Depth of Use: An Empirical Framework to Help Faculty Gauge the Relative Impact of Learning Management System Tools

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ABSTRACT

Learning management system (LMS) tools are increasingly relevant to scaling computing pedagogies. Measuring their utilization and impact at scale, however, remains computationally expensive. We examine the problem of estimating the utilization of a department-wide LMS, and its impact on the design, management and outcomes of Computer Science courses. We introduce 'depth-of-use' (DOU): a first-principles, resource-specific metric of LMS utilization. We then hypothesis-test the relationship between DOU and course attributes like modality (course level, mode-of-delivery, third-party app use), participation (enrollment, viewership), logistics (teaching support, digital skills training) and outcomes (average GPA, DFW rate). Experiments on metadata from over 1300 Computer Science courses taught at Virginia Tech between 2015 and 2019 suggest that our framing of DOU helps identify resource-level preferences of micro-cohorts of courses, linked to their content, logistics and pedagogies. We discover that, across the Computer Science department at Virginia Tech, overall LMS use is consistently linked to favorable learning outcomes. We also discover that a complex interaction between the needs for scale, ubiquitous access and interoperability drives strong LMS utilization, with graduate and online-only courses faring highest in their aggregate use of LMS services. Finally, we describe two key applications of our analyses. One, we demonstrate how DOU can help CS faculty identify the relative impact of transition from legacy apps to LMS services. Two, we describe how DOU can help instructional designers evaluate and improve their design interventions.

CCS CONCEPTS

• **Applied computing** → **Learning management systems**; • **Information systems** → *Data analytics*; • **Social and professional topics** → *Computer science education.*

KEYWORDS

Learning management system; utilization; adoption

ITiCSE '20, June 15–19, 2020, Trondheim, Norway

ACM ISBN 978-1-4503-6874-2/20/06…$15.00
https://doi.org/10.1145/3341525.3387375

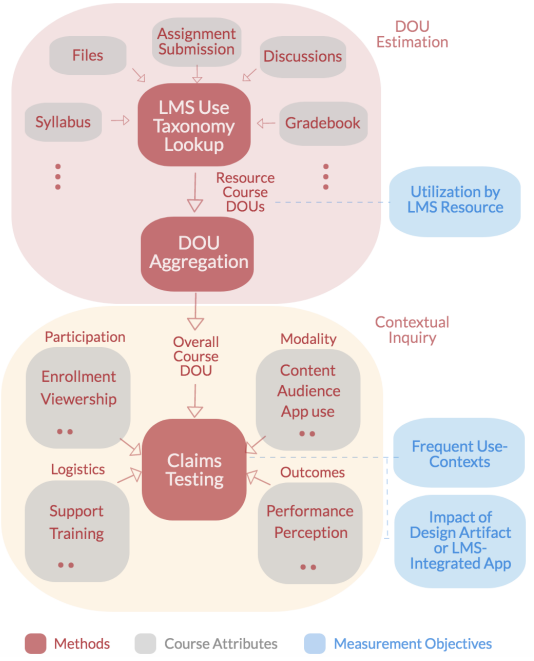

Figure 1: System overview: LMS depth-of-use (DOU) resources, contexts and objectives

ACM Reference Format:
Taha Hassan, Bob Edmison, Larry Cox II, Matt Louvet, Daron Williams, and D. Scott McCrickard. 2020. Depth of Use: An Empirical Framework to Help Faculty Gauge the Relative Impact of Learning Management System Tools. In *Proceedings of the 2020 ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE '20), June 15–19, 2020, Trondheim, Norway*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3341525.3387375

1 INTRODUCTION

Service-based (SaaS) learning management systems (LMS) have been, near-exclusively, the primary infrastructure for hosting and disseminating information between key stakeholders in the higher education domain [4]. In recent years, the market for these systems has largely consolidated around a handful of comprehensive app ecosystems [7]. A variety of native apps for class management,

Table 1: A classification of modes-of-use by LMS resource.

