Abstract Research is constantly engaged in finding more productive and powerful ways to support quality learning and teaching. However, although researchers and data scientists try to analyse educational data most transparently and responsibly, the risk of training machine learning algorithms on biased datasets is always around the corner and may lead to misinterpretations of student behaviour. This may happen in case of partial understanding of how learning log data is generated. Moreover, the pursuit of an ever friendlier user experience moves more and more Learning Management Systems functionality from the server to the client, but it tends to reduce significant logs as a side effect. This paper tries to focus on these issues showing some examples of learning log data extracted from Moodle and some possible misinterpretations that they hide with the aim to open the debate on data understanding and data knowledge loss.

1 Introduction

The relevance of e-Learning for education is steadily growing and has become even self-evident during the Covid-19 pandemic. The chance to inspect learners’ activities is leveraged by the rising adoption of Learning Management Systems (LMS), Massive Open Online Courses (MOOC), and other Online Learning Environments (OLE), which are significantly raising the collection of considerable volumes of log data. Greater attention is being paid to model student behaviour during their online learning; nevertheless, as shown by a number of studies on this topic Oliveira et al. (2016), Alario-Hoyos et al. (2020), the advancement of distance learning favours more in-depth monitoring to establish its effectiveness in educational environments. The main challenge is how to “translate” collected data into actionable data and meaningful insights.

Predictive Analytics is widely used in Learning Analytics to find meaningful relationships among learning data, identify patterns, and forecast student behaviour Ranjeeth et al. (2020). Research is constantly in search of more efficient and powerful ways to support quality teaching and learning Lang et al. (2017). Machine learning and data mining use collected datasets to train models to make real-time inferences based on new observations about student success, dropout or to predict student performance. However, although researchers and data scientists analyse educational data to find answers to ever broader questions in a transparent, responsible manner, the risk of training machine learning algorithms on biased datasets of the learning process could lead to incorrect predictions. As previous works already highlighted Knobbout et al. (2019), Romero et al. (2014), Kovanović et al. (2016), this is the case with the misunderstanding of learning log data that may lead to incorrect choices in data cleaning and preparation.

In the relatively young Learning Analytics field, gathering data presents some additional difficulties: event logs are often generated by algorithms designed for purposes other than online learning tracking, and, consequently, they often
lack some essential information that would make log data more usable and meaningful. Although this is changing, it is still too slow with respect to the increasing demand for quality data. As a matter of principle, event logs typically record all operations involving an interaction with the server, yet rich client-side interfaces allow many local operations without any page loading. Therefore, while improving the user experience (in terms of responsiveness and reduced bandwidth), they hide some local user actions, spoiling the data collection of some essential and valuable clicks.

Given these premises, this work aims to illustrate where educational log data can be challenging to interpret. We report the results of this investigation to take advantage and exploit this information to perform better data pre-processing, cleaning, and analysis while modeling learner behavior.

This work is structured as follows. Section 2 introduces Learning Analytics and its measurement activity. Section 3 provides an overview of log data collection. Limitations and variations are also highlighted. Finally, Section 4 presents an in-depth study on learning log data and the pitfalls it hides, as well as possible solutions to overcome them.

2 Background

E-Learning is an organised and planned process where courses are designed to transfer knowledge and competencies by means of study materials, activities, and user interactions. Educational Data Mining tries to extract actionable information from log data, enable knowledge construction, and support decision-making. Although a model cannot fully understand it, the learning process is complex, and a model-based representation of user’s interactions can grasp the main evidence and help discover some aspects that perhaps would remain unseen and unexplored in a traditional context. In this view, Learning Analytics (LA) may represent a profitable "meeting point" between pedagogy and data science.

The definition of LA as “the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs” Siemens and Long (2011), locates LA within the context of the Knowledge Discovery process Daniel (2015) and highlights that the measurement of educational data is the first challenge to face in the deployment of LA techniques.

Any measurement activity Pedhazur and Pedhazur Schmelkin (1991) necessarily begins with the definition of the quantity to measure, the selection of a measuring instrument, and ends up with an interpretation of the measurements carried out. As for the observables, measuring student behaviour during their active learning is difficult since it involves their previous knowledge, cognitive abilities, traits of personality, emotional states, attitudes, and skills. Variables that are not simple to measure are called constructs and, while learning online, they are commonly measured using tests, quizzes, questionnaires, and surveys Bergner (2017).

Online construct measurement is often based on log files that collect traces of user actions performed in sequence while learning online. The growing adoption of LMS, MOOC, and OLE has significantly increased the possibility to collect a wider amount of log data, and several authors have applied data mining algorithms to discover patterns in actions performed by students. They investigated features like resource usage, action frequency, average latency, login frequency, number of module accesses, login time, login regularity, total studying time, and regularity of learning interval Bernardini and Conati (2010), Conijn et al. (2017), Cooley et al. (1999), Darlington (2017), Siemens and Long (2011), Sael et al. (2013), Bovo et al. (2013), Yu and Jo (2014), Fincham et al. (2019). The authors have developed specific analytical tools for their objectives or case studies, in general, related to predicting student academic success and detecting at-risk students to avoid academic failure or drop-outs. However, although previous works were shown to be useful, to the best of our knowledge, most studies do not provide enough information about how log files have been extracted and the adopted preparation techniques to make their results easily replicable.

3 Learning Log Data Collection

A largely used LMS is Moodle, an open-source virtual environment that supports education providing two main kinds of learning and teaching modules: Resources MoodleDocs (2021a), items that can be browsed online or downloaded for offline use; and Activities MoodleDocs (2021b), more advanced modules that involve student interaction. Moreover, besides the creation and management of knowledge, this LMS also includes communication tools, like messaging and forums, to promote an active involvement in the learning process and within the learning community Wild et al. (2002).

Moodle log data captures user activity at different levels:

- **teaching level**: actions usually performed by teachers which affect the student learning experience (for instance, grading an assignment or creating/updating a module);
participating level: actions related to a user (student, teacher, or other course participants) learning experience, such as the user-artefact relationship, namely the learner-learning resource connection (for example, module view, posting to a forum or attempting a quiz);

• system level: actions that include, among other things, the user-user relationship (like profile views), or the communicative interactions between the members of the learning community.

