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Timing Matters: Approaches for Measuring and Visualizing Behaviours of Timing and Spacing of Work in Self-Paced Online Teacher Professional Development Courses

Jeremy Riel[1]*, Kimberly A. Lawless[2], Scott W. Brown[3]

Abstract

One feature of self-paced online courses is greater learner control over the timing of their work in a course. However, the greater timing flexibility that learners enjoy in such environments may play a different role in the learning process than has been previously observed in formal online or face-to-face courses. As such, the study of work timing merits further investigation. Toward this goal, this study forwards two measures that represent the timing of coursework: 1) the timing index, or the degree to which a participant completes 50% of their work, and 2) the spacing count, the frequency of work performed across the course timeframe. In this study, the authors demonstrate the use of these measures from a data set of 42 U.S. middle-school teachers who participated in a self-paced, online professional development course to support teacher implementation of a new blended-learning curriculum. Using the two measures, the authors identify timing behaviours of participants and examine the effects that timing has on teacher self-efficacy after completing the course. The two measures and visualizations demonstrated in this paper yield useful individual-level variables for course timing that can be used for further study on the effects on learning outcomes.

Notes for Practice

- Although the frequency by which participants perform interactions within course management systems
  and the total amount of time spent in online courses are important indicators of engagement commonly used in analytics packages, the timing at which tasks are completed can also be an important indicator.
- The methods presented in this study provide tools for researchers to capture and visualize variables representing the timing of work by participants.
- Tools for tracking and measuring timing in courses could be useful for course managers and researchers to help further promote participants' achievements, promote course personalization, and understand common challenges and patterns of participation that affect a course.

Keywords

Timing, participation, engagement, repetition, online learning, distance education, informal learning, self-paced learning, professional development, procrastination, spacing effect.

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*Corresponding author [1]Email: jriel2@uic.edu Address: University of Illinois at Chicago, 1040 W. Harrison St. M/C 147, Chicago, IL 60613, USA

[2]Email: klawless@uic.edu Address: : University of Illinois at Chicago, 1040 W. Harrison St. M/C 147, Chicago, IL 60613, USA

[3]Email: scott.brown@uconn.edu Address: University of Connecticut, 249 Glenbrook Road, Unit 3064, Charles B. Gentry Building, Storrs, CT, 06269, USA

1. Introduction

Online courses have expanded the opportunities for learning and research both through 1) the large numbers of participants informally seeking personal enrichment or for career professional development, and 2) the data collection capabilities of online learning platforms (Fournier, Kop, & Durand, 2014; Greene, Oswald, & Pomerantz, 2015). The design of online learning environments that use multimedia and interactive elements allow learners to spend time and perform work in diverse ways within these courses (Liyanagunawardena, Adams, & Williams, 2013). As online learning has increased in popularity, a growing mandate has arisen for understanding how and why online learning works and what processes are necessary as learners interact in online systems toward learning goals (Lowenthal & Hodges, 2015; Means, Toyama, Murphy, Bakia, & Jones, 2010).

One affordance of informal self-paced online courses is greater learner control in the timing of their work in a course (Willems, 2005). However, the greater flexibility in timing that learners enjoy in such environments may have different effects on learning than has been previously observed in formal online courses or face-to-face learning, which merits further investigation. For instance, when timing structures are imposed in a conventional course, it pressures participants to finish course work within a timely manner, sometimes leading to procrastination and avoidance (Ferrari & Tice, 2000; Howell, Watson, Powell, & Buro, 2006; Jo & Kim, 2013). As open-ended and self-paced courses gain in popularity, it is feasible to hypothesize that the lack of time constraints imposed can alter the participatory patterns in such courses, including the timing of when work is completed. Timing of work in these courses might then exhibit varying effects on learning outcomes. In addition, when work is completed might illustrate the value and usability of course materials for different purposes, which can lead to insights for course designers.

In this study, we put forward two measures for the study of timing and spacing of work in self-paced online courses, called timing index and spacing count. When used jointly, these two measures can reveal a more complete description about the timing of work in courses. This can give researchers and instructional designers a better glimpse into the types of timing strategies and behaviours that learners employ in their self-paced coursework. These two measures can be used to generate useful variables and visualizations of behaviour in online courses, allowing for more objective comparisons of timing phenomena across courses and better operational definitions of concepts. To this end, we demonstrate visualizations and analyses using the two measures and provide preliminary interpretations of their results as applied to a dataset from a self-paced online teacher professional development course intended to support teachers' pedagogy and implementation of a new curriculum. Considering advances in online course designs that offer time flexibility and self-paced activities to learners, it is increasingly important to prioritize the investigation of timing of work in educational studies. With approaches like the ones demonstrated in this paper, researchers can better understand the role that time plays in informal online learning processes.

2. Background and Context of Study

Participants in self-paced online courses often have specific needs and interests for which they participate, typically accessing only portions of courses or activities (DeBoer, Ho, Stump, & Breslow, 2014). Participants may also have less of a need to spend time on activities if they are already competent in the skills that the activities seek to develop (Perna et al., 2014; Shen & Kuo, 2015). To this end, participants in self-paced courses to date have exhibited myriad participatory patterns, sequences, and timing of work (DeBoer et al., 2014). Because of the variation in participatory patterns observed to date in self-paced online courses, it is useful to further investigate the role that timing plays in the learning process in these environments.

To date, only a few studies have examined the timing of work in open-ended or informal courses, which have been used in contexts such as teacher professional development, continuing education courses, or MOOCs (DeBoer et al., 2014; Kovanović et al., 2015; Miyamoto et al., 2015). This situation is likely due to the highly time-flexible nature of these courses, the low degree of pressure and low stakes on part of the learners to participate, and the difficulty in connecting the timing and amount of work performed to the course timeframe in a meaningful way, especially when course timeframes are different for each participant. As such, researchers suggest that timing behaviours used by participants in self-paced online courses need more attention. For instance, time-on-task has been notoriously hard to measure in browser-based systems in which the user is not constantly interacting, such as clicking or actively playing video (Calderwood, Ackerman, & Conklin, 2014; Karweit & Slavin, 1982). This difficulty in measuring learner interactions with the course material is especially true in online courses in which not all course activity occurs within browser-based learning environments (Kovanović et al., 2015). Also understudied are the sequence, repetition, and timing of learning activities, such as dialogue and creative works, and these should be prioritized in future work (Lemke, 2001; Mercer, 2008; Roth, 2006). In addition, simultaneous or parallel work during learning activities is another important dimension that should be analyzed, as work in flexible and self-paced online courses has been frequently observed not to be linear or follow conventional patterns (DeBoer et al., 2014). As such, new approaches that prioritize the conceptualization of the temporal elements of learning would be useful for instructional designers and the education research community.

Studies that investigate the timing of work have frequently defined timing in terms of the total amount of time spent or frequency of work. These measures have been helpful for some research questions but insufficient for the continued study of informal and self-paced online courses in which time is more flexible by design (Willems, 2005). For instance, procrastination as a timing behaviour has been defined in prior studies in a variety of ways. These definitions include turning in assignments within a certain number of hours before the deadline, accessing the course LMS after a certain date, or by surveying students to see if they have adopted a work-avoidant position or have low self-regulation perceptions (Ferrari, 1992; Wolters, 2003). However, it is difficult to directly observe or communicate with participants, or to know how engaged participants are on web pages (Clifton, 2012). In addition, raw time measures of how much work has been done do not lend themselves well to comparing across course contexts, as patterns of work timing may not manifest in the same way between a two-week quick course, a conventional 16-week course, or a one-week instructional unit.

As such, the timing behaviours of learners have been difficult to identify in self-paced online courses. The learning analytics field is well-poised to investigate time-based behavioural patterns and identify robust ways to investigate the timing aspects of course participation (Berzonsky & Ferrari, 1996). To this end, researchers in the learning analytics field have recently completed several valuable studies that explore the timing of online coursework (Kovanović et al., 2015; Miyamoto et al., 2015; Jo & Kim, 2013). Additional approaches that can better operationalize and aid in the interpretation of the completion of work in online, flexible courses with respect to time will be valuable to the field's understanding of online learning.