Announcements (An)	**Syllabus (S)**	**Discussions (D)**
0: No announcements	0: No syllabus	0: Discussions disabled
1: Placeholder announcements or schedules	1: Syllabus under *Files*	1: No discussion activity
2: Min. one per week or course-instrument	2: File previewed or embedded under *Syllabus*	2: Discussion groups with activity
Assignments: Delivery (A_d)	**Assignments: Submission (A_s)**	**Quizzes: Delivery (Q_d)**
0: No assignments on LMS or placeholders	0: No file upload, likely paper or app	0: No quizzes hosted on LMS or placeholders
1: Link to DOC, ZIP or third-party app	1: File upload on LMS	1: Link to DOC, ZIP or third-party app
2: Assignments fully hosted on LMS	2: Submission within LMS (text entry)	2: Quizzes fully hosted on LMS
Quizzes: Submission (Q_s)	**Gradebook (G)**	**Files (F)**
0: No online submission, likely paper or app	0: No grading activity in LMS	0: No files
1: Submission within LMS	1: Comprehensive grading for all assessments	1: Meaningful course resources under *Files*

assessment, productivity and communication, as well as the increasingly comfortable integration of third-party apps, imply a potentially challenging volume of LMS usage data to parse for reporting and analytics. In the past two decades, there has been ample work on qualitative driving factors of LMS adoption [3][2][21][13], and extending the scope of LMS tools for computing education [18][17]. However, this research is largely limited to self-reported LMS use, and there is no real consensus on the methods for measuring the utilization and impact of LMS tools. Some of the contributing factors are the diversity of data sources (app metadata, course site content, team drives, social media), the large volume of raw LMS page requests, and the multitude of situated LMS use-contexts on behalf of students and faculty. All of these, in turn, make it difficult to study the effects of faculty preferences, LMS-integrated apps, instructional design interventions, staff allocation and LMS evangelism, on course and student outcomes. Our study introduces 'depth-of-use' (DOU): a first-principles framework of course-level LMS utilization. We describe a taxonomy of LMS utilization (see table 1) to calculate ordinal DOU scores (low, medium or high) of overall LMS use, for over 1300 Computer Science courses taught at Virginia Tech. We then hypothesis-test these scores against course attributes like modality, participation, logistics and outcomes. Finally, we discuss how faculty and instructional designers can leverage DOU and LMS use metadata to assess and improve the efficacy of LMS tools and legacy third-party apps employed in computing pedagogies.

The rest of the sections are organized as follows. Section 3 defines the problem of depth-of-use (DOU) estimation, and the study hypotheses. Section 4 details the datasets, methods and results from hypothesis tests performed on DOU and its constituent dimensions. Section 5 and 6 conclude the study with a discussion of the broader implications of our approach for data-driven instructional assessment and feedback.

2 RELATED WORK

There is considerable prior work on qualitative grounds for LMS adoption, like teaching and learning efficiency, generational student expectations, and institutional expansion and consolidation [4][21][3]. For course instructors, the basic predictors of the pace of LMS adoption are departmental affiliation (STEM vs. non-STEM, say) and course modality (online vs. face-to-face, say). West et al. [21] surveyed 30 college instructors over two semesters, about their primary use-contexts, perceived utility, teaching efficacy, and overall satisfaction with Blackboard LMS. The authors describe 'integration challenges': how course instructors perceived it difficult to integrate LMS services into their current teaching practices. This notion of 'integration' is echoed by McGill et al. [12] for the case of student adoption of WebCT, whereby students with a more favorable view of the 'task-technology fit' of LMS services are more likely to have higher LMS utilization. The authors also note that instructor's view of LMS usability, support staff availability, and access to training resources affect student utilization of LMS services favorably. Wilcox et. al. [22] surveyed user perceptions on frequent modes of use and platform limitations for Canvas LMS. They identified a generation gap in expectations between students and instructors, wherein the pervasive student use of the mobile LMS app rendered a subset of course sites - designed by faculty members for the desktop - ineffective in navigation, flow and content organization.