As we will try to outline in the present work, these three levels all concur to define the interaction pattern of each user.

3.1 Human-readable logs

In Moodle, logs can be generated according to different needs by easily selecting a combination of elements in the log generation interface shown in Figure 1:

• group (the overall site or a specific course; this first selection is fundamental to determine the hierarchical level of log extraction, as we will explain throughout the paper)
• participants (all participants or a specific user)
• date (all days or a specific day)
• activities (all activities or a specific activity)
• actions (all actions or separated in ‘create’, ‘view’, ‘update’, ‘delete’, or ‘all changes’)
• sources (‘CLI’: usually deleted activities; ‘Restore’: typically teachers and managers activities related to role permissions and forum subscriptions; ‘Web’: user activities; ‘Web service’: platform usage via mobile app)
• events (all events or separated in ‘participating’, ‘teaching’ and ‘other’ - the latter usually indicates actions performed on the platform but outside the courses)

Figure 1: Moodle log generation interface

The generated default Standard Logs [MoodleDocs (2021c)], which can be displayed or downloaded in many file formats [MoodleDocs (2021d)], are very detailed and supplied with: their temporal information (the system sequential time); information concerning the user performing the action; the eventual recipient of the action (for instance a user that receives a message); the context [MoodleDocs (2021c)] within the platform; the component (the module type, e.g., Wiki, Page, File, Url, Quiz, or System); the event name (the action type performed on the module such as viewed, deleted, updated, created, submitted); the description of the event (with the IDs of the user and the module concerned); the origin (the sources: CLI, Restore, Web, Web service); and the IP address from which the action was performed. Figure 2 shows a typical generation of log data within the Moodle platform where we replaced the full names of the users with their IDs for privacy concerns.

As a matter of principle, in order to gather logs only relating to online user activities and to avoid unnecessary data cleaning, we suggest selecting the web source (origin) in the Moodle log generation interface. However, collected web data still hides useless information such as Admin settings editing, Guests activities (logged-in users that access courses without being required to enrol [MoodleDocs (2021f)]), and cron jobs usually, but not always (cf. Section 4.4), identified by the User full name ‘-’. The Moodle cron process is a PHP script, part of the standard core Moodle installation, that regularly runs in the background and performs a number of tasks (such as sending emails to notify forum posts to participants) at scheduled intervals, usually every minute [MoodleDocs (2021g)]. To understand the extent of this useless information, 136,446 out of 318,249 collected web records involved cron and Admin activities; therefore, they have been subjected to data cleaning.
3.2 Database Logs

All logs displayed in Moodle in a human-readable format are extracted from the database table `logstore_standard_log` (which stores all log data) and formatted in a user-friendly way. To query the logs directly from the database, it is possible to use the Configurable Reports block (MoodleDocs (2021h)), a third-party plugin that allows users to create custom SQL queries to execute on Moodle’s database. As illustrated in Figure 3, which shows the dynaset extracted from the table `logstore_standard_log`, the number of columns is much greater than those generated employing the platform tool in Figure 2.

Romero et al. (Romero et al. (2014)) suggest to extract logs in a machine-readable format, then select the most representative attributes to address a specific educational problem. Nevertheless, the conversion of logs into a sortable, filterable, and human-readable tabular format adds to the raw data as much context as possible, allowing each record to become more distinctive and easily identifiable to reconstruct what happened within the interaction on the platform. However, the Moodle log formatting process hides some errors, as we will outline in the next section.

![Figure 2: Log Data generated in Moodle](image)

![Figure 3: Log data generated in Moodle's database](image)

4 Learning Log Data Understanding

The above-cited studies and numerous others used log data to perform student behaviour analysis. Nonetheless, to the best of our knowledge, previous work discusses the challenges and strategies of their analysis without taking into consideration that the extraction of log data at the course level (group: a specific course) does not provide enough information to fully understand what the student is doing at the overall site level.

When collecting data on a course-by-course basis, some critical information regarding user interactions is missing. All actions concerning user-user relationships (for instance, message sending and reading) or involving student self-awareness (such as the grading overview and other aspects related to the user profile) are all logged at the system level (group: ‘overall site’ and events: ‘other’, in the Moodle log generation interface). For example, while carrying out group work on a course, two users start interacting by writing some messages. At the system level, the logs record that the user ‘59’ is "apparently" out of any course while sending the message to the user ‘62’ (cf. Figure 2). It is as if they...
go in and out of the course many times. Collecting data at the course level does not contain these actions and leaves temporal holes so that users seem to spend more time than expected on some resources/activities.

At the same time, the selection of the 'overall site' group (leaving all the other interface elements unchanged) will return the logs of the actions performed out of any course, as well as the logs of all the courses, following the timestamps sequence. However, logs concerning actions performed on modules (e.g., 'Event context' in Figure 2) do not provide any information on the course in which they occur. The only indication we get from these logs is the IDs identifying the user and the module in the Description field. Moreover, users could browse modules of different courses without accessing the home page (that will help identify the course scrolling through the log sequence) by simply clicking on a link (e.g., an email sent by the teacher) or opening multiple browsers tabs. Therefore, extracting logs at the 'overall site' group makes it challenging to determine the course to which they belong.

In an attempt to illustrate the point as clearly as possible, in the following sections, we provide several examples extracted from Moodle, version 3.9.4+, and some recommendations based on the results of our investigation. From now on, we will refer to the logs recording actions not related to the course level as site level, and we will use the word Student instead of User when an action can be performed only by the student role MoodleDocs (2021i).

4.1 The Description field

To identify the course, one solution could be to extract the module IDs from the Description field by means of regular expressions and join them with a list of all module IDs of every course. However, the Description field presents some irregularities introduced by the formatting performed on database log reporting. Table 1 depicts some examples of conversion issues from raw data.