However, there have been advances recently in both formal and informal educational settings. Spacing, practice, repetition, and increasing the intervals in which work is performed in a course are all work timing considerations that have received considerable study in education recently, as an effect on spacing out work over time has been demonstrated to have positive effects on learning outcomes in online environments (Kapler, Weston, & Wisehart, 2015; Miyamoto et al., 2015; Rohrer, 2015). The appeal of online continuing education courses to some participants is their flexible timing, or an environment in which time is variable and deadlines are not enforced. As such, the related benefits of how work is spread over time will likely need to be examined within such time-flexible learning environments to understand how spacing influences participants when they are in full control over their course timing.

Although many self-paced online professional development courses do not typically require participants to follow rigid timing requirements, such courses often still begin and end on specific dates (Riel & Lawless, 2015). For instance, MOOCs promote open participation, but additionally often impose deadlines in which the course will open and close at a certain time. With open online courses, instructors and staff are typically available to help participants with projects only during the established course timeframe. Participants may be afforded high levels of timing flexibility in these environments, but the presence of course start and stop times may invoke various timing behaviours. Given the new flexibility in timing in these popular informal learning environments, additional research should be conducted to see if the same timing phenomena that have previously been observed in conventional courses exist in these newly popular learning environments and whether they have similar effects. More specifically, it would be valuable to investigate if completing work late in the course timeframe (procrastination) or completing work frequently over time (spacing) have similar effects on learner knowledge and affect as those previously observed in more conventional learning environments.

The frequency of a learning activity is easy to measure in both online and face-to-face contexts, such as counting the number of times a person attends a class, turns in homework, or performs a classroom activity. For instance, in a study by DeBoer et al. (2014), participation in an online course was examined with four attendance measures that served as proxies for timing: number of hours, weeks, days, and clicks. Similarly, the number of active sessions or clicks by participants have historically served as proxy variables for the spacing of work over time (Andergassen, Mödritscher, & Neumann, 2014). Count measures like these are common in online learning environments with the increased ease in gathering server log and clickstream data. However, measuring the prolonged nature of interaction or the degree of repetition is challenging to do with raw interaction frequency counts because they do not explain when interactions occur in relation to the course timeline, but only instead that they, in fact, occurred.

Although the total amount of time spent on coursework or frequency of interactions are useful variables for understanding the role of time in an online learning course, they do not tell the full story of when work was completed and the effects of the timing of coursework on course objectives or learning processes. To take another step forward in this direction, we propose two new measures for investigating the timing of work. The first measure we propose is the timing index, which records when half of a participant's overall time spent is completed in relation to a relative course timeline. The timing index allows researchers to pinpoint the "halfway point" of a participant's time spent on coursework on a course timeline. This contrasts with the use of other temporal measures, such as overall time counts (e.g., total time spent, time-on-task) or counts of frequency of activities, which do not describe the timing of completed work on a timeline. The timing index is presented on a scale of 0 to 1, with 0 representing the beginning of the course and 1 representing the end. Using server clickstream logs, each participant's sessions are weighted and compiled to create a single timing index. This measure makes it possible for timing behaviours to be visualized on a timeline and promotes ease of interpretation.

The timing index by itself has a limitation when it is used to illustrate the relative time when work was completed. The measure performs well at showing work that is "lumped" toward the beginning or end of the course, indicated by scores on either extreme of the time index (e.g., values close to 0 or 1). However, because they are related to the mean timing score of a participant's work, values tending toward the timing index midpoint of 0.5 are more indistinct in interpretation with middle-range scores. To address the issue of parsing the central values of the timing index, we additionally propose a second measure called spacing count. Spacing count allows researchers to identify the degree to which course activities were either "lumped up" or spread out over a course by counting the number of active intervals in which participants engaged in activities at different times of the course. To develop the spacing count, we adopt a method like that used by Miyamoto et al. (2015) in one of their sub-studies on the spacing effect in MOOCs. Although it was only used in their study as an independent controlling factor, Miyamoto and colleagues divided a course up into countable "bins" or intervals in which work occurs to help explain relationships between frequency of user sessions and course completion with respect to the course timeline. As such, we refine the approach to illustrate the spacing of activity in conjunction with the timing index.

The examination of time intervals as variables can be used to reveal a more nuanced understanding of a participant's timing of work. In this study, the spacing count prioritizes the division of a course into intervals as a meaningful measure of timing. The measure captures the degree to which work was completed during a pre-set number of time intervals over the course. As a result, spacing count provides a different, but related measure of timing.

We argue that the investigation of timing is important for self-paced online courses where time restrictions are not embedded in the course design via milestones, but are still bounded by start and end times. Specifically, in self-paced online courses, the raw time between activities or the total time spent or time-on-task might be less meaningful when time constraints are not embedded in course design or if deadlines are not rigidly enforced. For example, in most MOOCs in the mid-2010s, timed milestones and course schedules indeed existed and are often required for course completion certificates. However, the time requirements and milestones in open online courses are not strictly enforced or promoted with self-paced learners and course timing does not always align with participants' schedules, needs, or personal learning interests (Riel & Lawless, 2015; Terras & Ramsay, 2015; Wang, Paquette, & Baker, 2014). As a result, the participants' behaviours are extremely varied (DeBoer et al., 2014). Because of the growing trend in self-paced timing in online courses, proportional and relative time measures might be easier for researchers to understand the importance of timing behaviours and strategies in relation to learning outcomes and processes, as well as to compare courses and design features across different timescales.

Toward these goals, the following research questions guided this work:

RQ1: What variations of timing behaviours manifest among course participants when considering 1) when they complete half of their work in a course, and 2) how frequently over the course time frame they complete substantive amounts of work?

RQ2: How are the dimensions of timing of work and spacing of work related to each other and what patterns of timing are observed from an instance of a self-paced, online professional development course?

3. Methods

3.1. Data

A dataset of a self-paced teacher online professional development course was used to exploratorily develop the measures and visualizations demonstrated in this paper. We analyzed clickstream data of teacher participation in the course over a 3-week period. The course was designed to support teachers' implementation of GlobalEd 2 (GE2, www.globaled2.com), a standards-based curriculum for middle school social studies. In short, GE2 is a live negotiations simulation for blended learning classrooms in which students play the role of science advisors in an international negotiation about a world crisis. Students work with representatives from other delegate countries (i.e., other classrooms) in an online communications environment to propose solutions to the given problem scenario. The goal of GE2, in addition to gaining knowledge about social studies and science, is to gain mastery in socioscientific literacies, inquiry, and writing skills. Because of the novel approach of the GE2 curriculum, significant teacher training and ongoing support is required for its successful implementation.

The GlobalEd 2 Professional Development Program (GE2PD) was designed to help middle school teachers gain knowledge and self-efficacy in implementing the GE2 curriculum. The GE2PD was provided in the weeks prior to the teachers' first implementation of GE2. The program consisted of self-paced instructional modules designed to familiarize them with the principles, procedures, and content knowledge needed for successful implementation. Activities included watching videos, completing ungraded comprehension checks, and participating in forums for each module. Participants were also required to complete a culminating project for each module and discuss it with other participants in the forum. For each project, participants produced an artifact that could be used directly in the classroom when they implemented the curriculum. The GE2PD was delivered in a customized version of the Moodle open-source learning management system in which digital clickstream logs were generated and stored in a MySQL database. Each interaction in the system was recorded with the timestamp, user ID, URL visited, and type of action performed by the user (e.g., view, login, logout, attempt activity).

3.2. Participants

Forty-two middle school social studies teachers completed the GE2PD. All participants who started the GE2PD completed the course. Teachers were recruited using social media and direct school contact to voluntarily participate in implementing the GE2 curriculum and the related GE2PD to support implementation. Teachers were evenly distributed between one Midwestern U.S. state and one Eastern U.S. state. The sample also evenly represented large, urban school districts and suburban school districts. Teachers were offered a small monetary stipend for their participation in the curriculum and PD course to assist with their implementation of the GE2 curriculum.

3.3. Procedures

3.3.1. Data preprocessing

The first step of preprocessing the clickstream log data from Moodle was to assign indicators of active user sessions to user server log entries. We defined a session as any active click sequence in which there was no more than 30 minutes of elapsed time between clicks. We chose 30 minutes as the cut-off point because some of the videos in the course were close to 20 minutes in length, leaving 10 minutes of available time if a participant watched the long videos in their entirety. If the elapsed time between a participant's clicks was over 30 minutes, the final greater-than-30-minute period was discarded from the previous session and a participant's next click in the server log would be indicated as a new session.