Likewise, an information systems (IS) perspective on LMS adoption has been thoroughly explored over the years [2][1][15]. A bulk of these studies apply and evaluate a canonical model of IS success first discussed by Delone and Mclean [5][6]. The model factorizes the individual and organizational success of an IS into quality (system, information, and service), use (utilization, intention of use) and net benefits (impact on overall satisfaction, and intention of use). Adeyinka and Mutula [2] conducted a university-wide study of IS success factors underlying WebCT adoption and operationalized LMS utilization using nature of use (mandatory or optional), frequency of use, access and availability. The authors found system use and intention of use both to be strong correlates of WebCT success. Ngai et al. [14] reported a stronger effect of the perceived usefulness and ease-of-use on LMS system use relative to that of attitude (interest expressed towards adopting a new system). Studies like Ozkan and Koseler [15] and Adeyinka [1] describe broader ways to operationalize this notion of system use, for instance, by measuring student engagement with the LMS, overall and by course activities. These studies rely heavily on self-reported LMS usage,

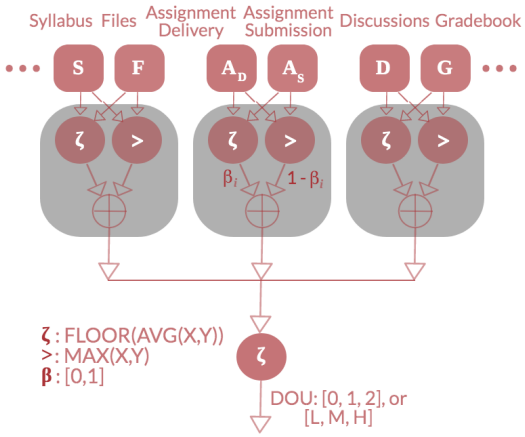

Figure 2: DOU estimation: S, F, D etc. refer to the LMS resource labels in the source taxonomy (table 1)

and are limited in the scope of actionable feedback they can provide for situated use-contexts specific to faculty, staff and students.

The breadth of qualitative correlates of LMS adoption studied in prior literature highlights how complex the discovery of use-contexts in the education domain can be. A variety of stakeholders bring competing standards to evaluate the quality of the content delivered via LMS course sites. This highlights the need for a thorough quantitative means of evaluating LMS use by resource (table 1) and context. To the best of the authors' knowledge, DOU is a first comprehensive measurement framework for LMS utilization and its impact on the design, management and outcomes of computing courses.

We make the following contributions in this study.

- We present depth-of-use (DOU), a first-principles, resource-specific view of the overall LMS use of a course,
- We hypothesis-test the relationship between DOU and course outcomes, modality, participation, and logistics,
- We identify two important use-cases of DOU: in helping CS faculty assess the relative utility of LMS resources and opportunity costs thereof, and in measuring the efficacy of design interventions.

3 DEPTH-OF-USE ESTIMATION

In this section, we describe 'depth-of-use', a first-principles framework for course-level LMS utilization. We then describe four research questions and nine corresponding hypotheses which test how strongly DOU for a course is correlated with its participation, modality, logistics and outcomes. For course modality, we examine audience (undergraduate vs. graduate), content (STEM vs. non-STEM), mode of delivery (online-only vs. face-to-face) and third-party app use. For course participation, we consider enrollment and viewership (weekly page requests for the Canvas site per student). For course logistics, we consider the number of teaching assistants and instructor participation in digital skills training. For outcomes, we consider average course GPA and DFW rate.

3.1 Notation and Definitions

Table 1 describes a taxonomy of LMS use, developed with aid from instructional designers at Virginia Tech. This taxonomy forms the basis of course-level *DOU* measurement in this study. We define depth-of-use for an LMS resource R_i as a simple logic rule DOU_i of the form $(R * k_i)$ where k_i is a whole number and $*$ is a relation operator. For instance, per table 1, $(An == 1)$ for a given course implies minimal use of announcements (placeholders or class schedules, no instructor or TA activity). A total of N resource *DOU*s are accounted towards each course. The data matrix has a shape of $M \times N$ for M courses in the dataset, with course-level *DOU*s defined as follows.

