Tracking Self-Regulated Learning Strategies in Blended Learning: A Digital Trace Approach

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Abstract

This study examined digital traces in the form of clicks on Learning Management System (LMS) modules to infer and monitor students' Self-Regulated Learning (SRL) strategies in a blended learning environment. Digital traces were aligned with students' responses on the A-SRL questionnaire (Magno, 2010), and these findings were further triangulated through student interviews. The results suggest that clicks on LMS modules containing theoretical material and gradebook indicate students' use of a single corresponding SRL strategy and may serve as a good indicator of SRL behavior, while other digital traces relate to multiple strategies at once and lack a singular interpretation. Additionally, it was found that students in blended courses may use SRL strategies outside of the LMS. The study offers practical implications for instructional designers and practitioners seeking to support SRL in blended learning environments.

Keywords: Self-regulated learning; digital traces; blended learning

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Introduction

The COVID pandemic has dramatically changed the learning landscape of higher education, accelerating a shift from traditional offline learning to fully online or partially online models. Partially online learning models include hybrid and blended learning, where face to face instruction is combined with online elements to varying degrees (Singh et al., 2021). In both online and blended learning models, learners need to be more self-directed and autonomous in managing their learning. These demands are closely aligned with the concept of Self-Regulated Learning (SRL), and the importance of SRL is well-established in both online and blended environments (Xu et al., 2023).

SRL is a cyclical process, during which students plan their learning activities, monitor, control, and assess their learning progress in order to reach their intended academic goals (Zimmerman, 2002). Research has consistently demonstrated that learners who use SRL strategies achieve higher academic performance than those who do not (Pintrich & De Groot, 1990).

While considerable research has focused on enhancing and measuring SRL in fully online learning (Kizilcec et al., 2017; Lee et al., 2019), blended courses are less studied in terms of the application and measurement of SRL (Anthonysamy et al., 2020). This gap is significant because students in blended courses must navigate both online and offline learning simultaneously (Broadbent et al., 2021), and results observed in fully online courses may not directly translate to blended settings.

There is extant research on different aspects of SRL as well as the effects it can have on academic performance (Xu et al., 2023). However, most studies rely on self-reported data (Han & Ellis, 2023). Digital traces, or data generated from students' interactions with online learning systems, have gained increasing attention with the shift toward online education as they offer researchers and practitioners a way to monitor SRL and student activity without overburdening students with surveys and interviews (Maldonado-Mahauad et al., 2018). The current study builds on this emerging approach by exploring the potential of using digital traces as an instrument to infer and monitor students' SRL strategies in a blended course.

Literature Review

Self-regulated Learning and Strategies

SRL has been conceptualized in various ways, with researchers offering multiple models to describe its process. Currently, several theories aim to describe and operationalize SRL (Panadero, 2017). According to the most widely used model, there are three phases of SRL: forethought, performance, and self-reflection (Zimmerman, 2000). Students iteratively engage in these phases during the learning process. In the forethought phase, learners set goals, plan strategies, and activate their motivation. During the performance phase, learners monitor their progress and adjust their strategies accordingly. In the self-reflection phase, learners evaluate their performance and reflect on their learning experience. Beyond Zimmerman's foundational model, Pintrich (2000) proposed an expanded framework that incorporates "monitoring" and

"control" phases, highlighting the cyclical nature of SRL. Unlike Zimmerman, who treats motivation as an influence on SRL, Pintrich's model positions motivation as an integral component of self-regulatory behavior itself, arguing that students cannot effectively self-regulate without a strong motivational drive. While models such as Boekaerts' (1999) model focusing on adaptation, or Winne and Hadwin's (1998) model that emphasizes cognitive processing and orchestration, offer valuable insights into specific facets of self-regulation, Zimmerman's model is widely regarded as offering the most comprehensive and holistic framework. Its strength lies in its detailed articulation of the cyclical processes of SRL, encompassing planning, performance, and reflection phases, which provides a robust framework for understanding and investigating the breadth of self-regulatory activities. Furthermore, the widespread adoption and application of Zimmerman's model in numerous educational contexts underscores its generalizability and practical utility for researchers and educators alike (Panadero, 2017).

The ability to self-regulate the learning process is not a fixed trait or quality of a person, but a dynamic set of skills and strategies that students may or may not employ to achieve academic goals (Zimmerman, 1989). This set consists of cognitive, metacognitive, and resource management strategies that students use as a part of their SRL behavior (Puzziferro, 2008). Cognitive strategies, such as rehearsal, help students better acquire and retain information (Zimmerman, 2000). Metacognitive strategies, for instance, goal setting, seeking assistance, and self-evaluation, help students to monitor and adjust the learning process (Schunk, 2005). Resource management strategies allow students to optimize their use of educational and environmental resources (Puzziferro, 2008). Self-regulated learning strategies may be taught to students in order to assist the process of constructing knowledge in a structured way (Zimmerman, 1989). The application of SRL strategies is usually related to high academic achievement in traditional learning settings (Pintrich & De Groot, 1990).

Because SRL is a recursive process that unfolds over time (Butler & Winne, 1995), more accurate and authentic research may be conducted by exploring how SRL strategies are used as sequences of events in real time (Rovers et al., 2019). Previous studies have typically measured students' use of SRL strategies with either structured interviews (Zimmerman & Pons, 1986) or self-report questionnaires, such as the Academic Self-Regulated Learning Scale (A-SRL-S), developed by Magno (2010), or MSLQ, published by Pintrich et al. (1991). Both methods rely on students recalling and reporting their past SRL behaviors rather than capturing actual SRL in real time. As a result, they are susceptible to recall bias (Winne, 2017). The think-aloud method, a form of interview where students verbalize their thoughts while completing a task, has been used to demonstrate SRL strategies in real time. However, this method can unintentionally prompt self-reflection, thereby altering the very behaviors it aims to capture and compromising the validity of the findings (Fan et al., 2023).