Additionally, data preprocessing involved calculating the total amount of work of each participant. We defined total amount of work in this course as the total number of seconds actively spent in the course system. To this end, work was conceptualized as the amount of observable effort expended by the participant in the system. This is contrasted to binary measures of completion of tasks or course milestones provided in the Moodle and other course systems' pre-installed user activity reports (e.g., completion checkboxes, submitted/not submitted). For this study, we did not count the completion of milestones as work as these measures did not capture the amount of time taken to complete the associated tasks. Most of the tasks in the course were required to be completed in the system and were not completed offline (e.g., watching video and participating in forums). Therefore, we inferred that the user clickstream logs are likely representative of the total amount of work performed in the course and that minimal work was performed out-of-system. Despite using amount of time as the measure of work in this study, any measure of work can be used if it is fine-grained enough to be meaningful. This includes the completion of course milestones or portions of projects as long as the completion and timing of portions can be recognized by the system.

3.3.2. Timing index

The timing index is used to measure when half of a participant's work is completed in an online course. In this study, a participant's total amount of work is defined as the total amount of time spent in the course while engaged in activities on the course website. Our goal was to develop a measure that indicated at what point in time participants completed substantive amounts of work. Because time spent on course activities is a direct indicator of the completion of course activities, it was used as the primary measure of work. The measure is scored on a 0 to 1 scale that places raw time on a uniform time index, with 0 representing the beginning of the course and 1 representing the end. The uniform index allows for comparison between times of varying length.

Each participant received timing indices at two levels. First, each active user session recorded by a participant in the server logs received a timing index score. Second, participants each received an overall timing index that describes the timepoint at which 50% of their overall time spent in the course was completed. Alternatively, this could also be interpreted as the timepoint at which 50% of the total amount of work of a participant was completed. The total amount of time spent in the course varied by participant, and is thus relative to the total amount of time spent in the course by participants.

Timing indices for each individual session are used to generate the overall timing index for each participant. The timing index procedure assigns values for each participant in terms of the percentage of the overall course time in which the session happened. For instance, a participant session that occurred at timing index 0.25 occurred at the first 25% of the course timeframe, while a timing index of 0.75 happened at the last three-quarters of the overall course time frame. The individual session timing indices were weighted against the amount of time spent in each session (and thus, the amount of work performed in each session). By combining the weighted timing indices, a combined timing index was generated that revealed when half of the participant's overall time spent on coursework (50% of total seconds) was completed by the participant. Thus, it operationalizes relative timing terms such as beginning, middle, and end in an understandable, albeit more abstracted measure of time.

Several steps are required to process the timing index. We developed these steps exploratorily as we interpreted the server interaction logs in our attempt to develop an objective and relative measure for investigating timing that could be easily interpreted and readily transferred to other contexts. Detailed step-by-step instructions on producing the timing index can be found in the method supplement attached to this article.

3.3.3. Spacing count

Spacing count represents the degree of prolonged experience and work in the course. Defined, it is a count of time intervals or bins in which the participant had active sessions where a substantive amount of work was completed. Instead of counting whether a session was present in an interval, we wanted to capture whether a substantive amount of work was completed. For this we defined substantive work as the amount of work — measured as a percentage number of the participant's overall amount of work — that is deemed a significant amount by the researcher. For this study, we chose a level of 5% for the substantive work threshold in an interval to reflect that the participant made a focused enough length of effort, but did not reflect simply logging on without much activity. This value serves as a threshold within each interval of time for how much work is needed to be done by a participant in the respective interval to be considered a "substantive" amount of work and be counted in the spacing count. For instance, in any given interval of time (say, 5% of course time), a "substantive work value" of 5% would mean that a participant who performed 5% or more of their overall amount of work during that interval would be said to have completed a "substantive" amount of work.

Again, it is important to emphasize that for this study, work is defined here as an amount of time spent by participants on course activities and not the completion of tasks or milestones. Completion indicators do not account for the amount or degree of effort spent by different participants and it is assumed these levels vary between participants. As such, the amount of time spent in the course on activities is one useful indicator for understanding variation in the amounts of work between participants.

The spacing count for each participant consists of the sum of time intervals within which a participant actively performed a substantive amount of work. A pre-established number of intervals was evenly divided over the course timeframe and set by the researchers. In addition, for spacing count eligibility within an interval, we counted the summed elapsed time of sessions within an interval. If all of the sessions within an interval totaled at least 5% of work when added, it was included in the spacing count.

Like the timing index, the procedure for generating the spacing count for each participant is also found in the method supplement attached to this article.

4. Results

4.1. Case Examples of Interpreting Timing Index and Spacing Count

4.1.1. Examples of interpreting timing index

Two cases of different participant timing index values from the dataset are given in Figures 1 and 2 to illustrate how the timing index is derived and how it can be interpreted on an easily understandable scale. Participant 34's timing index in Figure 1 can be read as a percentage of course time, so the value of .388 indicates that half of the participant's work was done early in the course. As the index can also be read as a percent, it is also correct to interpret that half of the participant's work was completed roughly in the first third of the course. The plot of sessions (blue dots) on the timeline show time index (x-axis) against amount of work completed compared to the participant's total amount of work (y-axis). The chart reflects the timing score of .388 for Participant 34, further illustrating that the participant's work was spread out over many sessions along the course timeline on the x-axis.

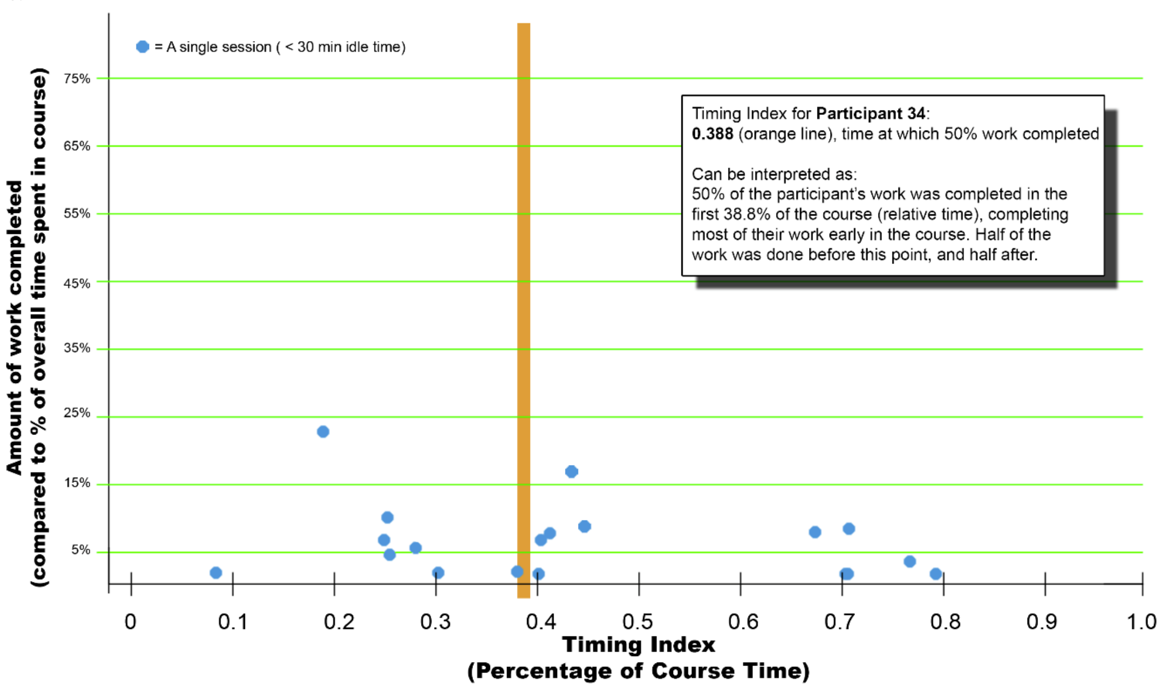


Figure 1. An example plot of a participant's *low* timing index (0.388 for Participant 34). The gold line indicates the timing index for Participant 34, or the point on the course timeline on a scale of 0 to 1 at which 50% of the overall work and effort they expended in the course was completed.

In contrast to Figure 1, Figure 2 illustrates a second participant's different timing index and patterns. Participant 26's timing index in Figure 2 is much higher (.882) than Participant 34's. If read as a percentage, the timing index of 0.882 reveals that half of Participant 26's work was done quite late in the course. A visual review of Participant 26's sessions in Figure 2 confirms that indeed no work was performed in the first 80% of the course.