Table 1: Conversion issues from raw data

| ID | Description |
|----|-------------|
| 1a | The user with id '18' viewed the 'assign' activity with course module id '708'. |
| 1b | The user with id '18' has viewed the submission status page for the assignment with course module id '708'. |
| 2a | The user with id '52' updated the completion state for the course module with id '107' for the user with id '52'. |
| 2b | The user with id '52' has added the option with id '6' for the user with id '52' from the choice activity with course module id '196'. |
| 3a | The user with id '47' viewed the 'chat' activity with course module id '146'. |
| 3b | The user with id '52' has sent a message in the chat with course module id |

Case 1: the 'assign' activity of the description a becomes assignment in the description b. This situation is bizarre because the same type of activity is stored in the database table mdl_modules with two different names and IDs (id 1: assign; id 2: assignment).

Case 2: the with course module id of description a becomes course module with id in the description b.

Case 3: the 'chat' activity in the description a becomes chat in the description b where the sentence is also truncated.

This way of fixing the problem is not straightforward and should consider all possible cases. However, the Description provides helpful information that can be used to analyse user actions, and these irregularities should be considered.

Another solution could be the use of the Configurable Reports block which, as shown above, allows users to create custom SQL queries to query Moodle’s database tables. Several tables are needed to build a query to perform the association between the module ID and the corresponding course, and correctly split the logs by clearly identifying which course every module belongs to. Anyway, the complete Moodle Database schema Green (2021) is available. However, it is also possible to use the PHP function get_fast_modinfo() that returns all information about activities of a specific course divided by sections in a faster way than querying the database MoodleDocs (2021j).

In our opinion, the most straightforward way to collect all logs without loss of information is to extract the web logs at course level and provide the generated table with an additional field identifying the course. Repeat this action for all the courses on the platform and concatenate all the tables into one. Then extract the web logs of the overall site and merge the two tables deleting duplicates: the result will provide all logs related to user activities at site and course levels without loss of information.

In any case, other solutions could be found, but in order not to miss knowledge when collecting student interactions on the platform Fincham et al. (2019), it should be known and taken into consideration that some logs are stored at the course level while others at the site level.
4.2 The Temporal information

Each log record is supplied with temporal information, a timestamp that typically identifies the Unix Time of the action performed. Log generation from Moodle interface converts the Unix Time in a human-readable format (for instance: 27 April 2021, 7:21 PM) with a minute-time granularity. For our purposes, as we noticed that a large number of actions could be performed in a minute, reducing our understanding, we extracted the Unix Time directly from the database (the timecreated field) to get a second-time granularity and converted it to a Date&Time standard format.

Time is a fundamental aspect to consider when modelling student behaviour, and the analysis and interpretation of the actions cannot fail to pass through the analysis of the time taken to perform them. However, the analysis of time is a very tricky task faced in a number of works [Kapusta et al., 2012, Kovanović et al., 2016, Knight and Wise, 2017, Chen et al., 2018, Lee, 2018, Rushkin, 2018, Knobbout et al., 2019], but it still needs a deep intervention that we will deal with in a later study.

In Moodle, events are recorded either at the beginning or at the end of the action [Kovanović et al., 2015, Kovanović et al., 2016]. A helpful example, illustrated in Table 2, shows log sequences when posting content on a forum. In all cases, the subscription mode option is set to “Auto subscription” [MoodleDocs, 2021k] to focus only on significant concurrent events and avoid not relevant logs.

Let us start with the creation of a new discussion in the forum. When the user enters the forum, the beginning of the event ‘course module viewed’ is recorded at time 1a. After clicking on the "Add a new discussion topic" button, an editing window opens, and the user starts writing. At time 1b, the button "Post to forum" is clicked, and the log records the event "Some content has been posted" marking the end of the writing action. The user is then redirected to the general view of the forum with the list of all the threads. At the very same time (1b=1c=1d), two more beginning events are logged: the creation of the discussion and the module view due to the redirecting action.

| ID | Timestamp | Event name          |
|----|-----------|---------------------|
| 1a | 2021-01-08T20:40:13 | Course module viewed |
| 1b | 2021-01-08T20:45:08 | Some content has been posted. |
| 1c | 2021-01-08T20:45:08 | Discussion created  |
| 1d | 2021-01-08T20:45:08 | Course module viewed |
| 2a | 2021-01-13T16:34:54 | Discussion viewed    |
| 2b | 2021-01-13T16:36:31 | Some content has been posted. |
| 2c | 2021-01-13T16:36:31 | Post created         |
| 3a | 2021-02-17T12:22:35 | Discussion viewed    |
| 3b | 2021-02-17T12:22:55 | Some content has been posted. |
| 3c | 2021-02-17T12:22:55 | Post created         |
| 3d | 2021-02-17T12:23:01 | Post deleted         |
| 4a | 2021-02-06T21:03:55 | Discussion viewed    |
| 4b | 2021-02-06T21:05:03 | Some content has been posted. |
| 4c | 2021-02-06T21:05:03 | Post updated         |
| 4d | 2021-02-06T21:05:03 | Discussion viewed    |

The second example takes into account the creation of a new post in a discussion already started. The user enters the thread at time 2a, then at a specific moment clicks on the link "Reply" and starts writing something. Unfortunately, we do not know precisely when as the rich client-side interface allows this local operation without any server request. At time 2b the user clicks on the "Post to forum" button, and the content is posted; at the same time (2b=2c), one more log is recorded: the creation of the new post. Beyond the event name, which obviously differs from the previous example, the fourth event is currently missing. Since the action is typically performed on the client, no new requests to the server and page reload are needed, and the user is allowed to answer a number of posts while on the same page.

After a post is added, Moodle grants 30 minutes to delete or edit it before sending a notification to the mailboxes of all subscribers. Like the second example, the third one illustrates a sequence of actions performed on the client-side: the creation of a new post and the subsequent decision to delete it.

The fourth example shows a typical log sequence when a post is updated. At the same time (4b=4c=4d) three logs are created and unlike the 2nd example, one more event is added: the view of the discussion. To update a post, a request is sent to the server, the page is reloaded, and a new log is added.
It is worth noting that the log “Some content has been posted” is always inserted before the record that informs about the type of action: “Discussion created”, “Post created”, and “Post updated”. Therefore, when counting the number of forum posts Fincham et al. (2019), it should be taken into account that the real action performed is clarified later.