Definition 1. *Depth-of-use (course)* $DOU_C \triangleq \zeta(T_1, T_2, ..T_{N/2})$ where

$$T_{ij} = \beta_i \Big(MAX\Big(DOU_i, DOU_j\Big)\Big) + (1 - \beta_i)\Big(\zeta\Big(DOU_i, DOU_j\Big)\Big) \quad (1)$$

where $\beta_i = [0, 1] \in W$

In other words, for each pair of LMS resource DOUs, say announcements and syllabus, the term T_{ij} picks between MAX() and $\zeta()$, the latter being the logic equivalent of a real-valued floored-average $\lfloor AVG(X, Y) \rfloor$ function. The choice of these logic functions affects how conservatively the overall DOU ranks the relative contribution of each of these two resource DOUs. $MAX()$, for instance, assigns the output to the larger of the two input contributions, while ζ reverts to the lower of the two (figure 2). Picking $\beta = 1$ implies that the instructional staff intends to consider the MAX() or the *best* of announcement and syllabus DOUs towards the overall LMS DOU. On the other hand, $\beta = 0$ rewards contributions from both DOUs when necessary, for instance, with assignment delivery and submission. This flexibility in designing custom DOUs is intended to encourage research on the usability and perceived efficacy of DOUs for a variety of learning environments.

3.2 Research questions and hypotheses

RQ1: Course modality. What is the relationship between DOU and course type, mode of delivery, and use of third-party apps?

- **H1:** Undergraduate courses have significantly higher DOUs relative to graduate DOUs.
- **H2:** Online-only courses have significantly higher DOUs relative to face-to-face courses.
- **H3:** Third-party app use significantly affects course DOU.

RQ2: Course participation. What is the relationship between DOU and student participation in a course?

- **H4:** Course DOU is significantly linked to the number of students enrolled full-time in the course.
- **H5:** Course DOU is significantly linked to pageviews for the LMS course website.

RQ3: Course logistics. What is the relationship between DOU, and the number of TAs, and staff participation in digital skills coursework?

- **H6:** Course DOU is significantly linked to the number of teaching assistants for the course.

Table 2: Key counts and DOU breakdown (% Lo, Med, Hi) for course cohorts in the dataset

Attr.	#	%	Attr.	#	%
Overall	1327	65, 25, 9	Undergrad	924 (70%)	69, 23, 7
Online	159 (12%)	52, 28, 19	App use	369 (28%)	48, 36, 14
Skills	378 (28%)	58, 30, 11	TAs	293 (22%)	10, 62, 27

Table 3: Compositions (%) of low, medium and high DOU groups by course attributes

Course attribute	Low	Med.	High
Undergraduate	74	63	56
Online	10	13	25
3rd-party app use	20	39	44
Enrollment	10	32	29
Viewership	1	35	55
#TAs	0.5	17	13
Skills training	25	33	33
GPA	42	50	65
DFW	31	24	27

- **H7:** Course DOU is significantly linked to the instructor's prior enrollment in on-demand digital skills coursework.

RQ4: Outcomes. What is the relationship between DOU and course outcomes?

- **H8:** Course DOU is significantly linked to the average GPA for the course.
- **H9:** Course DOU is significantly linked to the DFW rate of the course.

4 EVALUATION

4.1 Datasets and Methods

The primary dataset for this study is Canvas course page requests collected for 1327 courses hosted on Canvas LMS, offered by the Computer Science department at Virginia Tech between 2015 and 2019. Table 2 lists key aspects of these courses. A majority (69.6%) of the courses are intended for undergraduate audiences, and 88% use traditional, face-to-face instructional format. These majorities are also retained in each of the three DOU groups as per table 3, with important differences. The next sections discuss these patterns in detail.