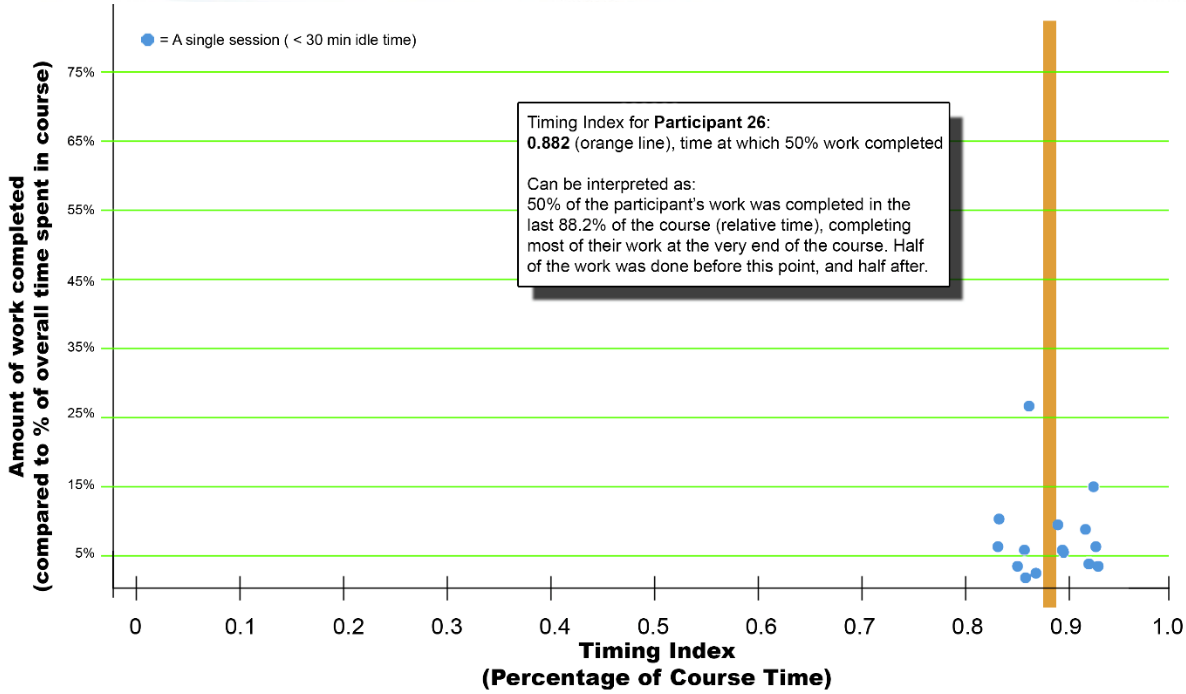


Figure 2. An example plot of a participant's *high* timing index (0.882 for Participant 26). The gold line indicates the timing index for Participant 26, or the point on the course timeline on a scale of 0 to 1 at which 50% of the overall work and effort they expended in the course was completed.

When compared to Figure 1, Figure 2 also demonstrates a limitation of simply counting the number of sessions of a participant to determine behaviours associated with work timing. Where Participant 34 in Figure 1 had 18 sessions (represented by blue dots) spread out over the course, Participant 26 in Figure 2 had roughly the same number of sessions (15), but tightly packed at the end of the course. Any number of sessions could be "massed" together at one point in time, but also spread out over the entire course. To this point, the use of a raw count of sessions would miss this important distinction and the timing index can be used to highlight the additional information.

As reviewed in the procedures section, each participant received two levels of timing index: 1) a time index that is assigned to each of the participant's interactions as recorded in the LMS server log and used to provide a weight against the elapsed time of each interaction, and 2) a combined timing index for the participant that averages the timing indices of each session weighted based on the amount of time worked in each session. Thus, the participant's single timing index is an indicator of the timepoint when 50% of their total amount of work was finished over the allocated time. The combined timing index score places weights on the length of each course interaction in the server logs on a common scale (0 to 1) by the timing of when the interaction occurred. This allows for the mean to be taken of all course interactions and allows researchers to readily identify and easily interpret when half of a participant's work is completed.

Alternatively, using the same metric, researchers can also quickly identify when in the course relative time frame any amount of percentage of work is completed. For example, a researcher can readily identify timepoints at which the first 25% or final 75% of work is completed. All that is necessary are minor alterations to the arithmetic in the procedures section based on the researcher's interests. Ultimately, a layer of abstraction is gained with this measure to make meaningful distinctions of timing on terms relative to the beginning, middle, and end of course that can be compared across contexts. The timing index also has the benefit of being easily interpretable by researchers in comparison to the number of elapsed seconds or calendar time.

4.1.2. Examples of interpreting spacing count

Figure 3 illustrates a visual example of how the spacing count value is assigned for each participant and its interpretation. With the spacing count, a given number of intervals span the course time frame equal to the number of intervals given by researchers during the development of the spacing count (in this study, intervals = 20). In Figure 3, intervals are represented by the blue shaded vertical regions, where colours of the shading are for sequential distinction purposes only. Instead of simply counting session counts for frequency of work without regard to timing or the overall time spent in the course, the spacing count additionally accounts for the time-based nature of spacing out work over the course timeframe. It also simultaneously counts the frequency of sessions. Each interval is evenly spaced and represents a "bin" or portion of the course timeline in which work can be performed. Because we set the substantive work level at 5%, a combined amount of work of sessions in each interval must add up to 5% to be eligible to be counted. For every interval that has at least 5% of a participant's overall work present, the participant would have their spacing count increased by one.

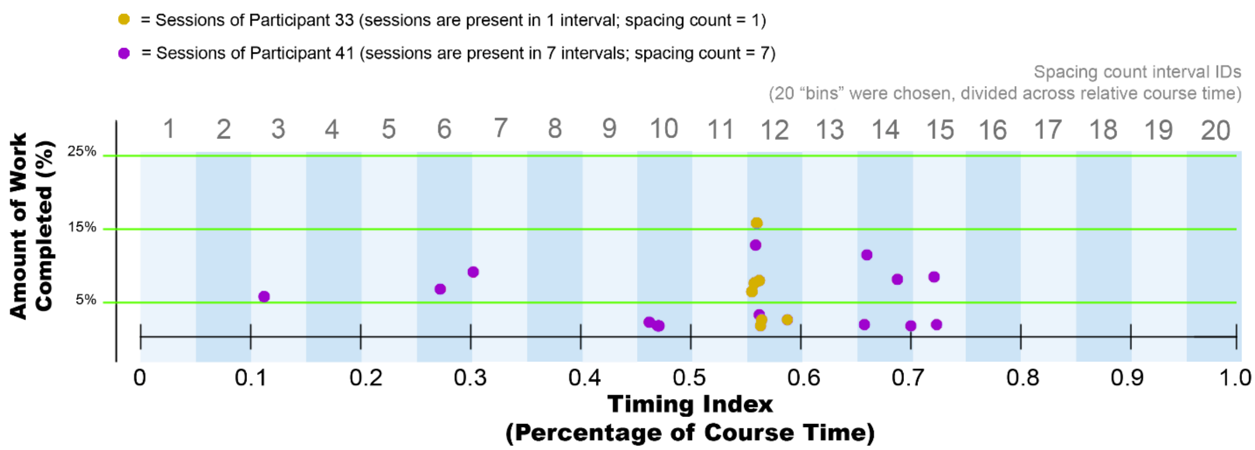


Figure 3. Plot of sessions of two participants, with spacing intervals in shaded regions. This chart illustrates the development of the spacing count metric (over 20 intervals) with two actual participants' sessions as they fall on the evenly spaced intervals. A sum of intervals in which sessions total 5% or more of work constitutes an individual's spacing count. Note that the timing index is used to visualize spacing.

In an example from the dataset, Participant 33 (gold dots) has only one interval in which their sessions met the set threshold of at least 5% combined substantive work, so their spacing count is equal to one. Alternatively, Participant 41 (purple) is shown to have sessions in which they performed at least 5% of work within 6 separate intervals. In addition, although most of the session points of Participant 41 are above the 5% threshold individually, two points are below the threshold in Interval 10 and would not be eligible for inclusion in spacing count individually. However, sessions within intervals are summed. As the sessions in Interval 10 total more than 5% of work threshold required by the sensitivity level within the interval, they are thus able to be counted as having done substantive work during that interval. This leaves Participant 41 with a spacing count of 7 (6 intervals with sessions naturally above 5% total work performed, and 1 interval with a sum of sessions above 5% work performed).