As we will see in the next section, several simultaneous actions are stored in the log files. To provide an idea of the number of concurrent events, only 127,637 out of the 181,803 (318,249 - 136,446) records above mentioned have no duplicates on the Unix Time basis. Given their large number, we think they deserve particular attention as they can represent automatic events (like the Activity Completion Tracking described in Section 4.3) and depend on the activity settings.

### 4.3 ‘Event context’, ‘Component’, and ‘Event name’ fields

The title fields illustrate the context, the component, and the name of the activities that the user is carrying out as extracted from the Moodle platform interface. The “Event context” is usually composed by the type of module (or course) followed by its name (the name of the module as it appears on the course homepage or the name of the course) or “System” (as we will describe in Section 4.4). The “Component” is the module type or again “System”. The “Event name” summarises in a few words the action performed.

Since the event context is usually composed by the component name (for instance, ‘Assignment:T-Test’ and ‘Assignment’ as in Table 3) and also the component sometimes contains the same information of the event name (this is the case of ‘File submissions’ and ‘Submission created’), they might be perceived as only loosely correlated redundant attributes. In fact, given the availability of attributes, Romero et al. [Romero et al. (2008)] suggest selecting the most representative attributes that can help to address a specific educational problem. However, in our opinion, the authors overlook the fact that to fully understand what is happening, the different levels of granularity that every attribute provides contribute to defining each user interaction pattern, as we will illustrate in this section.

Let us take as an example an Assignment activity (whose log entries are illustrated in Table 3) which allows teachers to collect submissions from students as uploaded files, requires them to click the submit button, and automatically marks the task as completed as soon as they submit (the assignment setting ‘activity completion’ MoodleDocs (2021) is enabled and set as “Student must submit to this activity to complete it”). What can be clearly seen in this table is the difference between the event context and the component. Whereas the former is always the same, the latter changes.

| T   | Timestamp     | Event context         | Component | Event name                                           |
|-----|---------------|-----------------------|-----------|------------------------------------------------------|
| 1   | 2021-04-29T18:12:20 | Assignment: T-Test  | System    | Course activity completion updated                  |
| 2   | 2021-04-29T18:12:20 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 3   | 2021-04-29T18:12:20 | Assignment: T-Test  | Assignment| The status of the submission has been viewed.        |
| 4   | 2021-04-29T18:12:23 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 5   | 2021-04-29T18:12:23 | Assignment: T-Test  | Assignment| Submission form viewed.                             |
| 6   | 2021-04-29T18:12:29 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 7   | 2021-04-29T18:12:29 | Assignment: T-Test  | File submissions | A file has been uploaded. |
| 8   | 2021-04-29T18:12:29 | Assignment: T-Test  | File submissions | Submission created.                   |
| 9   | 2021-04-29T18:12:29 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 10  | 2021-04-29T18:12:29 | Assignment: T-Test  | Assignment| The status of the submission has been viewed.        |
| 11  | 2021-04-29T18:12:34 | Assignment: T-Test  | Submission comments | Comment created |
| 12  | 2021-04-29T18:12:37 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 13  | 2021-04-29T18:12:37 | Assignment: T-Test  | Assignment| Submission form viewed.                             |
| 14  | 2021-04-29T18:12:46 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 15  | 2021-04-29T18:12:46 | Assignment: T-Test  | File submissions | A file has been uploaded. |
| 16  | 2021-04-29T18:12:46 | Assignment: T-Test  | File submissions | Submission updated.                        |
| 17  | 2021-04-29T18:12:46 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 18  | 2021-04-29T18:12:46 | Assignment: T-Test  | Assignment| The status of the submission has been viewed.        |
| 19  | 2021-04-29T18:12:49 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 20  | 2021-04-29T18:12:49 | Assignment: T-Test  | Assignment| Submission confirmation form viewed.                  |
| 21  | 2021-04-29T18:12:50 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 22  | 2021-04-29T18:12:50 | Assignment: T-Test  | System    | Course activity completion updated                  |
| 23  | 2021-04-29T18:12:50 | Assignment: T-Test  | Assignment| A submission has been submitted.                     |
| 24  | 2021-04-29T18:12:50 | Assignment: T-Test  | Assignment| Course module viewed                                |
| 25  | 2021-04-29T18:12:50 | Assignment: T-Test  | Assignment| The status of the submission has been viewed.        |
At time $T2$ the log records the student accessing the activity “Assignment: T-Test”, but at time $T1$ (the same as $T2$ but earlier in the list) the activity has been already logged as completed. In general, the automatic events are identifiable through the “System” component, as we will see in Section 4.4. At time $T3$ one more entry records the status of the submission as ‘viewed’. These three logs are concurrent ($T1=T2=T3$) because they happen at the very same time: the student accesses the assignment, and the activity is completed ($T1$), the module description is displayed at the top of the page ($T2$) while the status of the submission is showed at the bottom ($T3$). At time $T4$, the student clicks on the “Add submission” link, a new request to the server is sent ($\&action=editsubmission$), but the log records the same event as $T2$: this happens because the top of the loaded page is the same as before, while at the bottom ($T5=T4$), the submission status has been replaced by the form to submit the file. When the file is uploaded (via the “File picker” $\text{MoodleDocs (2021m)}$ or via “drag and drop” the type and the number of logs does not change), five concurrent events ($T6=T7=T8=T9=T10$) are recorded: event $T6$ identifies that the new request to the server ($\&action=view$) always loads the same page (like $T2$ and $T4$), $T7$ records the uploading of the file (the component changes to “File submissions” and identifies the module settings; if students were asked to submit text online, the component would be “Online text submissions” but both components can be present depending on the settings) and concurrently ($T8$) the creation of the submission is logged. Moreover, events at times $T9$ and $T10$ are exactly the same as $T2$ ($T4=T6$) and $T3$ because the page shows the module description at the top and the updated submission status at the bottom.