We use a combination of manual and automated strategies (web scraping, entity resolution, and topic modeling) to create LMS utilization metadata for each course. Key textual sources include, and are not limited to, the Virginia Tech course catalog and historical timetable, Canvas page request logs, course descriptions on the Virginia Tech website [19], as well as syllabus files and assessment page content from Canvas course sites. *DOU* is ordinal and not normally distributed, so we use non-parametric Kruskal-Wallis H-test [10] [11], in addition to an independent two-sample t-test with discrete-valued meta-variables (Table 4, $\alpha = 0.05, H_0 \neq 1 \; \forall \; p < \alpha$). We also evaluate group differences in all hypothesis variables for each of *Lo*, *Med* and *Hi* DOUs using one-way ANOVA (F-test, Table 4). To expand our analysis, we also test each of the hypotheses against all constituent dimensions of DOU (Table 5).

Table 4: Hypothesis-testing the relationship between DOU and course attributes

Hypothesis	H, p	F, p	t, p
H1: Undergrad.	23.4, <0.001*	24, <0.001*	-4.9, <0.001*
H2: Online	12.1, <0.001*	14.9, <0.001*	3.9, <0.001*
H3: App use	62.2, <0.001*	60.4, <0.001*	7.8, <0.001*
H4: Enrollment	30.6, <0.001*	20.9, <0.001*	-
H5: Viewership	783, <0.001*	72.7, <0.001*	-
H6: #TA	1.2, 0.54	1.4, 0.24	-
H7: Skills	8.3, <0.001*	7.5, <0.001*	2.7, <0.001*
H8: GPA	13.4, <0.001*	6.8, <0.001*	-
H9: DFW	10.0, <0.001*	5.8, <0.001*	-

*stat. significant, $\alpha = 0.05, F > F_{crit}$

4.2 Results

*4.2.1 Modality (**H1, H2, H3**).* As per Table 4, graduate CS courses have higher average DOUs relative to undergraduate courses (t-statistic is positive). Compare that to the fact that undergraduate courses have more than 3X higher enrollment on average (107.9), relative to graduate courses (33.4). As per table 5, graduate courses make a significantly in-depth use of discussion forums ($F = 53.6, p = 4e^{-13}$) while undergraduate courses have higher relative DOUs for assignment delivery ($F = 15.7, p = 7e^{-5}$), and assignment submission ($F = 15, p = 1e^{-4}$). Per table 4, online-only courses have superior overall DOUs ($F = 14.9, p = 1e^{-4}$) relative to traditional in-class instruction. They are also linked to in-depth LMS use for online syllabi ($F = 13.7, p = 2e^{-4}$), announcements ($F = 6.5, p = 0.01$), gradebook ($F = 21.4, p = 3e^{-6}$) and discussion forums ($F = 26.3, p = 3e^{-7}$). Third-party app use is linked to higher overall LMS DOU ($F = 60.4, p = 1e^{-14}$), with roughly 44% of high DOU courses relying on third-party apps (table 3).

*4.2.2 Participation (**H4, H5**).* Higher DOU courses feature larger overall enrollment ($F = 20.0, p = 1e^{-9}$) and viewership ($F = 72.7, p = 1e^{-30}$), as per table 4. Both of these are strong correlates of LMS utilization overall, and across a number of LMS resources considered individually (table 5). High enrollment is linked to frequent use of detailed online syllabi ($F = 13.5, p = 1e^{-6}$), assignment delivery ($F = 6, p = 2e^{-3}$), and LMS gradebook ($F = 37.2, p = 1e^{-9}$), among others. High site viewership is similarly linked to the use of announcements ($F = 61, p = 1e^{-25}$), discussion forums ($F = 91, p = 1e^{-36}$) and gradebook ($F = 174, p = 2e^{-36}$), etc.