The two participants in Figure 3 also illustrate the importance of the spacing count as complementary to timing index. The participant with purple points (Participant 41) has much of their work spread out over the entire course, while the participant with gold points (Participant 33) has all their work "lumped" in just one interval. These two participants ended up having similar timing index scores that indicate half of their work was completed near the halfway point of the course (~.500–.600). However, the plot shows that the distribution of this work is different. As such, the spacing count gives researchers another tool for understanding the timing of work in a course. The two measures can be used together in analyses to show a more complete picture of the timing of work in a course.

4.2. Descriptive Statistics of Timing and Spacing in the Course

To answer Research Question 1, descriptive statistics revealed substantial variation among participants in how they timed their work on both measures. A summary of descriptive statistics from the dataset appear in Table 1. The mean timing index was .593, indicating that on average, participants finished half of their work at almost the 60% mark on the course timeline. Alternatively, it could be interpreted as participants finished half of their work with 40% of the course timeframe remaining. On the other hand, the mean spacing count for participants was 5.57, indicating that on average participants were active in the system for 5.57 different course intervals. Twenty intervals were chosen to develop the spacing count, with each interval representing 5% of the course. We can simply multiply the average spacing count by the amount of time represented in each interval (5%) to see how to how much of the course work was spread on average.

Table 1. Descriptive statistics on timing measures

Timing Measures	Mean	S.D.	Max	Min
Timing index: When 50% of the work was completed (beginning of course = 0, end of course = 1)	.593	.143	.891	.334
Spacing count: Number of time intervals at which a substantive amount of work was completed	5.57	3.33	14	2

The mean spacing count thus equates to participants being active, on average, for approximately 28% of the overall course timeline. Individual timing index and spacing count scores can be interpreted in the same way as the mean scores discussed above. This same measure would be similar to that of the overall elapsed time in a course. However, elapsed time does not account for when in a course a student has completed their work, which is an important distinction in knowing at what point participants were active in spreading out their work.

4.3. Visualizing and Grouping of the Timing Index

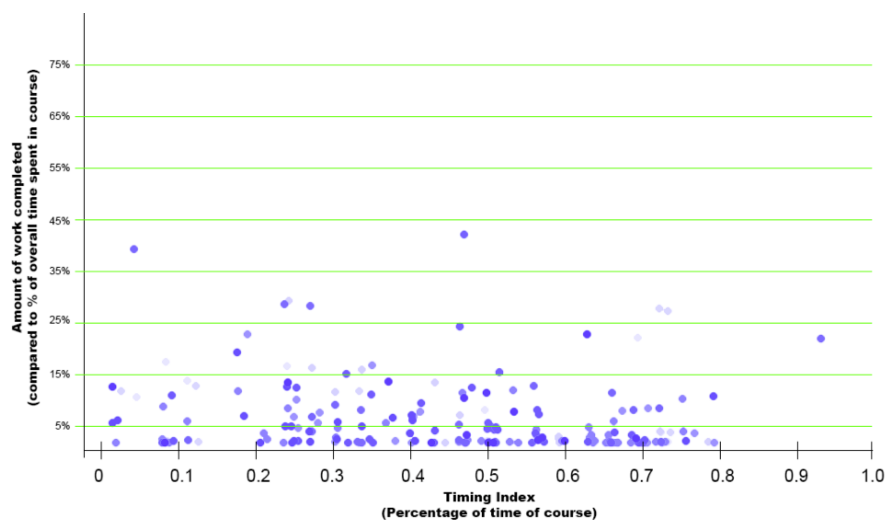
In addition to descriptive statistics, Research Question 1 can also be investigated with visualizations. The timing index can be used to visually analyze time-related behaviours in course participation, such as procrastination or early participation. One simple way to use a timing index is to group participants either by quartile (e.g., participants with the top 25% of timing index), by a specific timing index cut-off (e.g., 0.75, representing those who did half of their work in the last 25% of the course time), or other percentage or raw score threshold. This allows for easy division of groupings of "early starters" or "late starters" relative to their peers and not necessarily restricted by course raw time. Seeing the distribution of sessions of similarly scoring participants is one valuable way for researchers to analyze timing behaviours.

In Figure 4, three plots are provided, each representing a group of participants based on the quartile of their timing index score. Each point represents one session from a participant and the colour gradient shading represents different participants as output by the visualization script. Points were plotted with the x-axis representing the timing index of the session (a single dot) and the y-axis representing how much of a participant's work was completed in the session (given as a percentage of overall amount of work completed in that session).

In the first chart (e.g., blue points), participants were assigned to Group 1 (n = 11 participants) if their timing index score was in the lowest quartile, or alternatively below the 25th percentile of timing scores. This group represents those with the lowest timing index, which can be interpreted as the participants who completed half of their work earliest in the course. A visual examination of the plot confirms that a large portion of participants' sessions indeed occurred toward the beginning of the course timeline, with time indexes closer to zero. This visualization affords a researcher or instructional designer a quick, easily interpretable figure with which they can determine course completion in relative terms. In addition, reverse conversion to the calendar date for a specific time index is easily possible with some quick arithmetic.

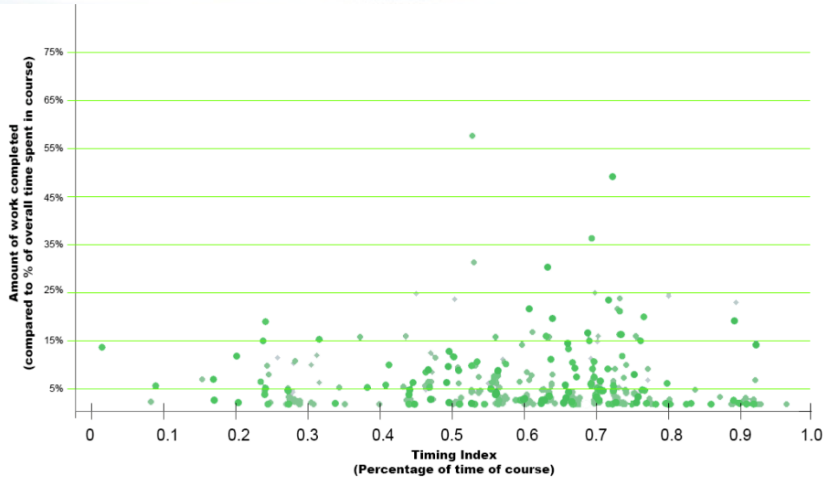
Similarly, the second chart with the green points represents those in Group 2 (n = 17 participants), which were assigned as such if their timing scores were between the two middle quartiles (25th–75th percentiles). Two quartiles were used in this group as they represent the middle-range of timing index scores and likely would fall within one or two standard deviations of the mean timing index of participants.

Finally, the third chart (red points) represents Group 3 (n = 14 participants), or the sessions of those participants who completed half of their work toward the end of the course. A review of the plots also confirms the skewed nature of the sessions toward the end of the course. It is this group that exhibits procrastination behaviours in the conventional sense, or largely waiting until the end of the course to complete work. However, the plot shows that much of the work remained spread out over time.

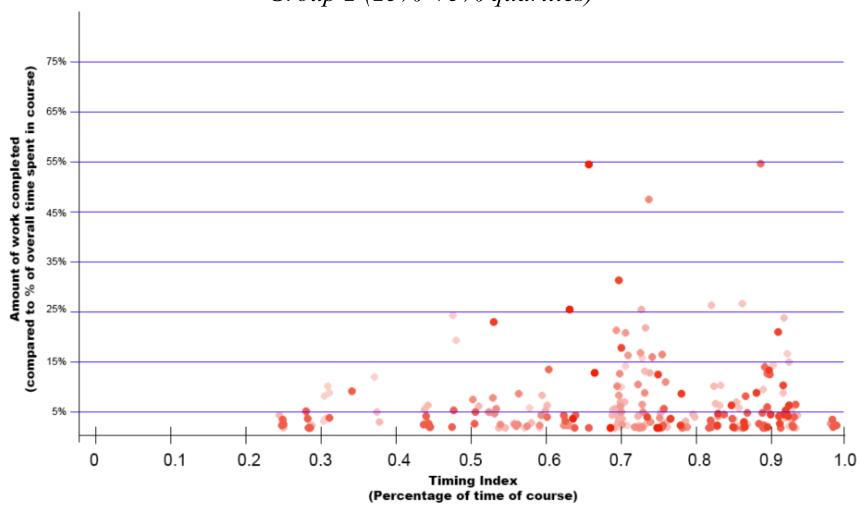


Group 1 (< 25% quartile)

Figure 4. Charts of participant sessions, grouped by timing index quartile.