At time $T11$ the student adds a comment in the submission status, and the component changes in “Submission comments” to indicate that comments are different from the Assignment activity although in the same context. This is the same occurrence as for forum posts (case 2b of Table 2): the log is recorded only at the end of the event after the student clicks on the “Save comment” link. Then at time $T12$ and $T13$, there are the same couple of events as in $T4$ and $T5$, but we are not able to understand what is happening until the event at time $T16$ highlights that the student updated the submission (created at time $T8$) by repeating the same action as before: clicking on the “Edit submission” button. This button, available for activity settings “Require students to click the submit button”, allows students to edit the submission many times before clicking it. Therefore, $T17$ and $T18$ repeat the event $T9$ and $T10$. At time $T19$ the student finally clicks on the “Submit assignment” button and the “Confirm submission” page ($\&action=submit$) is loaded at the same time ($T20$). When at time $T21$ the student clicks on the “Continue” button, there are more concurrent events: the system automatically records that the activity is completed ($T22$), that the submission is submitted ($T23$), and the assignment page is updated ($T24$) with the submission information ($T25$).

To understand these event logs in-depth, we replicated the assignment module and repeated the experiment many times by changing the settings to analyse the differences. We noticed that the sequence and the number of logs, as well as the number of quasi-simultaneous events, depend not only on the actions performed at the student side (edit submission, remove submission) but also at the teacher side (module settings). For example, it is worth noting that in Figure 2, every time a user goes to the next page in the lesson, the logs record the “course module viewed” event. Obviously, two lessons with a different number of pages on different courses lead to a completely different number of module views. Therefore, we think that when counting the number of actions performed on modules of different courses to analyse student behaviour on tasks or the time spent on them (the number of actions required from the student for submission completion) the system automatically records that the activity is completed ($T22$), that the submission is submitted ($T23$), and the assignment page is updated ($T24$) with the submission information ($T25$).

While illustrating the settings of the Assignment activity presented in Table 3, we stated that “Activity completion tracking” was enabled for the setting “Student must submit to this activity to complete it”. By analysing data, we discovered that the “Activity completion tracking” was also enabled for the setting “Student must view this activity to complete it”, as event $T1$ shows. This double setting was certainly an oversight of the teacher, but it held our attention because it might concern the student behaviour (for instance, a sign of self-regulated learning) as we would like to depict now. Table 4 shows a non-exhaustive list of particular cases: unhelpful logs have been deleted and the event context modified to clarify actions and identify differences immediately.

In case 1, users are requested to access the file to complete the activity (“Student must view this activity to complete it”). Once the file is viewed, two similar events are recorded ($ia=1b$) to mark the activity as completed. The second one is probably a mistake of redundancy. While being simultaneous ($ia=1b=1c$), the module view is recorded after the two previous events, as for the example of Table 3, and the same happens with other types of modules.

In case 2, users could access the file many times ($2a$ and $2b$) without any log concerning activity completion being recorded. When they want to mark the activity as completed, they can manually do it ($2c$). However, we did not find any way to distinguish this self-regulated behaviour from the automatic marking activity completion (case 1) as the Component of the event log is always “System” (cf. Section 4.4), and the Description is the same (only the user and the module IDs change).
Table 4: Activity Completion Tracking

| ID  | Timestamp          | Event context                                      | Component   | Event name                        |
|-----|--------------------|----------------------------------------------------|-------------|-----------------------------------|
| 1a  | 2021-05-01T18:40:16| File: Automatic Completion (view)                   | System      | Course activity completion updated|
| 1b  | 2021-05-01T18:40:16| File: Automatic Completion (view)                   | System      | Course activity completion updated|
| 1c  | 2021-05-01T18:40:16| File: Automatic Completion (view)                   | File        | Course module viewed              |
| 2a  | 2021-04-13T11:24:06| File: Manual Completion                             | File        | Course module viewed              |
| 2b  | 2021-04-13T11:15:29| File: Manual Completion                             | File        | Course module viewed              |
| 2c  | 2021-04-13T11:15:33| File: Manual Completion                             | System      | Course activity completion updated|
| 3a  | 2021-03-14T09:11:45| Assignment: Manual Completion                       | File submissions | A file has been uploaded     |
| 3b  | 2021-03-14T09:11:45| Assignment: Manual Completion                       | File submissions | Submission created           |
| 3c  | 2021-03-14T09:11:51| Assignment: Manual Completion                       | System      | Course activity completion updated|
| 4a  | 2021-05-01T20:01:18| Assignment: Manual Completion with submit button    | File submissions | A file has been uploaded     |
| 4b  | 2021-05-01T20:01:18| Assignment: Manual Completion with submit button    | File submissions | Submission created           |
| 4c  | 2021-05-01T20:01:26| Assignment: Manual Completion with submit button    | Assignment   | Submission confirmation form viewed|
| 4d  | 2021-05-01T20:01:32| Assignment: Manual Completion with submit button    | Assignment   | Course module viewed             |
| 4e  | 2021-05-01T20:01:34| Assignment: Manual Completion with submit button    | System       | Course activity completion updated|
| 4f  | 2021-05-01T20:01:34| Assignment: Manual Completion with submit button    | System       | A submission has been submitted. |

Case 3 shows the logs of an assignment activity where the completion progress is set as “Students can manually mark the activity as completed”. This means that the module should be considered as completed only when they voluntarily tick it. Nevertheless, when they submit a file (3a, 3b), the log “course activity completion updated” is automatically recorded (3c) and the check mark of the assignment is visible on the homepage of the course although the students have not ticked it. The same happens in case 4. The only difference with the previous example is that the submit button is requested to be clicked, and two other events are recorded (4c, 4d). This is definitely a bug [MoodleDocs (2021)] that needs to be handled. Again, we have not found a way to distinguish self-regulation from automatic action. We suggest checking the module settings to understand more in-depth student behaviour.