These validity concerns limit the effectiveness of using questionnaires and interviews as the sole method for measuring SRL. The emergence of digital traces offers a promising supplement for making research more authentic. Digital traces are generated in real time, are free from recall bias, and don't induce changes in students' SRL levels (Zhou & Winne, 2012).

Using digital traces to evaluate SRL strategies could mitigate problems associated with more traditional measurement instruments (e.g., social desirability, recall bias, and resource intensiveness), particularly if digital traces are used in conjunction with those instruments to avoid validity issues (Fan et al., 2023).

Digital Traces for SLR Monitoring and Their Validation

In the context of online education, digital traces refer to the data trails left behind by learners as they interact with online learning environments and tools (Rafaeli et al., 2019). Researchers use different types of digital traces: user-generated content (e.g., forum posts); assessment data such as grades and test scores; log files which include records of students' actions and clicks on certain online course modules, which are interpreted as students' actions or sequences of actions (Du et al., 2023). The widespread use of Learning Management Systems (LMS) has led SRL researchers to increasingly rely on clickstream data to analyze students' behaviors through their click activities in these systems (Baker et al., 2020; Crompton et al., 2020).

A recent comprehensive review of literature by Du et al. (2023), which explores the use of digital traces and their correlation with different SRL subprocesses and strategies, highlights the lack of consensus on how to measure SRL using digital traces. Some studies define digital traces in terms of SRL phases (e.g., forethought phase) and do not deconstruct it further into SRL strategies (Cerezo et al., 2020; Yang et al., 2018). Others choose a set of strategies based on an SRL model or questionnaire they use. These sets of strategies vary across studies, often due to differences in online platforms (e.g., the absence of specific modules may inhibit observing related strategies) or SRL models that researchers use (Antonio Perez-Alvarez et al., 2020; Kizilcec et al., 2017).

Several studies that use digital traces base their set of SRL strategies on Zimmerman and Pons' SRLIS questionnaire (1986). The memory strategy is operationalized as interacting with video lectures (Maldonado-Mahauad et al., 2018; Wong et al., 2019) or reading provided texts and adding notes (Antonio Perez-Alvarez et al., 2020; Bernacki et al., 2012; Bouchet et al., 2013; Pérez-Sanagustín et al., 2021). The goal-setting strategy is typically measured through interactions with course elements, such as course syllabus, planning panel (Antonio Perez-Alvarez et al., 2020; Huang & Lajoie, 2021; Milikić et al., 2020; Siadaty et al., 2016) or students' visits to the course information page or weekly overview page (Fan et al., 2023; Jansen et al., 2020; Saint et al., 2022). The self-evaluation strategy is attributed to resolving learning gaps by interacting with grade reports (Rodrigues et al., 2019), revising prior learning content (Fan, Saint, et al., 2021; Kizilcec et al., 2017; Lan et al., 2019), reviewing an assessment (Maldonado-Mahauad et al., 2018; Wong et al., 2019), and interacting with assessments (Fan, Matcha, et al., 2021; Halem et al., 2020; Matcha et al., 2020). The organizing strategy is not in the focus of previous studies due to the fact that it implies physical interactions with learning materials, which pose challenges for tracking by digital traces (Broadbent & Poon, 2015).

Despite the prevalence of measuring SRL through digital trace data, ongoing challenges persist in establishing a clear mapping between actual trace data and SRL processes (Fan, Matcha, et al., 2021; Saint et al., 2020a). Researchers typically infer that the behaviors they observe via digital traces are related to SRL. For example, rewatching an educational video may

be interpreted as memory strategy activation in order to rehearse the new material. However, such behaviors may also be caused by other, non-related to SRL reasons, such as a bad internet connection or distractions. Moreover, the same digital traces could reflect different latent variables, such as SRL, student engagement, motivation, etc. Thus, a problem of trace data validation arises (Winne, 2010).

Researchers tackle this problem by supplementing digital traces with other sources of data. Triangulating data can provide researchers with a fuller picture of actual SRL behavior (Winne, 2010). Questionnaires are often used to cross-reference students' reported SRL strategy use with trace data (Halem et al., 2020; Saint et al., 2020a). Other studies employ interviews as a means of validating and further contextualizing theoretical inferences drawn from trace data.

Triangulation of methods (aligning digital traces, questionnaires, and interviews) helps address the limitations inherent in each individual approach (Fan et al., 2023) and is particularly valuable in online environments, where direct access to students is limited. Du et al. (2023) proposed a guide to online trace data analysis for measuring SRL depending on the LMS systems and suggested to combine different types of data sources. Ye and Pennisi (2022) triangulated questionnaire, digital trace, and interview data in a fully offline asynchronous environment. Applying such triangulation may be even more valuable in a blended educational environment, since it makes it possible to supplement qualitative data with student interviews that further validate the research (Han & Ellis, 2023).

Blended Learning and SRL

Blended learning is an educational environment that allows practitioners to effectively combine the benefits of two approaches: face-to-face classroom and social engagement and interactions, but also the digital tools that provide enhanced learning possibilities (Singh et al., 2021). This integration of various digital resources, as well as the presence of real-world communication among students and instructors, creates a flexible format that can meet learner needs and foster an engaging learning experience.

The range of SRL strategies involved, as well as their effectiveness, can vary depending on the context. Previous research indicated that online learning students reported a higher frequency of utilizing SRL strategies compared to blended learning students (Broadbent, 2017). The type of strategies also differs: learners in blended environments tend to rely more on the SRL strategies that require communication skills (Zhang et al., 2023), while strategies such as goal-setting, task strategies, time management, and environmental structuring are more often used by learners in online environments. Additionally, while students in online learning environments apply SRL across all activities, students in blended courses may experience confusion. Since part of the learning process that happens face-to-face is regulated by the instructor (Broadbent et al., 2021), and another part, such as an online task or assignment, is regulated by students themselves, it might create difficulties to switch from one mode to another and to know when they need to follow teacher's instructions versus when to self-monitor and take responsibility for their learning (Onah et al., 2021).