Group 2 (25%–75% quartiles)



Group 3 (>75% quartile)

Figure 4 (continued). Charts of participant sessions, grouped by timing index quartile.

Descriptive statistics of each group provide an additional method for comparing groups. Table 2 describes the mean values and standard deviations for timing index scores and spacing counts, as broken down by timing index quartile group. As designed by breaking groups into quartiles, the timing index goes up as the quartiles increase. Interestingly, the mean spacing count for each group also follows a linear trend by going down as mean timing index goes up. This could be expected, as those who wait until later to finish their work have fewer opportunities to interact in the course, thus having a lower spacing score. By breaking the dataset into groups in this way, each group provides researchers a rank ordering of timing index membership so that the groups and their within-group timing behaviour patterns can be further studied. However, we do not perform any additional analyses on these groups in this study.

Table 2. Descriptive statistics on participants grouped by timing index quartile

	Timing Index Mean	Timing Index S.D.	Spacing Count Mean	Spacing Count S.D.
Group 1 (lowest quartile, beginning of course)	.416	.047	7.27	3.14
Group 2 (middle 2 quartiles, 25–75%)	.589	.170	6.07	2.72
Group 3 (highest quartile, end of course)	.740	.291	4.50	4.87

The visualizations and statistics from timing index grouping provide additional evidence for assumptions that timing behaviours are complex aspects of participation in open-ended courses and deserve additional analysis to better understand online learning mechanics. These visualizations and measures can help researchers further identify concepts and patterns of timing behaviours. It is also demonstrative of the challenging nature of plotting raw time to compare groups and patterns of timing behaviour. A raw time measure would be more challenging to interpret than a uniform scale. The timing index provides a scale that is simple to interpret and compare both within participants and groups in a course, but also between courses of varying time scales.

4.4. Combining Work Timing and Spacing

Timing index and spacing count are complementary measures that, when taken together, tell a richer story about the timing of work in a course. To investigate Research Question 2, we developed an additional simple visualization to "see" timing behaviours by plotting participants' combined timing index and spacing count on a scatterplot and viewing the regions of behaviour that emerge.

In Figure 5, we plotted each participant's timing index against spacing count values. We also plotted the two means of all participants' timing scores and spacing counts as a red point. From these means, we observed how the participants aligned with each other by first looking at a simple four-quadrant visualization based on the mean point of the two measures and its crosshairs. In this visualization, the two means for timing index and spacing count effectively provide a de facto grouping threshold that can be used to highlight regions from which patterns of timing behaviour can be observed. We highlighted the four quadrant regions that appear on the edges of the point for better visual attention. The points plotted within the scatterplot show visual variation in how participants timed their work in the course in a way that reflects the two measures combined.

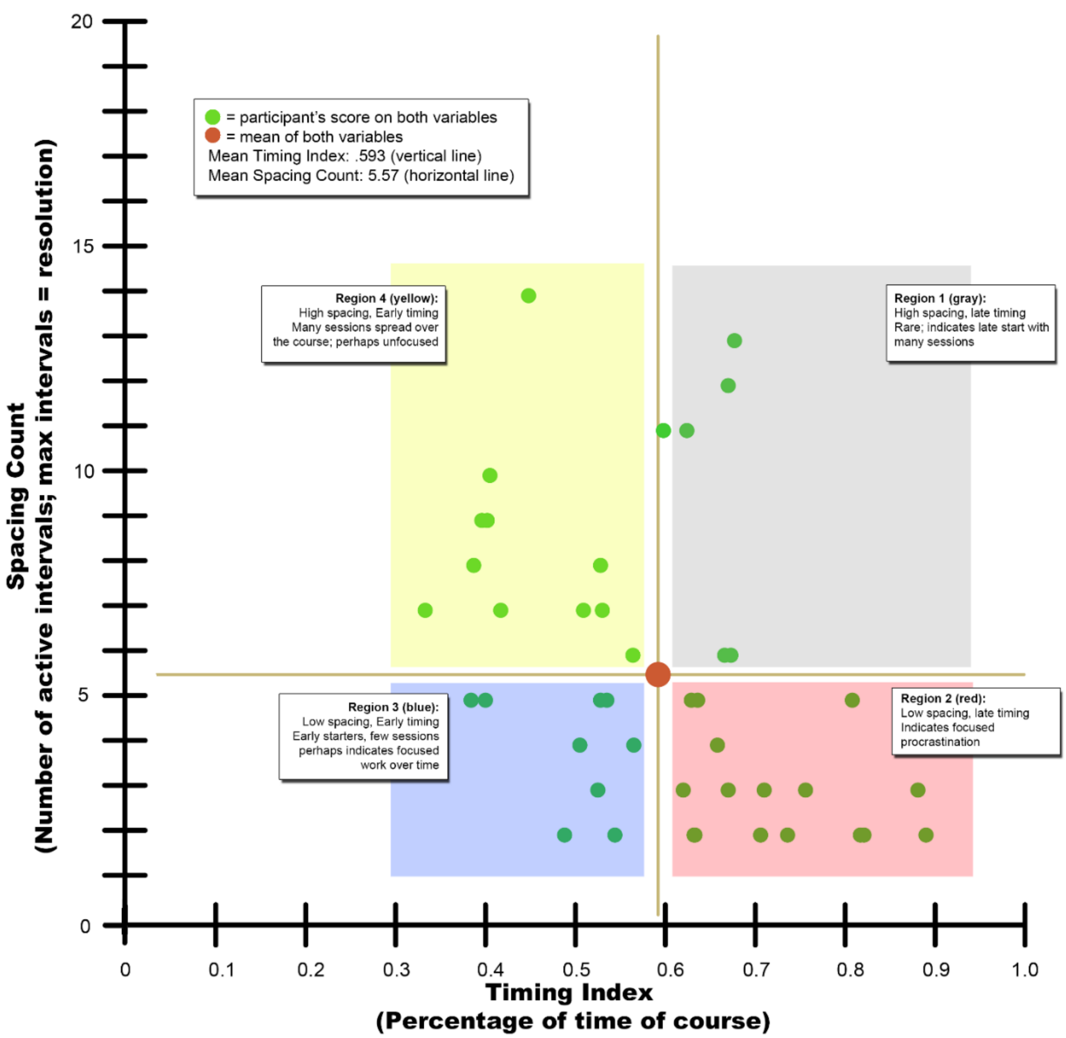


Figure 5. Scatterplot of timing index (x-axis) and spacing count (y-axis) for each participant. Range of each axis is the maximum value for each variable. The red centre of the crosshairs is the mean value for all participants for both variables.

Starting at the top right and moving clockwise, we did not expect to see many participants fall into Region 1 (gray), which was confirmed. This region indicates high timing index score / high spacing. To be in this region, a participant would have to both perform half of their work toward the end of the course and have a high spacing count (e.g., a high number of intervals in which they performed work during the course). It was also our assumption that assignment to this region would likely not be highly populated because of the short amount of time that participants would have to be counted over numerous work intervals. However, this region was not empty, as there were participants on the outer edges of the crosshair lines.

Region 2 (red) represents what we consider a late focusing pattern that can be observed from a combination of spacing count and timing index: a low number of spacing and a high timing index. This indicates that a participant did half of their work at the end of the course, and performed work over only a few intervals of the overall course timeline. Those in the late focusing group are also likely necessarily focused — there is not a lot of time to get work done and fewer opportunities to work over a greater number of intervals.

This category most closely aligns with concepts of procrastination reflected in the literature. However, we are hesitant to fully assign membership in this category as only procrastination, as there may be more involved with the timing of students' work that future work may show. As such, the methods used here may be a good next step toward understanding timing behaviours in online courses.

The low spacing number also carries over to Region 3 (blue), in what we consider a group that performed what we call early focusing. Members of this group had both a low spacing count and a lower timing index, indicating that work was done early in a focused way, or spread out over just a small few focused intervals in the course. The primary difference between this group and late focusers is the timing of half of their work, which provides a good distinction for interpreting the timing index as a measure of when work is completed. We do not necessarily know that participants focused on their work, as this was not directly observed. However, we do know that we observed participants completing their work over just a few time intervals, indicating more work was done in fewer intervals.