Another significant example is depicted in Table 5. At time T1 the user (‘59’) reads a discussion (‘4’) in the Forum (‘3’). We know that the module (Component) is “Forum”, the action performed (Event name) is “Discussion viewed” and the description illustrates in detail who is performing which action and where. However, as previously stated, we do not know which course the Forum belongs to (cf. Section 4.1). Then at time T2, the user clicks on the name of one of the participants (‘46’) to the forum thread, and we discover that the forum belongs to the course “DM&ML” with ID ‘21’ as illustrated in the event context and in the description field. Moreover, the component becomes “System” as the profile is not a module but represents an element - component - of the entire site while being available in the course context: students can only access the profiles of all the teachers on the platform, and of students enrolled in the same courses they participate in [MoodleDocs (2021)]. The user (‘59’) is now on the profile page of the affected user (‘46’), which includes two items: “Forum posts” and “Forum discussions”. The former illustrates all the posts of the user in all the forums of the course, the latter presents the first post of all the discussions that the user started (if the “Forum discussions” page is empty, this means that the user may have replied to many threads without starting any). Now we can clearly understand what the user (‘59’) performs at time T3. The component displays “Forum” but the event context is “Course”, therefore not a specific Forum as in the event T1. This explains that the user is currently viewing the report (event name: “User report viewed”) of all the posts of the affected user (“46”). At time T4, the only difference with the previous event is in the description field where the viewing mode is ‘discussion’.

It is worth noting that the immediate transition from T3 to T4 shows no evident new requests to the server. We can easily understand that the user clicked on the Back button (or opened two different browser tabs) to return to the user profile page of the observed participant as in T2, and immediately after on the link “Forum discussions”, as the log in T4 highlights. Starting from these observations, in our opinion, when counting module accesses [Kovanović et al. (2016)], these views of the Forum should not be taken into account. Nevertheless, they could be interesting when analysing social interactions and user-user relationships on the platform.

We terminate this roundup with the examples of Table 6 where the event context “Other” marks a module that has been deleted after some actions were performed on.

Deleted activities are placed in the Recycle Bin [MoodleDocs (2021)], and they are automatically permanently removed from the database after seven days. Therefore, unless saving logs over all weeks, it is difficult to retrieve information. Nevertheless, in our opinion, if the deleted activity has been replaced by another activity of the same type and settings, it would be helpful to merge the corresponding logs. Otherwise, if the deleted activity has not been replaced by a new one, considering actions carried out before deletion would be useless.
Table 5: Forum and Profile views

| T | Event context                        | Component | Event name               | Description                                                                                                                                 |
|---|-------------------------------------|-----------|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Forum: Teacher’s announcements      | Forum     | Discussion viewed        | The user with id '59' has viewed the discussion with id '4' in the forum with course module id '3'.                                             |
| 2 | Course: DM&ML                       | System    | User profile viewed      | The user with id '59' viewed the profile for the user with id '46' in the course with id '21'.                                               |
| 3 | Course: DM&ML                       | Forum     | User report viewed       | The user with id '59' has viewed the user report for the user with id '46' in the course with id '21' with viewing mode 'posts'.               |
| 4 | Course: DM&ML                       | Forum     | User report viewed       | The user with id '59' has viewed the user report for the user with id '46' in the course with id '21' with viewing mode 'discussion'.          |

Table 6: Other

| ID | Event context | Component | Event name     | Description                        |
|----|---------------|-----------|----------------|------------------------------------|
| 1  | Other         | Wiki      | Wiki page viewed|                                   |
| 2  | Other         | Forum     | Subscription created|                                 |

4.4 System

Since the use of System in the fields of the generated log table deserves particular attention throughout the article, we have often referred to this section where now we would like to make its meaning understood. When used in the “Event context” System can represent cron activities, the site level (as login/logout), namely actions not affecting a specific course or module or the communicative interactions between users. When used in the Component, it can identify any action not performed by the user (e.g., automatic events like the activity completion), or an action performed at the site level which, however, affects the overall course or a specific user, but not a particular module. Nevertheless, the detailed comprehension of its adoption cannot help but consider all the three fields (Event context, Component, Event name) together. Table 7 (where we replaced the usernames for privacy concerns) depicts some examples of the value System’s use in the various attribute fields.

Case 1 shows a typical situation after a mobile login. Log data ‘origin’ is recorded as a web event (cf. Section 3.1), while the event name records a typical web service activity. We monitored user’s actions for a long time, and to the best of our knowledge, we can state that these two events (1a and 1b) do not involve any action performed by the user. As a matter of principle, since they do not represent any learning actions (or related learning actions), their ‘origin’ field probably should have been different and therefore filtered.

Table 7: System

| ID | Event context | Component | Event name                      | Description                                                                 |
|----|---------------|-----------|---------------------------------|----------------------------------------------------------------------------|
| 1a | System        | System    | Web service token created       | The user with id '58' has been sent the web service token with id '12'.       |
| 1b | System        | System    | Web service token sent          | The user with id '58' created a web service token for the user with id '58'. |
| 2a | USER 63       | System    | Prediction process started      | The user with id '63' has started 'notuseful' action for the prediction with id '32'. |
| 2b | USER 9        | System    | Prediction process started      | The user with id '9' has started 'viewoutlinereport' action for the prediction with id '93'. |
| 3a | USER 62       | System    | Notification viewed             | The user with id '62' read a notification from the user with id '83'.         |
| 3b | System        | System    | Notification sent               | The user with id '52' sent a notification to the user with id '62'.          |
| 4a | System        | System    | User has logged in              | The user with id '69' has logged in.                                        |
| 4b | System        | System    | User logged out                 | The user with id '75' has logged out.                                       |
| 5a | USER 32       | System    | User profile viewed             | The user with id '32' viewed the profile for the user with id '32'.          |
| 5b | Course: Web mining | System | User profile viewed             | The user with id '54' viewed the profile for the user with id '63' in the course with id '8'.          |
| 5c | Course: Database | System | Course user report viewed       | The user with id '59' viewed the user report for the course with id '4' for user with id '59'. |
| 5d | Course: Database | User report | Grade user report viewed      | The user with id '59' viewed the user report in the gradebook.               |
| 6a | System        | System    | Message sent                    | The user with id '3' sent a message to the user with id '83'.                |
| 6b | System        | System    | Message deleted                 | The user with id '3' deleted a message with id '131' for the user with id '72' |
| 6c | System        | System    | Group message sent              | The user with id '83' sent a message with id '262' to the conversation with id '92'. |
| 6d | USER 62       | System    | Message viewed                  | The user with id '62' read a message from the user with id '3'.              |
| 6e | USER 59       | System    | Message contact added           | The user with id '59' added the user with id '83' to their contact list.     |
Case 2 registers the beginning of some prediction process. Moodle prediction models combine a target (the event to predict) and indicators (what it is supposed to lead to an accurate target prediction). Once new data (actions performed by the users) that matches the criteria defined by the model is available, Moodle starts predicting the probability that the target event will occur. Since the prediction process is automatically activated as a part of the Analytics process of the Moodle platform [MoodleDocs (2021q)], in our opinion, these events are not part of student actions and should not be taken into consideration when analysing their learning behaviour.

