Digital learning resources and student success: Analyzing engagement and academic performance

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Abstract

This study examines the impact of student engagement with digital learning resources – specifically sustained, timely, and distributed interactions with Learning Management Systems (LMS), e-textbooks, and digital study guides – on academic achievement outcomes in higher education. Using multiple regression analysis on data from 1,591 undergraduate students, the research identifies LMS engagement as a significant predictor of academic success, with specific behaviors such as prompt and consistent access strongly associated with academic performance. In contrast, e-textbooks and study guides play a more supplementary role. By incorporating confounding variables like age, gender, and academic mileage, the study offers a nuanced understanding of these relationships, underscoring the importance of an integrated approach to enhancing student engagement and learning outcomes.

Article Info

Introduction

The rapid digitalization of higher education, accelerated by the COVID-19 pandemic, has transformed how students engage with course materials and manage their learning processes. Learning Management Systems (LMS), digital study guides, and e-textbooks have become ubiquitous in modern educational settings, offering students unprecedented access to information and flexible learning opportunities. At the Singapore University of Social Sciences (SUSS), study guides serve as a learning resource, designed to facilitate self-directed learning. These guides provide a structured roadmap for students, helping them to focus on key concepts and effectively manage their independent study time. While LMS and e-textbooks are commonly used across higher education institutions, the integration of comprehensive study guides is a distinctive feature at SUSS, providing a more structured approach to asynchronous learning. These digital resources address the limitations of traditional classrooms by creating an interactive learning environment, providing faster feedback and enhancing student engagement. The significance of digital learning infrastructure became clear during the COVID-19 pandemic, which limited students' ability to attend classes in person. During this challenging time, digital technologies sustained the education system and allowed students to continue learning from home (Haleem et al., 2022). As educators and institutions increasingly invest in these technologies, it is crucial to understand not only their direct impact on academic performance but also how they foster student engagement, a key driver of academic success. Recent studies indicate that the way students interact with digital learning resources – through behaviors like frequency and consistency of access – significantly influences their motivation and academic outcomes (Lin et al., 2017a).

To fully harness the benefits of digital tools, it is essential to recognize the vital role of student engagement in academic success. Engagement with educational resources not only enhances learning but also promotes better organizational skills and time management (Kuh et al., 2008). Recent studies continue to affirm that student engagement is vital for academic achievement. For instance, Wolters and Brady (2021) emphasize that students who actively manage their time and engage with their learning resources tend to perform better academically, underscoring the importance of engagement.

As the shift from physical classrooms to digital platforms accelerates, maintaining student engagement in these environments has become crucial (Baloran et al., 2021). LMS, which serve as centralized hubs for course content, assignments, and communication, are specifically designed to promote such engagement (Dahlstrom et al., 2014; Brooks & Bichsel, 2014). However, as highlighted in the literature, merely providing access to an LMS does not ensure meaningful engagement or improved academic performance (Arnold & Pistilli, 2012). This underscores the necessity for strategies that not only facilitate access but also actively encourage student interaction with these platforms, as active engagement is crucial for achieving academic success.

Similarly, digital study guides and e-textbooks have proven to support student learning by offering structured, interactive, and accessible content. Study guides help students focus on key concepts and develop effective study habits, leading to better academic outcomes. E-textbooks, with their interactive features and multimedia content, can enhance comprehension and retention, particularly when students actively engage with the material (Rockinson-Szapkiw et al., 2013). Nevertheless, the impact of these resources on academic performance varies based on the quality of engagement and individual student preferences (Lin et al., 2017b). Effective engagement with digital resources requires not just access but also thoughtful design, tailored to the needs and preferences of students. Zeivots and Shalavin (2024) emphasize the importance of co-designing course materials to enhance student interaction and learning outcomes, particularly in online environments. While engagement is crucial, it is not the sole primary factor influencing better outcomes. The quality of course materials plays a fundamental role in supporting effective learning. However, even the most well-crafted course materials may not yield optimal outcomes if students are not actively engaged with them. Engagement involves the behavioral, emotional, and cognitive aspects, all of which contribute to a student's willingness to invest effort and persist in learning tasks. Hence, both the quality of course materials and student engagement are integral to achieving better academic outcomes. Consequently, educators should focus on designing high quality materials and implementing strategies to encourage student engagement to enhance learning outcomes.