Finally, in Region 4 (yellow), we observed a different category of timing behaviour with a number of participants. This group represents what we call **early spacing** participants who had a high number of time intervals (via spacing count), but performed half of their work earlier than the late focusing group. This region is interesting as it represents a high number of intervals in which participants frequently were working, but also that their work was spread out over time as indicated by the timing index. These participants might be considered as those who are always logged in to a course, doing work in small pieces, or "always on" and connected to the course.

Inspired by the four-region scatterplot, a researcher could further assign grouping variables to participants based on their presence in a quadrant. However, we do not analyze participants in this way for this study. Grouping by the region that participants fall into can be used in future studies as independent predictors or grouping variables, much like the quartile grouping performed in Section 4.2. For instance, a group of participants with a timing index of 0.5 could indicate a large spread of work over the course when coupled with a high spacing count, but alternatively could indicate a "clumped" spread of work around the course midpoint when coupled with a low spacing count. As such, future studies that make use of the scatterplot, or other cluster and exploratory data mining methods might identify new meaningful regions of timing behaviour.

5. Discussion and Conclusion

In this study, we put forward timing index and spacing count as measures to present the timing of work in a course in easily interpretable and comparable terms. These measures provide tools for analysis that can be used to identify and investigate various patterns of timing behaviour that might emerge in an actual course. Using a dataset from an online, self-paced professional development course, we demonstrated visualization, grouping, and analysis techniques that can be used to identify procrastination and other timing behaviours. The analyses and visualizations throughout this study illustrate how temporal behaviours of students can be studied in ways that retain important timing elements. These approaches can assist instructional designers with developing improved learning activities that maximize learning with respect to timing behaviours.

This study is understandably limited by the low number of participants. However, we felt it was important to develop these measures on a small, yet sufficient dataset to explore insightful measures, visualizations, and patterns. Although the patterns observed in this single study are not representative of all forms of online and self-paced learning, the methods we used to observe these patterns could be useful for researchers seeking methods for identifying and analyzing procrastination, spacing, or other timing behaviours.

There are additional considerations to the measures presented in this paper that can be further improved in future work. The timing index as presented in this paper conceptualizes "work" in terms of the total amount of time that participants spent on course activities, which is an indicator of effort and work. However, it does not measure task completion. The timing index could alternatively be used to measure work in terms of course milestone completion as well as time spent in the online course, but would require significant adaptation to what was presented in this paper. For this study, most of the work was required to be done online and within the system alone. As such, much of the course work was reliably captured in the server logs. This, however, is not the case for many courses. Although we developed a method to infer whether interactions from the server log were a part of active sessions or not, additional measures would be helpful in future studies for identifying this kind of outside-of-the-learning-management-system work.

Future investigations with the measures in this study could identify and analyze the effects of different timing behaviours on various forms of online learning, such as procrastination, early starting, or high degree of spacing. New categories that characterize how participants use their time in online learning can help create a richer understanding of how students participate in online courses, how their timing of work manifests, and what effects that different patterns of timing have on learning. Participant-level factors may additionally influence participants' timing of work, such as motivation, confidence, personal schedules, interaction with course design or content, and interaction with other participants. It is also feasible that researchers could identify in future studies more nuanced patterns of timing with additional approaches using cluster and data mining algorithms.

In this paper, we provided examples of how the two measures of timing index and spacing count can be used to investigate course participation from a temporal lens. This is of special interest to instructional designers, as timing measures can provide additional insights about how participants interact with a course or, alternatively, the elements of the course that participants tend to ignore. From a design perspective, if participants consistently do not interact with course elements in a timely way, there may be reason to seek improvements in the usability or content of the course during subsequent course revisions. As courses increasingly employ open-ended and self-paced strategies, these measures could help researchers reveal important patterns related to learning, usability, and outcome achievement.

Declaration of conflicting interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

Andergassen, M., Mödritscher, F., & Neumann, G. (2014). Practice and repetition during exam preparation in blended learning courses: Correlations with learning results. *Journal of Learning Analytics, 1*(1), 48–74. http://dx.doi.org/10.18608/jla.2014.11.4

Berzonsky, M., & Ferrari, J. (1996). Identity orientation and decisional strategies. *Personality and Individual Differences, 20*, 597–606. http://dx.doi.org/10.1016/0191-8869(96)00001-3

Calderwood, C., Ackerman, P. L., & Conklin, E. M. (2014). What else do college students "do" while studying? An investigation of multitasking. *Computers & Education, 75*, 19–29. http://dx.doi.org/10.1016/j.compedu.2014.02.004

Clifton, B. (2012). *Advanced web metrics with Google analytics* (3rd ed.). Hoboken, NJ: Sybex.

DeBoer, J., Ho, A. D., Stump, G. S., & Breslow, L. (2014). Changing "course": Reconceptualizing educational variables for massive open online courses. *Educational Researcher, 43*(2), 74–84. http://dx.doi.org/10.3102/0013189X14523038

Ferrari, J. (1992). Procrastinators and perfect behavior: An exploratory factor analysis of self-presentation, self-awareness, and self-handicapping components. *Journal of Research in Personality*, *26*, 75–84. http://dx.doi.org/10.1016/0092-6566(92)90060-H

Ferrari, J., & Tice, D. (2000). Procrastination as a self-handicap for men and women: A task-avoidance strategy in a laboratory setting. *Journal of Research in Personality, 34*, 73–83. http://dx.doi.org/10.1006/jrpe.1999.2261

Fournier, H., Kop, R., & Durand, G. (2014). Challenges to research in MOOCs. *Journal of Online Learning and Teaching, 10*(1), 1–15.

Greene, J. A., Oswald, C. A., & Pomerantz, J. (2015). Predictors of retention and achievement in a massive open online course. *American Educational Research Journal, 52*(5), 925–955. http://dx.doi.org/10.3102/0002831215584621

Howell, A. J., Watson, D. C., Powell, R. A., & Buro, K. (2006). Academic procrastination: The pattern and correlates of behavioural postponement. *Personality and Individual Differences*, *40*, 1519–1530. http://dx.doi.org/10.1016/j.paid.2005.11.023

Jo, I., & Kim, Y. (2013). Impact of learner's time management strategies on achievement in an e-learning environment: A learning analytics approach. *Journal of Korean Association for Educational Information and Media, 19*(1), 83–107.

Kapler, I. V., Weston, T., & Wiseheart, M. (2015). Spacing in a simulated undergraduate classroom: Long-term benefits for factual and higher-level learning. *Learning and Instruction*, *36*, 38–45. http://dx.doi.org/10.1016/j.learninstruc.2014.11.001

Karweit, N., & Slavin, R. E. (1982). Time-on-task: Issues of timing, sampling, and definition. *Journal of Educational Psychology, 74*(6), 844–851. http://dx.doi.org/10.1037/0022-0663.74.6.844

Kovanović, V., Gašević, D., Dawson, S., Joksimović, S., Baker, R. S., & Hatala, M. (2015). Does time-on-task estimation matter? Implications for the validity of learning analytics findings. *Journal of Learning Analytics, 2*(3), 81–110. http://dx.doi.org/10.18608/jla.2015.23.6

Lemke, J. (2001). The long and the short of it: Comments on multiple timescale studies of human activity. *Journal of the Learning Sciences, 10*(1–2), 17–26. http://dx.doi.org/10.1207/S15327809JLS10-1-2_3

Liyanagunawardena, T. R., Adams, A. A., & Williams, S. A. (2013). MOOCs: A systematic study of the published literature 2008–2012. *International Review of Research in Open and Distance Learning, 14*(3), 202–227. http://dx.doi.org/10.19173/irrodl.v14i3.1455

Lowenthal, P. R., & Hodges, C. B. (2015). In search of quality: Using quality matters to analyze the quality of massive, open, online courses (MOOCs). *International Review of Research in Open and Distributed Learning, 16*(5), 83–101. http://dx.doi.org/10.19173/irrodl.v16i5.2348

Means, B., Toyama, Y., Murphy, R., Bakia, M., & Jones, K. (2010). Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies. Report. Washington, DC: US Department of Education Office of Planning, Evaluation, and Policy Development.