*4.2.3 Logistics (**H6, H7**).* While not linked to overall LMS DOU, as per table 5, the number of teaching assistants is significantly linked to higher DOUs for assignment delivery ($F = 6, p = 2e^{-3}$), and assignment submission ($F = 5, p = 4e^{-3}$). Higher enrollment in a broad-charter professional development program for digital skills is linked to higher overall LMS DOU ($F = 7.5, p = 6e{-}3$), as well as announcements ($F = 15.1, p = 1e{-}4$) and gradebook ($F = 4, p = 0.03$).

Table 5: Hypothesis-testing the relationship between aspects of DOU and key meta-variables from Section 3

(a) announcements, syllabus, files and assignment delivery

Hypothesis	An		S		F		A_d	
	t, p	F, p	t, p	F, p	t, p	F, p	t, p	F, p
H1: Undergrad.	-4.4, <0.001*	19, <0.001*	-5.0, <0.001*	25, <0.001*	-5.4, <0.001*	29, <0.001*	4, <0.001*	15, <0.001*
H2: Online	2.6, 0.01*	6.5, 0.01*	3.7, <0.001*	13, <0.001*	5.5, <0.001*	30, <0.001*	-4.3, <0.001*	18, <0.001*
H3: App use	7.4, <0.001*	54, <0.001*	8.0, <0.001*	63, <0.001*	7.2, <0.001*	52, <0.001*	-8.7, <0.001*	75, <0.001*
H4: Enrollment	-	1.4, 0.2	-	13, <0.001*	-	43, <0.001*	-	5.9, 2e-3*
H5: Viewership	-	61, <0.001*	-	138, <0.001*	-	385, <0.001*	-	11, <0.001*
H6: #TAs	-	2.2, 0.11	-	1.3, 0.26	-	7, 8e-3*	-	6, 2e-3*
H7: Skills	3.9, <0.001*	15, <0.001*	3.2, <0.01*	10.5, <0.01*	1.8, 0.06	3.3, 0.06	-3.7, <0.001*	13, <0.001*
H8: GPA	-	4.1, 0.01*	-	6.2, 2e-3*	-	7.3, 6e-3*	-	0.34, 0.70
H9: DFW	-	4.6, 9e-3*	-	4.4, 0.01*	-	5.5, 0.01*	-	1, 0.34

(b) assignment submission, gradebook, discussions, quiz delivery and submission

	A_s		Q_d		Q_s		G		D	
H1	4, <0.001*	15, <0.001*	-1.1, 0.27	1.2, 0.27	-1.1, 0.27	1.2, 0.27	-2.3, 0.01*	5.5, 0.01*	-7, <0.001*	53, <0.001*
H2	-4, <0.01*	18.3, <0.01*	-4, <0.01*	22, <0.01*	-4, <0.01*	22, <0.01*	4, <0.01*	21, <0.01*	5.1, <0.01*	26, <0.01*
H3	-8, <0.01*	73, <0.01*	-5, <0.01*	31, <0.01*	-5, <0.01*	31, <0.01*	6, <0.001*	36, <0.001*	3, <0.01*	9, <0.01*
H4	-	12, <0.01*	-	-	-	2.2, 0.13	-	37, <0.01*	-	0.34, 0.7
H5	-	29, <0.01*	-	-	-	2.7, 0.09	-	174, <0.01*	-	91, <0.01*
H6	-	5, 4e-3*	-	-	-	0.02, 0.87	-	0.27, 0.6	-	1.6, 0.19
H7	-3, <0.01*	13.0, <0.01*	0.6, 0.5	0.4, 0.5	0.6, 0.5	0.4, 0.5	2, 0.03*	4, 0.03*	1.9, 0.05	3.6, 0.05
H8	-	1.6, 0.19	-	-	-	0.4, 0.5	-	4.2, 0.03*	-	4.2, 0.01*
H9	-	1.7, 0.1	-	-	-	8e-3, 0.92	-	5.5, 0.02*	-	4.7, 8e-3*

*stat. significant, $\alpha = 0.05, F > F_{crit}$

*4.2.4 Outcomes (**H8, H9**).* The average course GPA is significantly linked to overall DOU as per table 4 ($F = 6.8, p = 1e^{-3}$), and the use of announcements ($F = 4.1, p = 0.01$), syllabi ($F = 6.2, p = 2e^{-3}$) and discussion forums ($F = 4.2, p = 0.01$). DFW rates are linked to overall LMS DOU ($F = 5.8, p = 3e^{-3}$, modest negative correlation), and the use of announcements ($F = 4.6, p = 9e^{-3}$), and gradebook ($F = 5.5, p = 0.02$) among others.