This ambiguity in blended learning formats also complicates the measurement of SRL skills. While data available from digital traces in online courses reveal the full scope of students' actions and allows us to draw conclusions on their behavioral patterns and thus, the level of self-regulation (Maldonado-Mahauad et al., 2018), in blended environments, students refer to both online activities and face-to-face interactions and instructions, which remain invisible for learning systems and platforms. Hence, to address these challenges, the current study uses a mixed-methods approach, combining a questionnaire, digital traces, and interviews.

Current Study

While previous research has demonstrated that digital traces can be used to track student behavior (Du et al., 2023), there is still a need to interpret which specific actions within an LMS reflect students' SRL strategies. It also remains unclear to what extent these actions correspond to specific strategies and whether such interpretations can be generalized across different learning environments.

The current study assumes that some strategies are more traceable in a digital environment than others. For example, memory strategies may be reflected by the number of times of watching video-lectures (Maldonado-Mahauad et al., 2018), while other strategies, like help-seeking, might not be as visible in blended courses, as there is always room for personal offline communication among students as well as with the instructor. Building on previous research (see Du et al., 2023), this study attempts to examine which strategies belong to both categories using methods triangulation.

To strengthen the evidence linking SRL strategies to students' digital traces, interviews were conducted to gather additional insights from the students. They serve to deepen the understanding of students' self-regulation practices, and to highlight individual differences.

The study attempts to answer the following research questions:

RQ 1: Which SRL strategies could be observed through digital traces in blended courses?

RQ 2: How does digital trace interpretation reflect actual SRL behavior?

Materials and Methods

Sample

The sample comprised 16 first-year master's students enrolled in an educational sciences program at a top-ranked Russian university. The participant demographic included 11 female and 5 male students, with ages ranging from 21 to 33 years (M = 25, SD = 3,79). All participants self-reported prior experience with blended learning environments. Participants were recruited via email invitation sent to all students (N = 24) enrolled in a blended learning course upon its completion and final grade posting. Participation was voluntary and offered no incentives. Of the invited students, 16 agreed to participate in the study.

Course Context

The study took place after a 7-week blended introductory course on statistics and data analysis. The course consisted of seven synchronous lectures and seven seminars, covering three key topics: data and variables, descriptive statistics, and comparison of means. The course was offered in a hybrid format, with lectures streamed online and also available for in-person attendance, allowing students to choose their preferred mode of participation every week. Lecture recordings, additional materials (e.g., textbooks, PowerPoint presentations used by the lecturer), self-assessment tests, course syllabus, and gradebook were available via a Moodle-based LMS.

Measures

To identify which SRL strategies could be observed via digital traces in a blended learning environment, the study aligned digital trace data on students' SRL behavior with a well-known A-SRL scale (Magno, 2010) and is additionally supplemented by interviews with students. The A-SRL scale was selected for its relevance to academic setting and its brevity relative to other questionnaires. The primary purpose of administering the A-SRL scale was to provide a framework for understanding the relationships between students' self-reported SRL strategy usage and their interactions with learning materials within the LMS, as captured by digital trace data.

The instrument consists of seven factors, each corresponding to an SRL strategy:

- Memory strategy—techniques which help learners memorize and retrieve new information (Cronbach's Alpha = 0.65).
- Goal setting—the setting of educational goals in order to exert the effort required to achieve them (Cronbach's Alpha = 0.59).
- Self-evaluation—activities for monitoring the learning process in relation to defined goals (Cronbach's Alpha = 0.44).
- Seeking assistance—asking others for help, or consulting external help and resources (Cronbach's Alpha = 0.60).
- Environmental structuring—efforts to arrange the physical setting to make learning easier (Cronbach's Alpha = 0.66).
- Learning responsibility—prioritizing study above other activities (Cronbach's Alpha = 0.34).
- Organizing—overt or covert rearrangement of instructional materials to improve learning (Cronbach's Alpha = 0.33).

Each factor was measured by several 4-point Likert scale questions. The questionnaire was translated to the Russian language and administered online; 16 students responded (see Appendix A for the questionnaire). Although several factors yielded low Cronbach's alpha values, it may be attributed to the limited sample size. Cronbach's alpha is sensitive to sample size; with small n, even modest variations in responses can significantly impact the coefficient. Specifically, lower-than-expected item covariance in a small sample can result in an artificially depressed alpha. Importantly, Cronbach's alpha measures the internal consistency of the questionnaire itself, indicating how well items within a factor correlate, not the reliability of individual respondents. Given the small sample size, we are focusing on exploring the

relationships between these self-reported SRL strategies, LMS activity (module clicks), and interview data. The distribution of SRL strategy usage within this specific student population is not the primary focus of this analysis. Since the questionnaire is based on a validated instrument with established construct validity, the results are considered to be interpretable and suitable for exploratory analysis, acknowledging the sample size limitations.

The students' digital traces were acquired from the university's LMS. Each student's clicks on a certain LMS module available for students (e.g., syllabus) throughout the length of the course were summarized to create a single value of a variable corresponding to each module (e.g., clicks on syllabus):

- Clicks on lecture recordings—all hybrid lectures were recorded and available for students to watch later.
- Clicks on lecture slides—a module, containing all PowerPoint presentations used by the lecturer.
- Clicks on additional materials—three statistics textbooks, recommended by the lecturer.
- Clicks on the course syllabus—a spreadsheet, containing information on deadlines and knowledge requirements.
- Clicks on the course introduction—a link to a presentation on the final grade formula and other course details.
- Clicks on gradebook—a dashboard with grades for tests and the final project.
- Clicks on self-assessment tests—quizzes, which were readily available for students to test their knowledge without fear of getting an unsatisfactory grade.

All click-based variables were standardized to ensure comparability across modules and simplify subsequent analysis. Given the small sample size, no outlier removal was applied, as the goal was to support descriptive profiling and correlation analysis, rather than model distributional properties. For descriptive statistics before standardization, see Table 1.