Despite the many advantages of digital learning resources, understanding how student behavior and engagement with these tools influence academic outcomes is essential for making informed decisions about resource allocation and instructional design. However, in an increasingly digital and interconnected world, the existing literature remains sparse in addressing the characteristics of student engagement in online learning (Paulsen & McCormick, 2020). This study aims to fill that gap by exploring the relationship between student engagement with digital learning resources and academic achievement in higher education. Through an analysis of data on LMS access, study guide usage, and e-textbook interaction, we seek to identify the key engagement behaviors most predictive of academic success.

Literature review

Digital learning resources and their impact on student engagement and academic success

A Learning Management System (LMS) is a web-based platform designed to meet student needs by supporting the delivery, administration, and management of courses (Aldiab et al., 2019). LMSs are integral to modern education, providing centralized access to course materials, facilitating communication, and enabling student progress tracking. These platforms enhance engagement through features like discussion forums, quizzes, and assignment submission systems, all accessible via web browsers or mobile devices (Nasser et al., 2011; Kasim & Khalid, 2016).

Beyond providing access, LMS empowers students by enabling them to monitor their academic progress, fostering autonomy and self-regulation (Watson & Watson, 2007; Al-Fraihat et al., 2020). In online learning contexts, where self-initiated participation is key, this autonomy becomes even more crucial (Lin et al., 2017a). Research supports the role of LMS in boosting engagement and performance, with studies showing that regular interaction with LMS tools improves organizational skills, time management, and academic success (Junco & Clem, 2015). However, the effectiveness of LMS depends on active and meaningful engagement with course content (Arnold & Pistilli, 2012; Salas-Pilco et al., 2022). Bond et al. (2020) further emphasize that higher engagement levels, particularly through educational technology, are strongly linked to improved outcomes.

Building on the foundational role of LMS in student engagement, digital study guides complement these platforms by structuring student learning and focusing on key concepts. These guides provide a roadmap that enhances understanding and retention of course material. Effective study guides also promote critical learning strategies like self-explanation and retrieval practice. Moreover, adaptive study guides tailored to individual needs can significantly improve academic outcomes (Agarwal & Bain, 2019). As with LMS, the success of digital study guides relies on their ability to actively engage students in their learning process.

Just as study guides support focused learning, e-textbooks offer a flexible, interactive approach that complements these guides by integrating multimedia elements to enhance comprehension and retention. Research by Lin et al. (2017b) has shown that the specific behavior patterns students exhibit when accessing online learning materials can significantly influence their motivation and learning performance, suggesting that the quality and consistency of engagement are critical to academic success. Features like embedded quizzes, videos, and hyperlinks facilitate active learning and engagement with the material. Daniel and Woody (2013) found that students using e-textbooks often perform better academically compared to those using traditional print textbooks, especially when e-textbooks are well-integrated into the curriculum. However, challenges such as screen fatigue and preferences for printed materials highlight the need for careful implementation of e-textbooks.

Integrating these digital resources in higher education is essential for enhancing learning experiences and outcomes. Educators increasingly leverage LMS, study guides, and e-textbooks to create a comprehensive learning environment. Effective integration requires thoughtful planning and alignment with pedagogical goals (Moore et al., 2011). When seamlessly integrated into the curriculum, these digital resources can significantly enhance student engagement and academic performance (Garrison & Vaughan, 2012). However, variability in digital literacy among students and instructors can pose challenges to effective integration (Bates, 2022).

Educational data mining, learning analytics, and student engagement

To fully leverage digital tools like LMS, digital study guides, and e-textbooks, educational data mining (EDM) and learning analytics (LA) have become vital tools in enhancing student engagement and academic success. These fields involve analyzing large datasets from digital platforms such as LMS, digital study guides, and e-textbooks to identify patterns in student behavior, learning activities, and engagement levels. This analysis allows educators to develop targeted interventions, optimize learning experiences, and improve academic outcomes.

Recent studies emphasize the growing importance of predictive modeling within both EDM and LA. These models help forecast student performance, identify students at risk of failure, and personalize learning experiences to enhance outcomes. The application of machine learning – such as decision trees, neural networks, and support vector machines – has been particularly effective in increasing the accuracy of these predictions, leading to timely and appropriate interventions (Namoun & Alshanqiti, 2021).