5 APPLICATIONS AND DISCUSSION

Having surveyed the relationship between DOU and our hypotheses, we discuss two key applications of our analyses. We begin by describing how Computer Science faculty can use DOU to understand the impact of LMS services relative to legacy apps, and the opportunity-cost of a future transition. We then describe how DOU can evaluate the efficacy of professional development programs and resource allocation at the department level.

5.1 Choosing an LMS: Helping Faculty Evaluate the Costs and Benefits of LMS Tools

Evident from the literature surveyed in section 2, LMS adoption is a complex process, geared by the perceived quality of the overall system and the information it serves, as well as historical differences in pedagogies, and faculty-perceived opportunity cost of transition [21]. While determining the relative contribution of each of these factors is an open research problem, evidence in section 4 puts the needs for scale, interoperability and ubiquitous access, as three of the most important correlates of LMS adoption. It also provides insights into the structural and pedagogical reasons that shape the perceived utility of LMS resources for CS faculty expecting, for instance, a department-wide transition to a newer LMS.

5.1.1 Modality. According to hypothesis **H1** in table 5a, larger class size coincides with higher or 'deeper' use of announcements, most likely because mailing lists become increasingly inefficient and harder to organize and search at scale. Larger audience sizes also coincide with more frequent LMS use for assignment submission and delivery. One key reason is that it allows for a larger range of content to be submitted and greater flexibility in scheduling and organizing take-home exams and offline evaluations. In comparison, according to hypotheses **H3** and **H5** in table 5, the use of third-party apps coincides with that of online discussion forums, but not for assignment delivery and submission (t-statistic is negative). Services like Piazza are particularly favored by CS faculty because of their advanced forum management, content processing and tagging features, compared to the newer Discussions app aboard Canvas. This does not, however, take away from the utility of Canvas's file and assignment/quiz management apps, in part because of the ease

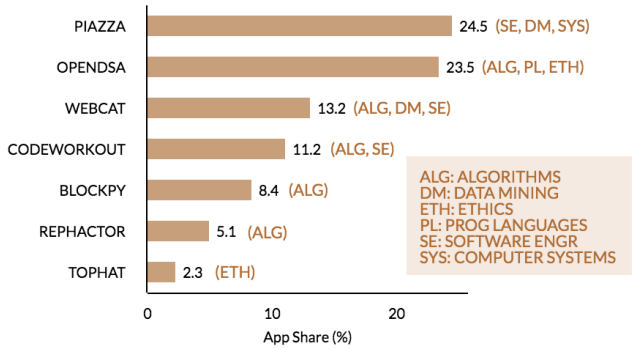

Figure 3: Third-party apps by frequency of use and computing specialization areas

of integration with grading apps, which reduces concerns about manual data imports, as well as data protection and privacy.

Figure 3 describes the frequently-used third-party apps at Virginia Tech Computer Science department, and the specialization areas of corresponding courses. The commonly used services in these app-suites are discussion forums and course content management (Piazza, Top Hat), exam management (WebCAT), programming instruction and interactive visualizations (OpenDSA, BlockPy, CodeWorkout), etc. Used by 27.8% of all courses considered, and often by undergraduate courses on programming, algorithms and software engineering, these apps do not affect course GPA and DFW rates (considered together or individually). While they offer seamless integration with LMS tools (for course, student and exam management), a majority of these apps lack one-to-many LTI connections which allow cross-course access, collaboration and research features. Lack of essential interoperability and ubiquitous access features often limits the wider adoption of these apps beyond their parent departments and research groups [18].