Table 1

Descriptive Statistics for Students' Digital Traces

	Mean	SD	Min	Max
Clicks on lecture recordings	6.7	4.9	0	16
Clicks on lecture slides	16.1	8.7	4	21
Clicks on textbooks	8.5	6.4	1	21
Clicks on course syllabus (pdf)	4.2	3.6	0	13
Clicks on course introduction (pptx)	3.3	3.1	0	11
Clicks on gradebook	8.7	1.1	7	10

Clicks on self-assessment test 1	1.5	1.1	0	4
Clicks on self-assessment test 2	1.4	1.1	0	4

Following the completion and analysis of the questionnaire, participants were invited to participate in an hour-long semi-structured interview. Participation in the interviews was voluntary and no incentives were offered. Eight of the initial sixteen questionnaire participants agreed to be interviewed. While the participant pool was reduced, no apparent self-selection bias was detected, with high variance in both achievement level and SRL strategies usage of recruited students.

The interviews were conducted by two of the study's authors, who had no prior relationship with the participants or the course instructor. Prior to conducting the interviews, the interviewers completed a brief training session to familiarize themselves with the interview guide. The interviews were designed to explore the validity of the relationships identified between specific digital trace data and SRL strategies, and to provide further confirmation that the digital traces were reflective of SRL behaviors. The interview guide (see Appendix B) followed the structure of the course, prompting students to discuss their learning organization, homework routines, approaches to the final project, and other relevant course-related activities. Each question in the guide was designed to elicit information pertaining to students' SRL behaviors throughout the course and their use of LMS. Following the completion of all interviews, the recordings underwent manual transcription.

Analysis Strategy

To answer RQ1 (Which SRL strategies could be observed through digital traces in blended courses?) a Pearson's correlation analysis of the reported use of SRL strategies and clicks on LMS course modules was performed.

To answer RQ2 (How does digital trace interpretation reflect actual SRL behavior?), a thematic analysis of the interviews was conducted via ATLAS.Ti software. The analysis followed a widely used 6-step structure (Braun & Clarke, 2006) and was conducted by two independent coders to ensure reliability. First, an in-depth reading to familiarize with the interviews was conducted. After that, each interview was read and coded. Codes aimed to reflect students' ways of using certain LMS modules (e.g., "self-tests as a means of rehearsal", "lecture slides for notes"), learning practices (e.g., "tutor messages for setting deadlines"), and attitudes (e.g., "grade as a motivator"). Codes were then categorized into initial themes by two coders independently. After that, codes and themes were jointly reviewed and refined across coders to ensure trustworthiness. Codes that were present in both coders' results and occurred in many interviews were used to form three themes. Finally, themes were reported.

Results

RQ1: Which SRL strategies could be observed through digital traces in blended courses?

Among the examined strategies, the Memory strategy was the only one to demonstrate a correlational relationship with multiple digital traces (Table 2). Specifically, higher Memory strategy was associated with more views of lecture slides ($r = 0.512$, $p < 0.1$), course syllabus ($r = 0.546$, $p < 0.1$), gradebook ($r = 0.459$, $p < 0.1$), and the second self-assessment test ($r = 0.796$, $p < 0.1$). Notably, the first self-assessment test was not significantly related to the Memory strategy, or any other strategy for that matter. More surprisingly, the more often students viewed lecture recordings, the weaker was their Memory strategy ($r =- 0.548$, $p < 0.1$). This might be explained by the blended nature of the course under study, but overall, it warrants further exploration in the qualitative part of the analysis.

Table 2

Pearson Correlation Coefficient for SRL Strategies According to the Questionnaire and Students' Digital Traces

	Memory Strategy	Goal Setting	Self-Evaluation	Seeking Assistance	Environmental Structuring	Learning Responsibility	Organizing
Clicks on lecture recordings	**-.548***	-.116	-.174	-.213	.084	**-.581***	**-.437***
Clicks on lecture slides	**.512***	.037	-.064	-.008	**.471***	.194	.337
Clicks on textbooks	.230	.021	.055	-.088	**.601***	.249	.200
Clicks on course syllabus (pdf)	**.546***	-.253	.282	.240	.208	.219	.206
Clicks on course introduction (pptx)	.045	-.178	.161	-.148	.280	.280	**.203***
Clicks on gradebook	**.459***	-.230	.120	.124	.284	.330	.526
Clicks on self-assessment test 1	.248	-.130	.028	-.077	-.280	.341	.233
Clicks on self-	**.796***	.136	.167	.240	.080	**.496***	**.455***

assessment test 2	

*p < 0.1

Environmental Structuring was positively related to clicking on lecture slides ($r = 0.471$, $p < 0.1$) and textbooks ($r = 0.601$, $p < 0.1$). Learning Responsibility was negatively related to watching lectures ($r = -0.581$, $p < 0.1$) and positively related to the second self-assessment test ($r = 0.496$, $p < 0.1$), as was the case with Organizing ($r = 0.455$, $p < 0.1$). Organizing was further related to viewing the course introduction ($r = 0.203$, $p < 0.1$) (even though course introduction and syllabus usage were expected to be related to Goal Setting and Self-Evaluation). Goal Setting, Self-Evaluation, and Seeking Assistance were not reflected in interactions with LMS materials at all.

RQ2: How does digital trace interpretation reflect actual SRL behavior?

During the interviews, students were asked how they used different LMS modules. Their answers and corresponding codes help to enrich the understanding of the relationships between clicks and SRL strategies. As a result of the analysis, three main themes emerged: "Common SRL behavior," "Dissimilar SRL strategies," and "Non-traceable SRL strategies" (see Table 3).