Moreover, learning analytics has been shown to be instrumental in enhancing student engagement, especially in online learning environments. By analyzing various forms of student engagement – behavioral, cognitive, social, and emotional – learning analytics provides insights that can be used to tailor educational approaches and support students more effectively. Studies have found that multifaceted engagement approaches, supported by learning analytics, significantly improve students' learning performance (Johar et al., 2023).

As the use of digital tools in education continues to expand, the integration of EDM and LA will become increasingly critical in driving student engagement and academic success. These technologies enable the creation of more personalized learning experiences, directly supporting student achievement by identifying and enhancing the behaviors most predictive of success.

By leveraging the latest advancements in EDM and LA, as discussed in the literature review, this study explores the relationship between student engagement with digital learning resources and academic achievement. At SUSS, where study guides are a central component of the learning strategy, engagement with these resources played a pivotal role in the research. These guides provide students with interactive content designed to complement other digital tools like LMS and e-textbooks. Therefore, the focus on SUSS's unique reliance on study guides differentiates this study from those conducted at institutions where such resources are less integral. This deeper understanding will enable educators and administrators to implement data-driven strategies that enhance digital learning environments and improve student outcomes.

Methodology

Building on the insights from the literature, this study utilized a data mining approach to quantitatively assess the relationship between student engagement with digital learning resources and academic success. By analyzing engagement metrics, this methodology aimed to uncover patterns and correlations that provide a deeper understanding of how digital resources like LMS, digital study guides, and e-textbooks influence academic outcomes.

Data collection

The participants in this study included 1591 undergraduate students enrolled in four courses at SUSS. Data was collected from various digital platforms, including LMS, digital study guides, and e-textbooks. The study focused on the following engagement metrics:

Metric	Description
Immediacy	Measures the time lapse between a start date in access and a student's first online access
Recency	Measures the time lapse between an end date in access and a student's last online access
Frequency	Measures the number of sessions of online access between a start date and an end date in access
Duration	Measures the total access time from each session of online access
Interval	Measures the time lapse between a student's last online access and his first online access relative to the time lapse between a start date and an end date in access
Spread	Measures the dispersion of the sessions of online access
Mean-Gap	Measures the average gaps between successive sessions of online access

Figure 1. Engagement metrics. (Wong & Chong, 2018; Tan & Koh, 2018).

These engagement metrics, initially developed in previous studies by Wong and Chong (2018) and Tan and Koh (2018), were implemented across LMS, digital study guides, and e-textbooks. This study extended previous research by analyzing these metrics with additional demographic and academic performance data, providing a more comprehensive understanding of how various factors influenced student outcomes.

Data preprocessing was essential to ensure consistency and readiness for analysis. The steps involved included normalization, reverse scoring, and the creation of composite engagement metrics. To standardize engagement metrics measured on different scales, min-max normalization was applied, scaling metrics to a common range [0, 1]. Metrics that had an inverse relationship with academic performance were reverse-scored, ensuring that higher scores consistently represented higher levels of engagement. Finally, these processed metrics were combined to create composite engagement scores for LMS, e-textbooks, and digital study guides, which were used as independent variables in the regression analysis.

Multiple regression analysis

Multiple regression analysis was employed to assess the relationship between engagement metrics and academic performance, allowing for the control of confounding variables. This approach enabled us to evaluate the distinct contributions of each engagement metric to academic success, providing deeper insights into how specific behaviors influence academic outcomes.

The regression model included independent variables such as reversed-scored and normalized immediacy, reversed-scored and normalized recency, normalized frequency, normalized duration, reversed-scored and normalized interval, reversed-scored and normalized spread, and reversed-scored and normalized mean-gap, alongside potential confounders (e.g., age, gender). This approach helped to isolate the unique contribution of online engagement behaviors to academic success. We included the following confounders due to their potential influence on both engagement and academic outcomes:

1. Age – Age can influence both engagement and academic performance. Older students might have different learning styles, responsibilities, or time management skills compared to younger students, which could affect how they engage with digital tools and perform academically. For instance, an older student might be more disciplined in engaging with LMS due to work experience, which could lead to better academic outcomes independent of the engagement metrics being studied.

2. Gender – Gender can also influence engagement patterns and academic outcomes. Male and female students may engage with digital learning resources in different ways. These differences in engagement behavior can introduce variability in how students interact with learning tools, potentially confounding the relationship between engagement and academic success. For instance, one gender might be more inclined to use discussion forums, while the other might prefer direct study from e-textbooks. Such differences in engagement approaches could influence academic outcomes in ways that are not related to the engagement metrics themselves but rather to the underlying gender-based preferences in learning behaviors.