Case 3a shows the same event context and component as record 2a/b, but some actions are performed. Indeed, whenever the user clicks on the “View full notification” link in the Notifications menu (bell icon at the top of each page), this log is registered. Case 3b is similar to case 1 because both the context and the component are System and they indicate that the action is not performed by the users who can only send messages (case 6), not notifications. In general, notifications alert users about events and are performed via the cron; therefore, also this type of event should not be considered in the analysis.

Case 4 displays user actions when logging in or out. Although the user is directly involved in the action, like in case 3a, these actions are logged at site level, most likely to specify that the user is logged into the site as a whole. However, even though in previously mentioned studies the number of logins was counted as a parameter of participation and performance level, in our opinion, this event should not be considered as relevant as it only informs of the new login after a long time of inactivity (without loading pages). Users are logged out after a specific time set in the Moodle site administration settings (8 hours by default [MoodleDocs (2021r)]). Nevertheless, within this time window, they can access the site many times, with no need to log in.

Case 5 represents some actions performed on the user’s profile page. In case 5a, the user accessed their profile: the component is the System because a user profile page is available for any authenticated user [MoodleDocs (2021s)]; the context shows the user name, and the description displays two identical IDS (‘32’). Case 5b is similar to case 5a, but the user viewed someone else’s profile despite the same event name. As stated before, students are not allowed to access profiles of students enrolled in other courses. Indeed, the context is no longer the user but the course; the description shows two different IDS (‘54’ and ‘63’) and the indication of the ‘event context’ course ID. It is only by considering the three fields together that similarities of cases 5a and 5b can be cleared up. The last two cases illustrate the action performed by the user when accessing grades from the profile page by clicking on the “Grades overview” link (5c) or from the ‘Grades’ link (5d) on the Moodle navigation drawer menu on the left. After clicking on the “Grades overview” link and selecting a specific course, the target page displays the grade report for the course, and the logs record the course in the event context and System in the component. This happens because grades are recorded at the site level, regardless of the course, but they are related to a specific course. The same events (and the same logs) are recorded by clicking on the user picture (top right menu) then ‘Grades’. Conversely, when a user accesses a specific course and clicks on the ‘Grades’ link on the navigation drawer menu, the log indicates that the component is not the system but the “User report” for that course, and the event name displays the word “Grade” (the user is already in the course) with respect to “Course” (the user has not accessed any course despite the event context). Nevertheless, the same grade report, namely the same target page as 5c, is shown. The only difference is the path taken to reach it.

Case 6 refers to messaging. In Moodle, users can only send messages to their contacts and anyone in their courses or to the members of the group they belong to (if any) [MoodleDocs (2021t)]. A message is sent (both individually and in group mode) or deleted by a user in the System context (i.e., the site level) and read in the User context. This happens because in the Moodle Messaging system, messages are dispatched employing a message queueing service. In other words, messages are not ‘sent’ by the user, but the system stores the messages on the queue until they are processed or deleted (6a, 6b, 6c). On the other hand, when the user reads a message (6d) or adds another user to their contact list (6e), the log records a voluntary action performed by the user as the event context clarifies.

Many other examples could be presented, and each of them would reflect a particular situation, but in our opinion, what would be helpful is to try to replicate the logs, through multiple attempts, to understand the actions performed and, therefore, the behaviours of the users.

5 Conclusion

In this work, we aimed to illustrate where educational log data can be difficult to interpret to take advantage of this information to perform better data pre-processing and cleaning. We illustrated and examined various types of log sequences and proposed different facets to consider when preparing data for investigation and analyses. Erroneous comprehension of data and knowledge of data generation dynamics could lead to biased datasets and consequently wrong interpretation of research findings.
Since these findings have significant implications for understanding how to treat data before any analysis, we would like another essential aspect to emerge, more addressed to web application developers. By going in the direction of the mobile applications, the smarter the client, the less the data will be available to those who want to analyse them. Moreover, using the Back button to navigate to a page already seen does not generate any log record because the previously requested page is being loaded from the browser cache, and no interaction with the server is happening. This weakness makes it hard to understand if the students linger on a page because they are looking for something or click on the navigation drawer menu on the left, and the anchor links are not registered, or they are doing something else outside the platform.

Another important implication of this paper is that perhaps the counts’ measures performed in learning analytics research should be reconsidered. We tried to highlight that the detailed comprehension of the actions performed cannot help but consider all log fields together. With all the challenges in detecting learner behaviours and without a clear comprehension of logs and activity settings, the use of counts measures could lead to misinterpretations of student behaviour. This is particularly true when analysing data of different courses.

By reflecting on the vastness of similar cases, researchers should be aware of the responsibility of misunderstanding when they trace data to perform analytical studies, and we hope that our work could conduct further investigation on the pitfalls that log generation hides in learning analytics research.

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References

Paulo Cristiano de Oliveira, Cristiano Jose Castro de Almeida Cunha, and Marina Keiko Nakayama. Learning management systems (LMS) and e-learning management: an integrative review and research agenda. JISTEM-Journal of Information Systems and Technology Management, 13(2):157–180, 2016.

Carlos Alario-Hoyos, María Jesús Rodríguez-Triana, Maren Scheffel, Inmaculada Arnedillo-Sánchez, and Sebastian Maximilian Dennerlein. Addressing global challenges and quality education. 2020.

S Ranjeeth, TP Latchoumi, and P Victor Paul. A survey on predictive models of learning analytics. Procedia Computer Science, 167:37–46, 2020.

Charles Lang, George Siemens, Alyssa Wise, and Dragan Gasevic. Handbook of learning analytics. SOLAR, Society for Learning Analytics and Research, 2017.