Table 3

Codes and Themes Generated During Thematic Analysis

Code	Overall number of quotes	Number of students	Theme
Lecture slides as means of rehearsal	12	7	Common SRL behavior
Using slides for notes	7	5	
Textbooks for theory	5	4	
Textbooks difficult	7	5	
Lecture recordings as a substitute for a missed lecture	5	4	
Self-assessment as means of familiarization	5	5	Dissimilar SRL strategies
Self-assessment as means of rehearsal	2	1	

Self-assessment for reflection	11	7	
Syllabus for planning	3	2	
Syllabus for self-evaluation	3	2	
Viewed grades rarely	7	7	
Deadlines in the chat	3	2	Non-traceable SRL
Tutor's reminders	6	3	strategies
Did not view LMS often	4	3	
Consulting with classmates	7	4	

Theme 1: Common SRL Behavior

Students' use of the memory strategy was found to be similar. They recognized the need to prepare for the upcoming seminars and used the LMS to revisit theoretical materials and rehearse. There was a common path taken by students: revisit the presentation, check the textbook, if necessary, rehearse the material via a self-assessment test:

> To truly understand this topic, I had to read textbooks and other materials afterwards. I would write down confidence intervals for myself, write down all the terms, and so on. I used textbooks, online courses, presentations, depending on where I liked how the material was presented. (Student 1)

This behavior is in line with using memory strategy (Bernacki et al., 2012; Bouchet et al., 2013) and suggests that clicks on lecture slides, textbooks, and lecture recordings modules should correlate with it.

However, those modules varied in perceived effectiveness and usefulness. Lecture slides, despite not being an additional material (they were used by the lecturer as a visualization tool and then uploaded to LMS), were used by students to refresh their knowledge, write down formulas they hadn't have time to write down during the lecture:

> When you study something within a seminar or lecture, a week passes, you don't always go back, and you want to refresh your memory… The presentations often helped to get, well, a brief summary. (Student 2)

Textbooks provided a deeper theoretical material, and were used to deepen the understanding of certain topics and to write notes: *"*It was the case that we studied, for example, confidence intervals. And in order to really understand this topic, I then used textbooks*."* (Student 1). But at times, students perceived textbooks as being too complicated and preferred not to use them: *"*I saved presentations for myself... I used the textbook to a lesser extent, because, for me, it was written in such a complex language*."* (Student 3). Some students felt that theoretical material provided in lectures was enough for them and did not refer to the textbook:

*"*I did not get to the textbook. Well. Firstly, I did not have time, and secondly, I did not need it. I understood everything anyway. In principle, the classes were enough for me*."* (Student 4).

Lecture recordings weren't used as a source of new material or a way to memorize theory:

> I didn't access lecture recordings because I made notes of everything that I needed… I didn't listen to any of the recordings because my notes were enough for me, and I asked all the questions that I had during the classes. (Student 1)

Students used lecture recordings only as a substitute for a missed synchronous lecture—to learn material but not to memorize it: "[When I missed a topic] I just watched the recording again, where the teacher, as always, led the class, explaining everything. I took notes in the same way as I usually did [when attending synchronously]." (Student 5).

Thus, clicks on LMS modules related to theoretical materials were found to be representative of students utilizing a singular strategy (memory strategy) common for the whole group, despite the fact that some modules were used more than others.

Theme 2: Dissimilar SRL Strategies

Other SRL strategies manifested in vastly dissimilar ways for different students. Students resorted to checking the gradebook as a part of self-evaluation strategy: "I always wanted to see if I'm doing well or if I'm not doing well, or if I'm deviating too much, I was afraid, according to the scores. So I was, yeah, I was looking [to the gradebook]" (Student 4). They also used the self-assessment test: "[I used the self-assessment test] to understand what I know and what I don't know. And secondly, to prepare for subsequent exams. But, first and foremost, to understand what I know and what I don't know." (Student 1). The course syllabus was similarly used to check whether students were prepared for the final test or not, thus helping them to evaluate their own performance:

> It helped me to understand how to prepare for the tests. Because we had two mini-tests outlined, they were based on the topics of this syllabus. I would look at it to see if I knew all the material. I would review the syllabus before the tests. (Student 1)

Thus, a singular SRL strategy manifested itself as clicks on three separate LMS modules. In a similar way, students used the course syllabus and the introduction page as a part of the goal-setting strategy. As opposed to memory strategy, there was no common way of utilizing these strategies. Students saw different ways of evaluating performance and planning activities as the best fit for themselves.

Additionally, those modules were sometimes used by different students as a part of dissimilar SRL strategies. For example, some students told us about using self-assessment tests in different, less expected ways, in addition to self-evaluation. Tests were used as a proxy of a final exam (even though students were not told that the final test would resemble self-assessment in any way), which allowed students to imagine a rough picture of it to be better prepared and to increase their psychological comfort:

> [I used the self-assessment test] in order to understand what the final exam would look like, because it wasn't quite clear what would be there, So, at least this way, I could see what to expect roughly, and somehow mentally prepared. (Student 5)

Re-taking tests multiple times allowed students to memorize the questions, they felt that that might be useful on the exam: "I went through each test until it was automatic, so I could memorize the answers. And by the way, I also used them before the exam. I even memorized some questions that seemed the most difficult to me." (Student 3). This indicates that taking a self-assessment test may be interpreted both as a sign of self-evaluation strategy and memory strategy.

Similarly, the course syllabus, which contained information on all topics of the course and deadlines, was used to plan performance and learning activities:

> [I used the course syllabus] to understand what we would be studying next and when we would need to take a test on that material. The entire list of topics that we needed to cover was clear. For example, if you already know some of the topics from this list, you could roughly estimate when you would need to pay special attention to the lectures. (Student 5)

Hence, students' behavior in accessing the syllabus could be attributed to both self-evaluation and goal-setting strategies.

Thus, goal-setting and self-evaluating strategies were found to manifest themselves as clicks on dissimilar LMS modules for different groups of students, and clicks on the self-assessment tests and the course syllabus were found to be related to different students using those modules as a part of various SRL strategies.