3. Company sponsorship – Company sponsorship can significantly influence both student engagement and academic performance. Sponsored students often demonstrate higher levels of engagement, driven by the financial and professional incentives associated with their sponsorship (Barrow & Rouse, 2018). This heightened motivation may lead them to invest more time in their coursework and utilize digital learning resources more effectively. Additionally, the requirements often tied to sponsorships, such as maintaining a specific grade-point average or achieving certain academic milestones, create a stronger sense of obligation to perform well academically. This external motivation can positively influence academic outcomes, independent of the

students' engagement with digital learning resources. Therefore, company sponsorship is a critical factor to consider in the analysis, as it may confound the relationship between engagement metrics and academic performance by contributing to improved outcomes through mechanisms unrelated to digital engagement.

4. Years since last study – Years since last study can be a significant potential confounder. Students returning to study after many years might require a period of adjustment to re-acquaint themselves with academic expectations, new learning technologies, and the pace of study. This adjustment period could affect their initial performance and engagement, confounding the relationship between engagement metrics and academic success. Furthermore, students who have been out of an academic setting for an extended period may experience a decline in study habits, academic skills, and familiarity with the learning environment. This atrophy can negatively impact their academic performance, regardless of their engagement with digital learning resources.

5. Academic mileage – "Academic mileage" refers to the cumulative academic experience that a student accumulates over time, measured through various indicators of academic engagement and performance. In this study, academic mileage data includes variables such as total credits units taken, withdrawn, failed, and completed.

Academic mileage variables are potential confounders for the following reasons:

a. Total credit units taken – A student who has taken more courses may have broader academic experience, leading to better-developed study habits that can independently influence their academic performance. Their improved outcomes may result from greater exposure to course material, rather than directly from higher engagement with digital tools. Students with higher total credit units taken may engage differently with digital tools because they have more experience and familiarity with the platforms. They may also be better at managing their time and resources, which could confound the relationship between engagement metrics and academic success.

b. Total credit units withdrawn and failed – These variables might reflect underlying academic difficulties or external challenges that could independently affect both engagement and academic outcomes. A student who frequently withdraws or fails courses might have lower engagement and academic performance due to factors unrelated to the use of digital learning resources, such as personal, financial, or health issues. Furthermore, external pressures such as balancing work and study could independently influence their level of engagement with digital tools.

c. Total credit units completed – The number of completed courses may indicate persistence and academic success, which could be associated with both higher engagement and better academic outcomes. Students who have completed more courses might engage more effectively with digital tools due to accumulated experience and familiarity with the academic system. This could lead to higher academic performance, confounding the relationship between current engagement metrics and academic outcomes.

Analysis and discussion

This section presents the results of our analysis, which proceeded in two phases. First, we examined the impact of composite engagement metrics for Learning Management Systems (LMS), e-textbooks, and digital study guides on academic performance, as measured by final weighted course scores. These composite metrics were constructed to encapsulate the overall engagement levels by aggregating dimensions such as immediacy, recency, frequency, and duration of interactions with digital learning resources.

Following this, we extended the analysis by incorporating individual engagement metrics alongside key confounding variables, including age, gender, company sponsorship, years since last study, and academic mileage. This more detailed examination aimed to uncover the specific aspects of engagement that most strongly influence academic outcomes, while also accounting for other factors that may affect the relationship between engagement and performance.

Phase 1: Analysis of composite engagement metrics

In the first phase of our analysis, we assessed the impact of composite engagement metrics for Learning Management Systems (LMS), e-textbooks, and digital study guides on academic performance, as measured by final weighted course scores. These composite metrics were designed to capture the overall engagement levels across multiple dimensions, such as immediacy, recency, frequency, duration, interval, spread, and mean-gap.

The multiple linear regression analysis revealed that the composite engagement metric for LMS had a significant positive relationship with academic performance. Specifically, the coefficient for LMS engagement was 8.4468 ($p < 0.001$), indicating that higher levels of engagement with the LMS were strongly associated with better academic outcomes. This finding aligns with existing literature that emphasizes the importance of structured and consistent interaction with course materials for academic success (Kuh et al., 2008).

