/OSF.IO/DNWK5. The R scripts used to analyse the data are also available in the Open Science Framework at https://doi.org/10.17605/OSF.IO/E65HJ.

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