Theme 3: Non-traceable SRL Strategies

Due to the blended nature of the course, a portion of students' SRL behavior occurred face-to-face instead of online. Goal setting was not solely reliant on the course syllabus because students could rely on other sources of information for planning. Some used calendars and task tracking software before the beginning of the course, while others relied on communication with their peers. For example, information on course deadlines was shared between students in a group chat (created by the students themselves) in Telegram:

> We have a person in our Telegram chat who writes down all the deadlines, so I know that most people check there, that is, some specifically look at a table [syllabus] where you need to submit things, but I didn't need that because I checked the Telegram chat." (Student 1)

Behavior related to the seeking assistance strategy also occurred offline: "[If you struggle with a certain topic,] you clearly define for yourself what is unclear, you find that point... And then you go somewhere with it. Either to a knowledgeable classmate, someone who understands, or to the teacher." (Student 6).

Another significant finding of the interviews is the fact that students often prefer to download or even print out course materials. Downloading textbooks or lecture slides allowed students to access them offline and to organize files in a preferred storage system on a personal computer: “I understood that I was clearly not finished with this presentation yet, and it would be easier for me to save it in some folder there [on my PC], and open it quickly [later].” (Student 5). A number of students printed out course materials. Printed lecture slides were convenient to merge with handwritten notes and to highlight: “When I wrote my notes, I printed some slides from the presentation for myself, and put them there, maybe, to have something especially important, some formulas. Therefore, yes, I also looked at the presentation.” (Student 5). In a similar way, the syllabus was printed out for easier daily access: “There were absolutely all deadlines, all homework assignments, and by what date. And I printed out this plan for myself and just always looked at it.” (Student 5). Thus, some SRL behavior was untraceable via clicks on LMS modules, due to students acting outside of the LMS.

Overall, the qualitative analysis showed that some SRL behavior was clearly related to clicks on certain LMS modules and easy to interpret, while other types of behavior were dissimilar and associated with clicks on multiple modules, making it harder to interpret. Additionally, some SRL behavior was found to be untraceable via clicks due to occurring outside of the LMS.

Discussion

The results of the current study show that there are certain types of digital traces that allow us to measure students’ use of SRL strategies in blended courses. Previous literature associates interacting with video content (and specifically re-watching lectures) with rehearsing and repeating, which could be attributed to memory strategy (Davis et al., 2016; Delen et al., 2014; Maldonado-Mahauad et al., 2018). However, there are no studies that show a direct relationship between clicks on video content and memorizing. Similarly, the findings of this study show that video watching is not associated with memory strategy. On the other hand, the correlation analysis and interviews support the finding that students resort to memory strategy when viewing lecture slides, which is in line with previous research (Perez-Alvarez et al., 2020; Bouchet et al., 2013; Pérez-Sanagustín et al., 2021).

Existing research shows the relationship between interacting with text materials and memory strategy (Bernacki et al., 2012). However, the results of this study show an insignificant correlation between clicks on the textbooks module and memory strategy, although it was mentioned in the interviews. Students preferred lecture slides to textbooks as a main source of theoretical material, but used textbooks to get a deeper understanding of theory when it was necessary. Hence, students’ interactions with this module were not frequent enough to show a statistically significant correlation, but interviews suggest that this correlation, indeed, exists.

A negative and statistically significant correlation between clicks on video lecture recordings and memory strategy, learning responsibility, and organizing was not supported by interviews. Students viewed the lecture recording module as a mere substitute for a synchronous lecture they had failed to attend. Only a few of them told us about actually using lecture recordings, probably due to the high attendance rate. It is important to add that a lecture

recording was not equivalent to a synchronous online or offline lecture, due to comparatively low sound and video quality. Students with higher SRL behavior would opt to view a lecture synchronously online or face-to-face (Bjork et al., 2013), which could not be reflected by digital traces.

Thus, a negative correlation between clicks on lecture recordings and numerous SRL strategies may be explained by the fact that the lecture recordings module was only accessed by students with lower overall SRL behavior, who did not attend lectures synchronously and hoped that a lecture recording might help them. As a result, lecture recordings proved to be a poor indicator of SRL behavior in this blended course setting, where students typically favored synchronous interactions with the lecturer. In contrast, research on SRL in MOOCs has demonstrated a strong relationship between lecture recording views and memory strategy usage (Maldonado-Mahauad et al., 2018). This finding highlights important differences in students' approaches to video watching in online and blended learning environments.

Clicks on the gradebook module are suggested to be related to self-evaluation strategy, as shown by previous research (Saint et al., 2020b; Wong et al., 2019), however, it is not supported by the correlation analysis in this study. The statistically significant positive correlation between clicks in this module and memory strategy is not supported by the interviews either—students did not mention using the gradebook in regard to any SRL strategy. This could be due to the low number of graded assignments in the course, providing little incentive for students to check the gradebook. It is likely that clicks on the gradebook course module were influenced by other latent variables, which requires future investigation.

Thus, instructional designers in blended courses can use clicks on LMS modules containing theoretical content (but not lecture recordings) as indicators of students' engagement in SRL practices. This information may serve as an indicator of students' SRL (Bernacki et al., 2012; Fan, Matcha, et al., 2021) and can be valuable for providing SRL scaffolding (Azevedo & Hadwin, 2005) or predicting which students may have lower academic achievement due to a lack of self-regulation (Kizilcec et al., 2017). Tracking, analyzing, and interpreting clicks on lecture slides and textbooks modules impose minimal additional burden on instructors. It requires aggregating all clicks on corresponding modules throughout a certain period of time and standardizing them.

Other digital traces also indicate students' SRL behavior but lack a clear interpretation because of their relationship with multiple SRL strategies at once. For example, clicks on the course syllabus and self-assessment tests were related to three SRL strategies simultaneously, as shown by the interviews. This finding doesn't seem particularly unusual, as students' use of different SRL strategies indicates an overall engagement with SRL behavior (Kizilcec et al., 2017). However, this ambiguity in interpretation has negative theoretical and pedagogical implications. Firstly, unclear interpretation prevents further theoretical development of SRL as a construct because it doesn't allow researchers to differentiate between the components of SRL. Secondly, SRL scaffolding is difficult because the instructor cannot provide personalized support to a student if the student is not using the full range of self-regulated learning strategies. Additionally, an instructor lacking the information on which of the student's SRL strategies is less developed is unable to focus their resources on scaffolding this strategy, making the process of scaffolding less effective.