In contrast, the composite engagement metrics for e-textbooks and digital study guides did not show a statistically significant relationship with final weighted course scores. The coefficient for e-textbook engagement was -0.3014 (p = 0.254), and for study guide engagement, it was -0.2343 (p = 0.438). This result indicates that the impact of these tools on academic success may be more complex, potentially depending on individual study habits or the specific integration of these resources within the learning process.

Several factors could explain the lack of significance for e-textbooks and study guides. As discussed in previous studies, the way students interact with these tools might not be as consistent or structured as their interaction with the LMS. Unlike the LMS, which often serves as the central hub for course-related activities, e-textbooks and study guides might be used more sporadically, depending on individual study habits and preferences. Additionally, students may print digital study guides and rely on physical copies, which are not captured in the engagement metrics collected from digital platform.

The model's R-squared value of 0.122 indicates that the composite engagement metrics collectively explain about 12.2% of the variance in academic performance. This suggests that while engagement with digital learning resources is indeed a factor in academic success, a significant portion of the variance is influenced by other factors, underscoring the complexity of academic performance (Arnold & Pistilli, 2012).

Overall, these findings contribute to the broader literature by reinforcing the critical role of LMS engagement in academic success, while also underscoring the need for a more nuanced understanding of the roles that e-textbooks and digital study guides play in diverse learning contexts. These results underscore the importance of timely and consistent LMS engagement, raising critical questions about the optimal integration of other digital tools, such as e-textbooks and study guides, to fully realize their educational potential.

Phase 2: Analysis of individual engagement metrics and confounding variables

Building on the insights gained from the composite metrics analysis in Phase 1, Phase 2 delves deeper into individual engagement behaviors and their specific impact on academic outcomes, while accounting for various confounding factors. This enhanced model aimed to isolate the distinct contributions of individual engagement metrics, offering a more nuanced understanding of how these behaviors influence academic performance. The key findings are:

1. LMS immediacy – The analysis revealed a significant positive relationship between the LMS immediacy metric and academic performance (β = 9.772, p < 0.001). This indicates that students who promptly accessed LMS resources after they became available were more likely to perform well academically. This underscores the critical role of timely engagement with

learning materials, reinforcing the notion that prompt access to course resources is essential for academic success.

2. LMS recency – The LMS recency metric also demonstrated a significant positive association with academic performance (β = 6.4745, p < 0.001). Students who accessed LMS resources more recently, in relation to the course timeline, tended to achieve higher grades, further emphasizing the importance of consistent engagement throughout the course.

3. LMS interval – The LMS interval metric, calculated as the time span between a student's last and first access, divided by the overall course access window (end time minus start time), emerged as another significant predictor of academic success (β = 4.8464, p < 0.001). This metric reflects how evenly a student spreads their engagement across the course duration. The positive association suggests that students who distributed their LMS resource access more evenly over time, rather than concentrating it at certain points, tended to perform better academically.

4. E-textbook mean-gap – The mean-gap metric for e-textbook usage was significantly associated with academic performance (β = 1.9402, p = 0.001). This suggests that students who interacted with e-textbooks more frequently, with shorter gaps between sessions, were more likely to achieve better academic outcomes. This finding points to the importance of regular and consistent e-textbook engagement for enhancing academic performance.

5. Other e-textbook metrics – Interestingly, other e-textbook engagement metrics, such as frequency and interval, did not show significant relationships with academic performance. This suggests that while regularity in e-textbook usage (as captured by the mean-gap metric) is crucial, other aspects of e-textbook engagement may not be as influential in this context.

6. Non-significance study guide metrics – None of the study guide engagement metrics were significantly related to academic performance in this model. This suggests that the impact of digital study guides on academic outcomes might be more complex, depending on how they are used with other learning tools. It may also imply that study guides serve better as supplementary resources rather than primary learning tools.

Confounding variables

1. Total credit units taken – This variable exhibited a small but significant negative relationship with academic performance (β = -0.0086, p = 0.035). This suggests that students who enrolled in

more courses might experience a slight decline in their average performance, potentially due to the increased workload and divided attention.

2. Total credit units failed – This variable was negatively associated with academic performance ($\beta = -0.0460$, $p = 0.002$), which is expected as it reflects prior academic difficulties.