Mercer, N. (2008). The seeds of time: Why classroom dialogue needs a temporal analysis. *Journal of the Learning Sciences, 17*(1), 33–59. http://dx.doi.org/10.1080/10508400701793182

Miyamoto, Y. R., Coleman, C. A., Williams, J. J., Whitehill, J., Nesterko, S., & Reich, J. (2015). Beyond time-on-task: The relationship between spaced study and certification in MOOCs. *Journal of Learning Analytics, 2*(2), 70–74. http://dx.doi.org/10.2139/ssrn.2547799

Perna, L. L., Ruby, A., Boruch, R. F., Wang, N., Scull, J., Ahmad, S., & Evans, C. (2014). Moving through MOOCs: Understanding the progression of users in massive open online courses. *Educational Researcher, 43*(9), 421–432. http://dx.doi.org/10.3102/0013189X14562423

Riel, J., & Lawless, K. A. (2015). Massive open online courses (MOOCs) and the technologies that support learning with them. In Khosrow-Pour, M. (Ed.), *Encyclopedia of Information Science and Technology* (3rd ed.), 7529–7537. Hershey, PA: IGI Global.

Rohrer, D. (2015). Student instruction should be distributed over long time periods. *Educational Psychology Review*, *27*(4), 635–643. http://dx.doi.org/10.1007/s10648-015-9332-4

Roth, W. M. (2006). Learning science: A singular plural perspective. Rotterdam, Netherlands: Sense.

Shen, C., & Kuo, C.-J. (2015). Learning in massive open online courses: Evidence from social media mining. *Computers in Human Behavior, 51*, 568–577. http://dx.doi.org/10.1016/j.chb.2015.02.066

Terras, M. M., & Ramsay, J. (2015). Massive open online courses (MOOCs): Insights and challenges from a psychological perspective. *British Journal of Educational Technology*, *46*(3), 472–487. http://dx.doi.org/10.1111/bjet.12274

Wang, Y., Paquette, L., & Baker, R. (2014). A longitudinal study on learner career advancement in MOOCs. *Journal of Learning Analytics*, *1*(3), 203–206. 10.18608/jla.2014.13.23 http://epress.lib.uts.edu.au/journals/index.php/JLA/article/view/4200

Willems, J. (2005). Flexible learning: Implications of "when-ever," "where-ever" and "what-ever." *Distance Education*, *26*, 429–435. doi:10.1080/01587910500291579

Wolters, C. A. (2003). Understanding procrastination from a self-regulated learning perspective. *Journal of Educational Psychology, 95*(1), 179–187. http://dx.doi.org/10.1037/0022-0663.95.1.179

Method Supplement

TIMING INDEX PROCEDURE

Several steps are required to process the timing index. We developed these steps exploratorily as we interpreted the server interaction logs in our attempt to develop an objective and relative measure for investigating timing that could be easily interpreted and readily transferred to other contexts. In the following paragraphs, we provide a summary of the steps to derive the timing index score for each course participant.

Step 1: Transform timestamps to number of seconds. The first step was to transform the timestamps on log entries for each participant from date-times into number of seconds from the course starting baseline. As most server logs are in Unix time are recorded in number of seconds already, the Unix time for the start of the course was calculated and compared to timestamps. All timestamps were transformed to equal the number of seconds from the 0-point, or the baseline. For instance, a timestamp that occurs 25,000 seconds after the start of the course would equal 25000.

Step 2: Calculate elapsed time for each log entry. The elapsed time for each log entry was calculated. Line by line, the number of seconds between each log entry and its next subsequent log entry was calculated. A value of the time difference between the present and next log entry was assigned to the first log entry, denoting the number of seconds between each interaction. Final timestamps in a session (e.g., those that would have elapsed times > 30 minutes) were not counted in elapsed time. When reaching a new session in the line-by-line procedure (i.e., elapsed times > 30 minutes), the elapsed time of greater than 30 minutes is not recorded and the procedure is moved to the next entry in the log.

Step 3: Weight the elapsed time of individual log interactions by their timing index. The interaction timing index for each entry was used to weight the amount of time spent on a given log entry by participants. In other words, we weighted the elapsed time of a log entry by when the interaction occurred relative to the course's beginning. It is important not to interpret this value directly, as it is only used to calculate the overall timing score by taking the mean of all weighted elapsed time scores for all of a participant's log entries and comparing that mean to the total amount of time spent in the course.

Step 4: Compute overall timing index (when 50% of work is completed). Finally, we computed the overall timing index for each participant, which indicates when 50% of a participant's work was completed on the relative course time scale measuring from 0 to 1. Each weighted score from Step 3 was summed and then divided by the total amount of time spent by the participant in the course (measured in number of seconds). Equation 1.1 illustrates this procedure.

$$A = \sum (W_1, W_2 \ldots W_n) / C \qquad (1.1)$$

Where: A = A participant's combined timing index.
W_n = Weighted interaction timing indices from Step 3 for all interactions with a duration for a participant.
C = Total time spent by the participant in the course (in seconds)

SPACING COUNT PROCEDURE

The spacing count is dependent upon the development of the timing index measure discussed in the section above, so timing index was processed first for each participant. There are three steps to the process.

Step 1: Derive interaction and participant variables. First, it was necessary to derive both the elapsed time and timing indices (with values 0 to 1) for each interaction (or entry) in the server log. This was done via the process discussed above for developing the combined timing index for each participant. During data pre-processing, sessions were also determined. It was necessary to also compute the overall amount of time spent by each participant, as it served as a measure of total amount of work performed by the participant for this study.

Step 2: Set the number of intervals and substantive work. A number of intervals or bins was determined from which the participants' presence of work was counted. The number of intervals of 20 was chosen. These 20 intervals across the course represents an evenly divided percentage of 5% of course time within each interval and aids in the quick interpretation of the measure for researchers. Each interval represents the same percentage of time in comparison to the overall course. Thus, all intervals added up equal 100% of the course.

Instead of counting whether a session was present in an interval, we wanted to capture whether a substantial amount of work was completed. For this we defined *substantive work,* which is the amount of work — measured as a percentage number of the participant's overall amount of work — that is deemed a significant amount by the researcher for a time. This value serves as a threshold within each interval of time for how much work is needed to be done by a participant in the respective interval to be considered a "substantive" amount of work and be counted in the spacing count. For instance, in any given interval of time (say, 5% of course time), a "substantive work value" of 5% would mean that a participant who performed 5% or more of their overall amount of work during that interval would be said to have completed a "substantive" amount of work. We chose a level of 5% for the substantive work threshold in an interval to reflect that the participant was focused enough, but not simply logging on without much activity. In addition, we counted the summed elapsed time of sessions within an interval. If all of the sessions within an interval totaled at least 5% of work when added, it was included in the spacing count.

Step 3. Compute spacing count. This step determines the spacing count for each participant. Each participant's log entries are processed in chronological order. Using a simple *for loop* script, the pseudo-code in Algorithm 1 illustrates the iterative process used for testing whether the substantive work threshold for aggregate work in each resolution interval was met and to programmatically generate the spacing count for each participant from the server logs. For every interval in which a participant's aggregate time spent was above the substantive work threshold (measured in seconds, *S*), the *spacing count* (*A*) increases by 1.

This loop runs iteratively through each time-bound interval, comparing whether the current log entry is in the interval under question (signified by loop index *i*). In each iteration, the loop tests whether it is within the time boundaries for the interval (eligible if time index *Y* is less than loop index *i* multiplied by 1/*N*). A loop index *i* starts at one due to the multiplication that is necessary in the loop. Thus, the endpoint target *N* in the loop has a value of *N*+1 to account for this.

This process returns value *A* for each participant, the spacing count.

Algorithm 1: Iterative loop pseudocode used to compute spacing count

*** for each log entry L***

```
for (i = 1, i < N+1) {

if (Y_L < i*(1/N)) {
     c = c + T_L
}
else (or, if the last log entry) {
     if (c > S) {
            A++
     }
     c = T_L;
     i++;
}
}

return(A);
```

Where: i = Loop index.
A = Spacing count.
N = Interval resolution (number of intervals in the course).
S = Number of seconds necessary to meet "substantive work" threshold, which is determined for each participant.
Y = Time index for each log entry L (but not an interaction at the end of a session, idle time > 30 minutes; those are discarded).
T = Elapsed time for the log entry L.
c = Temporary additive time counter for intervals, allowing the program to progress through all time intervals in the course (total number = N intervals).