It is important for practitioners to be aware of the fact that students may use SRL strategies outside of the LMS. A significant portion of SRL behaviors are not revealed by digital traces in blended courses because of their nature. Many processes that researchers expect to happen online may have a blended nature or take place completely face-to-face. For example, students may print out all available materials and interact with them in real life, or create group chats separate from the main LMS platform and discuss studying-related issues there. A low number of one student's clicks on an LMS module compared to other students may not suggest a student with lower use of a corresponding SRL strategy.

Limitations of the Study

It is important to note the limitations of this study, which are also reflected in previous research (Eggers et al., 2021) and affect the generalizability of the results. First, the small sample size limited the scope of statistical analyses, and some relationships may not have been discovered due to this limitation. However, the small sample size enabled a more in-depth exploration of students' learning behaviors, allowing for detailed qualitative insights that might not have emerged in a larger study. At the same time, the limited number of observations inevitably affected the statistical power of the qualitative part of the analysis and may have contributed to the non-significance of certain effects. Nevertheless, the relationships that did emerge appear relatively strong, as they were evident even in this constrained context. Importantly, the quantitative results in this study are intended to complement the findings of the qualitative analysis, rather than stand alone. Future studies should aim to replicate and extend these findings using larger and more diverse samples to enhance their generalizability.

Second, the types of digital traces used in this study are not universal; they were tied both to specific features and options provided by the LMS modules as well as to the course content. Nonetheless, the study attempted to mitigate this limitation by focusing the interviews and the questionnaire specifically on the student experience on this specific course.

Another limitation connected to digital traces lies in the nature of blended courses, which implies that some significant part of the learning process stays out of the scope of the platform and cannot therefore reflect the whole variety of SRL strategies that learners might use in face-to-face parts of the course. The potential for future research lies in conducting a quantitative study of the correlation between SRL strategies and digital traces in blended courses which would have a bigger sample and would not be limited to a single course.

Self-selection bias was also initially a concern—only 16 out of 24 (66%) course students agreed to participate in the questionnaire, and even fewer students gave interviews (8). However, as interviews showed, there was sufficient variance in student profiles. Some students reported excellent preparation, having a high GPA and being responsible, while others told us about cheating on the final exam and having trouble with the final project. Moreover, the potential impact of self-selection bias on our findings is limited due to the specific focus of our research. Our study primarily investigates the relationships between students' clicking behaviors, their reported SRL strategies, and their qualitative interview reflections. While the overall levels of academic achievement or general SRL usage within the sample might be influenced by self-selection (e.g., if only highly motivated students volunteered), these factors are not central to our research questions. Instead, we are primarily interested in how variations in clicking behaviors

relate to variations in reported SRL strategies and interview narratives. Therefore, while acknowledging the potential for self-selection bias to influence the absolute levels of performance or SRL, we argue that it is less likely to substantially alter the relationships between the variables under investigation. Nevertheless, future research employing more representative sampling techniques is warranted to further validate these findings and assess the potential influence of self-selection bias more comprehensively.

Another factor to consider when interpreting our results is that all participants in this study had prior experience with blended learning courses. This pre-existing familiarity with the blended format may have influenced their learning strategies, expectations, and overall engagement with the course under investigation. For instance, students with prior positive experiences may have been more adept at navigating the online components, utilizing digital resources effectively, and integrating online and face-to-face learning activities. Conversely, those with prior negative experiences might have approached the course with pre-conceived notions or anxieties that affected their self-regulated learning behaviors and their interactions with LMS. Therefore, the observed relationships between clicking behaviors, SRL strategies, and interview narratives might be specific to learners with a degree of pre-existing comfort and competence in blended learning environments. It is possible that novice blended learners, lacking this prior experience, would exhibit different patterns of engagement and demonstrate different relationships between these variables. Future research should explore the potential impact of prior blended learning experience by including participants with varying levels of familiarity with the blended format, allowing for a more comprehensive understanding of how experience shapes learning in blended environments.

Conclusion

The present study aims to explore the potential of using digital traces as a tool to infer and monitor students' SRL strategies in a blended course, addressing the current research gap and contributing to the development of effective SRL strategies in blended learning environments. To do that, the triangulation of methods was used. The questionnaire, interview, and digital traces analysis were used to investigate the relationship between students' SRL strategies and clicks on different course modules in LMS, and to find the real processes behind these clicks.

Clicks on LMS modules related to theoretical materials (textbooks and lecture slides) had a positive correlation with memory strategy use by students. This result may be valuable for instructional designers of blended courses. Clicks on other LMS modules were found to either relate to several SRL strategies at once, which made their interpretation difficult, or to not have a meaningful correlation with SRL strategies at all.

Thus, while our study demonstrates the potential of using digital traces to monitor SRL strategies in blended learning environments, it does so with several limitations. Despite the proliferation of opportunities to leverage digital data, they still fall short of providing researchers and practitioners with the ability to rely exclusively on these data sources. Triangulation of data sources emerges as a way forward for researchers, and it would be beneficial to continue employing this methodology in related future studies.

Statements and Declarations

Competing Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics

This study involved an analysis of hybrid course students' LMS trace data and interview recordings. Given the nature of the data and the minimal risk to participants (as the data were anonymized, no personally identifiable information was collected or used, and the interview recordings focused solely on learning behaviors rather than sensitive personal topics), this research was classified as low-risk and did not require full review by Higher School of Economics (HSE) University's Institutional Review Board (IRB). LMS trace data was analyzed in aggregate. Interview recordings were transcribed and analyzed thematically, with all identifying information removed to ensure anonymity. All participants signed informed consent forms prior to participating in the study. This determination was made in accordance with HSE University's guidelines on research ethics.