3. Age – The analysis indicated a slight negative impact of age on academic performance ($\beta = -0.0167$, $p = 0.030$), suggesting that older students might encounter challenges, such as balancing study with other responsibilities, which could affect their grades. Additionally, age might influence engagement patterns with digital resources. Older students might approach LMS usage and other resources with different expectations or preferences, potentially engaging more strategically or cautiously compared to younger students who might be more accustomed to frequent and diverse interactions in digital learning environments. These differences in engagement approach – intensity and style of engagement – could contribute to varying academic outcomes.

4. Company sponsorship – The indicator that students were not sponsored by a company was associated with lower academic performance ($\beta = -0.1411$, $p = 0.008$). This finding suggests that students without sponsorship might achieve lower academic outcomes, due to the lack of additional financial and professional incentives that could enhance their motivation and performance.

5. Gender – Gender did not show a significant impact on academic performance ($\beta = -0.1124$, $p = 0.870$), indicating that engagement metrics influenced academic performance similarly across genders in this context.

The model explained 41.3% of the variance in academic performance, a substantial improvement from the Phase 1 model. This suggests that incorporating individual engagement metrics and confounders provides a more detailed and accurate understanding of the drivers behind academic success. The F-statistic of 34.27 ($p < 0.001$) confirmed the overall significance of the model.

Conclusions and recommendations

This study's findings from both Phase 1 and Phase 2 offer important insights into how student engagement with digital learning resources affects academic performance. By examining composite and individual engagement metrics, we not only reaffirm the critical role of timely and consistent engagement but also reveal how different digital resources contribute uniquely to academic outcomes. In the next section, we detail key takeaways regarding the importance of LMS engagement, the supplementary role of other digital resources, and the influence of confounding variables, followed by recommendations for educators and policymakers.

LMS engagement as a key driver of academic success

One of the primary conclusions from Phase 1 is the central role that Learning Management Systems (LMS) play in supporting academic success. Consistent with existing literature (Kuh et al., 2008), we find a strong positive association between LMS engagement and academic performance, highlighting the importance of structured, ongoing interaction with course materials. This suggests that LMS, when utilized effectively, can be instrumental in fostering sustained engagement and improving academic outcomes.

Phase 2 builds on this by showing that specific LMS behaviors – such as immediacy, recency, and the distribution of access over time – are significant predictors of success. Students who engage regularly and promptly with LMS resources tend to achieve higher grades, underscoring the importance of not only providing access to digital tools but also promoting their timely and consistent use. This highlights the potential impact of institutional strategies that encourage these patterns of engagement.

To prompt this level of engagement, institutions can consider the following strategies:

1. Automated reminders and alerts – Setting up automated reminders within the LMS can encourage students to engage promptly with new content and assignments. Notifications for upcoming deadlines, available resources, and suggested study schedules can help students manage their time effectively and promote frequent engagement.

2. Learning analytics – Learning analytics can further enhance tech-enabled learning by allowing educators to monitor engagement in real-time and personalize interventions. For example, analytics could help identify students at risk of disengagement early on, enabling timely support. A real-time dashboard could allow educators to track key engagement metrics, identify patterns of low engagement or disengagement, and intervene when necessary. By supporting timely intervention, this tool can help educators keep students on track throughout the course.

3. Student-facing engagement dashboard – Introducing a student-facing engagement dashboard could empower students to monitor their own engagement patterns, supporting self-agency and fostering self-regulated learning. This can encourage students to take responsibility for their learning, make adjustments when necessary, and see the direct link between their engagement habits and academic performance.

4. Faculty engagement and reminders – Faculty can play a critical role by regularly updating content, responding to discussion posts, and sending periodic messages encouraging students to check LMS materials. Active instructor involvement can signal to students that engagement is expected and valued.

E-textbooks and study guides: Supplementary, not primary tools

The non-significant results for e-textbook and study guide composite metrics in Phase 1, combined with the mixed results from individual metrics in Phase 2, suggest that these tools may play more of a supplementary role in the learning process. While regular and consistent interaction with e-textbooks (as captured by the mean-gap metric) was associated with better academic performance, other aspects of e-textbook engagement and all study guide metrics did not show a significant impact.

This may reflect how students use these tools – more sporadically or as supplementary resources rather than primary learning platforms. These findings align with previous research, which suggests that while e-textbooks and study guides are valuable, their impact on academic outcomes may depend on individual study habits and how these resources are integrated into the broader learning environment. Future course designs should consider incorporating student feedback and co-design processes to enhance engagement with digital readings, as suggested by Zeivots and Shalavin (2024), to maximize the effectiveness of these resources.