5.1.2 Participation. There are several important correlates of utilization that inform how relevant class size might be. While DOU is a strong positive-correlate of enrollment and viewership, graduate CS courses make a more exclusive use of LMS resources and have higher DOUs, with smaller class sizes on average. This points to the fact that undergraduate courses often rely on aforementioned legacy apps, especially for discussion forums (**H1**, table 5b). Similarly, in table 3, which describes the fraction of courses with above-average enrollment and viewership for all DOU groups, the high DOU group has a slightly smaller fraction of these courses (29%) compared to the medium DOU group (32%). Viewership, in contrast, is the aggregate of LMS and third-party app use, and both viewership and 3rd-party app use increase their relative share in the high DOU group.

5.1.3 Outcomes. The connection between learning outcomes and DOU, as per tables 4 and 5, is concerned with the use of LMS announcements, syllabi, and discussion forums, among others. The frequent use of native LMS apps by graduate courses coincides with lower variance of average course GPAs relative to undergraduate courses (OLS regression: $\theta_{ugrad} = -0.1, t = -2.6, p = 9e^{-3}$). Graduate courses often feature lower average enrollment and fewer teaching assistants. Coupled with the institutional and departmental balance of teaching and research responsibilities, these factors can drive higher use of native LMS apps and lessen the adoption of third-party tools. However, given the evidence in this section, undergraduate CS audiences need a broader push to scale up existing computing education tools and shore up their integration with LMS tools, in order to encourage personalized learning pathways.

5.2 Instructional Design: Choosing When and How to Intervene

System administrators and instructional designers can leverage this framework to begin to identify opportunities for meaningful LMS evangelism. DOU can point to faculty preferences about the use of legacy apps and resource allocation. For instance, in table 5, the hypothesis **H7** questions the relative utility of a comprehensive professional skills program (compared, for instance, to #TAs in **H6**) for assignment delivery and submission. The cohort with digital skills training is at best indifferent to 'deeper' LMS use. In an expert review by four instructional designers at Virginia Tech, we discovered that low DOU courses were often part of one of three micro-cohorts: 'junk-drive' (use of LMS course site as a file drive), 'gradebook-only', and 'access-portal' (exclusive use of third-party apps via course site). These cohorts require different interventions, each a function of the technology self-efficacy of course instructors, and the opportunity-cost of adopting new LMS tools. DOU can serve as a data-driven signal of the need for personalized interventions or additional teaching support for micro-cohorts of CS faculty. A detailed treatment of design interventions is left for future work.

6 CONCLUSIONS AND FUTURE WORK

In our analysis, we frame course-level utilization of LMS services as 'depth-of-use' or DOU, an aggregate of intuitive LMS resource-level logic rules. DOU helps us examine a variety of use-contexts in faculty and student adoption of LMS services. Our hypothesis-testing reveals that the need for scale, ubiquitous access and interoperability drives a broad swath of Computer Science courses towards 'deeper' LMS use. Our meta-analysis hopes to initiate an exploratory line of research on large-scale evaluation of LMS use. Our research seeks to unify expertise from course planning, policy design and quality assurance in order to test multi-level claims of efficacy (or lack thereof), and recommend interventions.

Our dataset and analysis describes all CS course sites commissioned on Canvas between 2015 and 2019 at Virginia Tech. Its scope can be broadened in several important ways. We examine these as directions of future work as follows. To aid generalizability, we intend to reproduce our analyses for Scholar LMS, in use before Canvas at Virginia Tech. Next, we hope to test key aspects of course modality (flipped/blended classrooms), and content and system quality (example pervasiveness [20], cognitive task models [16], recommender engagement [9], outcome bias [8], site aesthetics, mobile platform support and accessibility [22]) against DOU in order to analyze their impact on the usability of LMS services. We also plan to account for user-activity within LMS-hosted third-party apps. We plan to collaborate with several app vendors to better understand the impact of their interactional and content quality on learning outcomes.

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