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Author Contributions

Maxim Boitcov: study conception and design; data collection; analysis and interpretation of results; draft manuscript preparation.

Anna Gorbunova: study conception and design; interpretation of results; draft manuscript preparation.

Anastasiia Kapuza: study conception and design; data analysis; draft manuscript preparation.

Regina Sutarmina: study conception and design; data collection.

All authors reviewed the results and approved the final version of the manuscript.

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Appendix A

Items of A-SRL-S questionnaire (Magno, 2010) used to measure SRL strategies usage by the students.

Memory strategy

- I use note cards to write information I need to remember.
- I make lists of related information by categories.
- I rewrite class notes by rearranging the information in my own words.
- I use graphic organizers to put abstract information into a concrete form.
- I represent concepts with symbols such as drawings so I can easily remember them.
- I make a summary of my readings.
- I make outlines as guides while I am studying.
- I summarize every topic we would have in class.
- I visualize words in my mind to recall terms.
- I recite the answers to questions on the topic that I made up.
- I record the lessons that I attend to.
- I make sample questions from a topic and answer them.
- I recite my notes while studying for an exam.
- I write messages for myself to remind me of my homework.

Goal setting

- I make a detailed schedule of my daily activities.
- I make a timetable of all the activities I have to complete.
- I plan the things I have to do in a week.
- I use a planner to keep track of what I am supposed to accomplish.
- I keep track of everything I have to do in a notebook or on a calendar.

Self-Evaluation

- I make a detailed schedule of my daily activities.
- I make a timetable of all the activities I have to complete.
- I plan the things I have to do in a week.
- I use a planner to keep track of what I am supposed to accomplish.
- I keep track of everything I have to do in a notebook or on a calendar.

Seeking assistance

- I use a variety of sources in making my research papers.
- I use library resources to find the information that I need.
- I take my own notes in class.
- I enjoy group works because we help one another.
- I call a classmate about the homework that I missed.

- I look for a friend whom I can have an exchange of questions.
- I study with a partner to compare notes.
- I explain to my peers what I have learned.

Environmental Structuring

- I avoid watching the television if I have a pending a homework.
- I isolate myself from unnecessary noisy places.
- I don't want to hear a single sound when I'm studying.
- I can't study nor do my homework if the room is dark.
- I switch off my TV for me to concentrate on my studies.

Learning Responsibility

- I recheck my homework if I have done it correctly before passing.
- I do things as soon as the teacher gives the task.
- I am concerned with the deadlines set by the teachers.
- I prioritize my schoolwork over other activities.
- I finish all my homework first before doing unnecessary things.

Organizing

- I highlight important concepts and information I find in my readings.
- I picture in my mind how the test will look like based on previous tests.
- I put my past notebooks, handouts, and the like in a certain container.
- I study at my own pace.
- I fix my things first before I start studying.
- I make sure my study area is clean before studying.

Appendix B

Guide used to conduct semi-structured interviews.

Section 1: Learning Goals and Habits

- Can you walk me through how you approached the beginning of the course?
  (Prompts: Did you set any goals for yourself? What were you hoping to get out of the course?)
- What did you typically do before a new study week started or before class sessions?
  (Prompts: Any preparation rituals? How did you organize your study time?)
- How did the course fit into your broader weekly schedule or other responsibilities?
- Tell me about how you tracked or remembered important course information—assignments, deadlines, grading rules.
  (If they mention SmartLMS, follow up: What exactly did you look at? How often?)
- What helped you stay on track (or made it difficult to do so)?
  (Follow-up: What kinds of challenges did you face in managing your time?)
- When you missed a class or task, what strategies did you use to catch up?
- What learning materials did you return to most often during the course? Why those ones in particular?

Section 2: Learning Environment

- Where did you usually study or work on assignments?
  (Follow-up: What made that environment work for you—or not?)
- What kind of setting helps you concentrate and study effectively?
- What usually distracted you while studying? What helped you refocus?
- When did you usually study—mornings, evenings, weekends? How did you decide on that timing?

Section 3: Working with Materials and SmartLMS

- How did you usually work with the course materials provided during classes?
  (Prompt: Did you take notes? In what format?)
- Can you describe how you interacted with SmartLMS during the course?
  (Prompts: What kinds of materials did you use there? Did you download files? Did you organize them somehow?)
- Beyond what we've already discussed, were there other ways you used SmartLMS throughout the course?

Section 4: Self-Assessment Quizzes

- Tell me about your experience with the optional self-assessment quizzes.
  (Prompts: How did you approach them? What did you do before/during/after taking them?)
- How did you decide whether or not to take the quizzes? What were they useful for?

- If you used other materials to prepare, what were they and how did they help?

Section 5: Midterm Exam

- How did you prepare for the midterm exam?
  (Prompts: What strategies did you use? What materials did you return to?)
- How did you go about completing the exam? What was your thought process during the task?
- What did you do immediately after finishing the exam?

Section 7: Final Project

- What was your process for working on the final project?
  (Prompts: When did you start? Did you plan ahead?)
- What role did you play in your team or group?
- What materials did you rely on most when preparing your project? Why those?
- Did you seek feedback from peers or instructors while working on your project?
  (Follow-up: How did you use that feedback?)
- After the project defense, how did you reflect on the feedback you received?

Section 8: Grades and Tracking Progress

- How did you monitor your progress during the course?
- Did you use the "Grades" section in SmartLMS? What for?
- What helped you notice or feel your own learning progress throughout the course?

Section 10: Learning Outcomes and Reflection

- Looking back, how would you describe your overall experience in the course?
- When did you feel you were making progress? What helped you feel that?
- What did you do when you struggled with a topic or assignment?
- Did you collaborate with classmates? How did that collaboration look in practice?
- Were there times when you explained something to your classmates?
  (Prompt: Can you share an example?)
- Did you use other resources beyond SmartLMS (e.g., internet, books, videos)? What kinds?