The role of confounding variables

The inclusion of confounding variables such as age, gender, company sponsorship, years since last study, and academic mileage in Phase 2 provided a more nuanced understanding of the factors influencing academic performance. The significant negative impact of variables such as total credit units taken, total credit units failed, and age on academic performance highlights the importance of considering a student's broader academic and personal context when evaluating their engagement and success.

Interestingly, the negative association between company sponsorship and academic performance, where students without sponsorship performed worse, underscores the potential motivational benefits of external financial and professional incentives (Barrow & Rouse, 2018). This finding suggests that company-sponsored students might be more motivated to engage with digital tools and achieve higher academic outcomes, due to the additional pressure to meet sponsorship requirements.

Conversely, this finding also implies that self-financed students, who might experience greater financial and emotional pressures, could struggle to balance the demands of work and study, potentially leading to lower engagement with digital resources. The added pressure from self-financing could detract from the time and energy available for academic tasks, affecting their academic performance and overall well-being. Institutions could consider offering self-paced and hybrid course formats that can help self-financed students better balance work and study or providing targeted financial aid, scholarships, or grants aimed at self-financed students to alleviate some of the stress associated with funding their education. Additionally, offering academic support, such as coaching or time-management workshops, could help these students develop effective strategies to maintain engagement.

Implications for educators and policymakers

These findings have several important implications for educators and policymakers in higher education. The significant role of LMS engagement in driving academic success suggests that institutions should prioritize the effective deployment and integration of LMS. However, not all engagement is equally beneficial; the type and quality of engagement are crucial in fostering positive academic outcomes.

Research from this study highlights that specific types of LMS engagement – such as immediacy, recency, and the distribution of access over time (interval) – are key predictors of success. *Immediacy*, which reflects how promptly students engage with new content, supports timely learning and reduces the risk of falling behind. *Recency*, or how recently students accessed LMS resources relative to course timelines, indicates sustained engagement and consistent revision, which aids retention of course deliverables and learning objectives. Finally, *Interval*, which refers to spreading engagement evenly across the course duration, discourages last-minute cramming and promotes a steady learning pace.

For educators, these findings suggest that prompting timely, sustained, and well-distributed engagement is more effective than encouraging general LMS access. Institutions can foster these types of engagement through targeted reminders and timely updates, regular and small assignments, and encouraging consistent progress by designing structured check-ins with students. By focusing on these specific engagement behaviors, institutions can better support students' academic success and make LMS interactions more meaningful and beneficial.

Looking forward, as LMS technology develops with Artificial Intelligence (AI), these strategies could be further strengthened. AI-driven tools such as personalized content recommendations, adaptive learning paths, and predictive analytics could support students based on their unique engagement patterns. These advancements could make LMS platforms even more responsive and supportive of individual learning needs, further enhancing the efficacy of the recommendations outlined in this study.

Limitations

This study included 1,591 undergraduate students from SUSS, an institution that emphasizes self-directed learning through digital study guides and e-textbooks. Therefore, the

results may not generalize to institutions that rely less on these tools. Moreover, the SUSS-specific context of learning guides means that their role as supplementary or primary tools may vary significantly in other higher education environments.

Although the study controlled several confounding variables such as age, gender, company sponsorship, and academic mileage, other unmeasured factors may still influence academic performance. For example, study habits or preferences for learning tools might play a role in how digital resources impact student outcomes.

The study focused on the use of digital learning resources, but it did not capture whether students used printed physical copies of digital study guides. This is a potential limitation, as some students may rely on printed versions of these materials for their learning, which could affect their engagement with the digital resources being measured.

The study did not explore the temporal dynamics of engagement over a semester. Engagement behaviors might fluctuate at different points during the academic term (e.g., near exam periods or assignment deadlines), which could affect academic performance. A more detailed analysis capturing these fluctuations might provide a more nuanced understanding of how engagement evolves and impacts outcomes over time.

Future work

Future research could explore these limitations by expanding the study to include a more diverse sample, incorporating self-reported engagement measures, and analyzing additional digital tools. Moreover, further studies could provide deeper insights into the temporal aspects of engagement and its impact on academic outcomes.

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