Justian Knobbout, Huub Everaert, and Esther van der Stappen. From dirty data to multiple versions of truth: How different choices in data cleaning lead to different learning analytics outcomes. 2019.

Cristóbal Romero, José Raúl Romero, and Sebastián Ventura. A survey on pre-processing educational data. In Educational data mining, pages 29–64. Springer, 2014.

Vitomir Kovanović, Dragan Gašević, Shane Dawson, Srečko Joksimovic, and Ryan Baker. Does Time-on-task Estimation Matter? Implications on Validity of Learning Analytics Findings. Journal of Learning Analytics, 2(3):81–110, 2016. doi:10.18608/la.2015.23.6

George Siemens and Phil Long. Penetrating the fog: Analytics in learning and education. EDUCAUSE review, 46(5):30, 2011.

Ben Daniel. Big Data and analytics in higher education: Opportunities and challenges. British journal of educational technology, 46(5):904–920, 2015.

Elazar J Pedhazur and Liora Pedhazur Schmelkin. Measurement, design, and analysis : an integrated approach. Hillsdale, N.J. : Lawrence Erlbaum Associates, 1 1991.

Yoav Bergner. Measurement and its uses in learning analytics. Handbook of learning analytics, 35(2), 2017.

Andrea Bernardini and Cristina Conati. Discovering and recognizing student interaction patterns in exploratory learning environments. In International Conference on Intelligent Tutoring Systems, pages 125–134. Springer, 2010.

Rianne Conijn, Chris Snijders, Ad Kleingeld, and Uwe Matzat. Predicting student performance from LMS data: A comparison of 17 blended courses using moodle LMS. IEEE Transactions on Learning Technologies, 10(1):17–29, 2017. doi:10.1109/TLT.2016.2616312

Robert Cooley, Bamshad Mobasher, and Jaideep Srivastava. Data Preparation for Mining World Wide Web Browsing Patterns. Knowledge and Information Systems, 1(1):5–32, 1999. doi:10.1007/bf03325089

William J Darlington. Predicting underperformance from students in upper level engineering courses. 2017.
Nawal Sael, Abdelaziz Marzak, and Hicham Behja. Web usage mining data preprocessing and multi level analysis on moodle. In 2013 ACS International Conference on Computer Systems and Applications (AICCSA), pages 1–7. IEEE, 2013.

Angela Bovo, Stéphane Sanchez, Olivier Héguy, and Yves Duthen. Clustering moodle data as a tool for profiling students. In 2013 Second International Conference on E-Learning and E-Technologies in Education (ICEEE), pages 121–126. IEEE, 2013.

Taeho Yu and Il-Hyun Jo. Educational technology approach toward learning analytics: Relationship between student online behavior and learning performance in higher education. In Proceedings of the fourth international conference on learning analytics and knowledge, pages 269–270, 2014.

Ed Fincham, Alexander Whitelock-Wainwright, Vitomir Kovancović, Srećko Joksimović, Jan-Paul van STAALDUIJEN, and Dragan Gašević. Counting clicks is not enough: Validating a theorized model of engagement in learning analytics. In Proceedings of the 9th international conference on learning analytics & knowledge, pages 501–510, 2019.

Rosemary H Wild, Kenneth A Griggs, and Tanya Downing. A framework for e-learning as a tool for knowledge management. Industrial Management & Data Systems, 2002.

MoodleDocs. Resources, 2021a. URL https://docs.moodle.org/39/en/Resources
MoodleDocs. Activities, 2021b. URL https://docs.moodle.org/39/en/Activities
MoodleDocs. Forum settings, 2021k. URL https://docs.moodle.org/39/en/Forum_settings
MoodleDocs. Activity completion, 2021l. URL https://docs.moodle.org/39/en/Activity_completion
MoodleDocs. File picker, 2021m. URL https://docs.moodle.org/39/en/File_picker
MoodleDocs. Submitting the assignment, 2021n. URL https://moodle.org/mod/forum/discuss.php?d=391272
MoodleDocs. Error: View profile, 2021o. URL https://docs.moodle.org/39/en/error/moodle/cannotviewprofile

Jozef Kapusta, Michal Munk, et al. Cut-off time calculation for user session identification by reference length. In 2012 6th International Conference on Application of Information and Communication Technologies (AIT), pages 1–6. IEEE, 2012.

Simon Knight and Alyssa Friend Wise. Time for Change : Why Learning Analytics Needs Temporal Analysis Faculty of Transdisciplinary Innovation University of Technology Sydney Bodong Chen University of Minnesota IMPORTANCE AND CHALLENGES FOR TEMPORALITY IN LEARNING. 4:7–17, 2017.

Bodong Chen, Simon Knight, and Alyssa Wise. Critical issues in designing and implementing temporal analytics. Journal of Learning Analytics, 2018.

Youngjin Lee. Effect of uninterrupted time-on-task on students’ success in massive open online courses (moocs). Computers in Human Behavior, 86:174–180, 2018.

Ilia Rushkin. Time-on-task estimation with log-normal mixture model. arXiv preprint arXiv:1805.01819, 2018.

Vitomir Kovancović, Dragan Gašević, Shane Dawson, Srećko Joksimović, Ryan S. Baker, and Marek Hatala. Penetrating the black box of time-on-task estimation. ACM International Conference Proceeding Series, 16-20-Marc:184–193, 2015. doi:10.1145/2723576.2723623.
Mohammad Khalil and Jacqueline Wong. The Essence of Time: Taking a Look at Learning Sessions in MOOCs. *Proceedings of 2018 Learning With MOOCS, LWMOOCS 2018*, (September):131–133, 2018. doi:10.1109/LWMOOCS.2018.8534681.

Yijun Ma, Lalitha Agnihotri, Ryan Baker, and Shirin Mojarad. Effect of student ability and question difficulty on duration. *Proceedings of the 9th International Conference on Educational Data Mining, EDM 2016*, pages 135–142, 2016.

Yan Li, Boqin Feng, and Qinjiao Mao. Research on path completion technique in web usage mining. *Proceedings - International Symposium on Computer Science and Computational Technology, ISCSCT 2008*, 1:554–559, 2008. doi:10.1109/ISCSCT.2008.151.

Karrie E Godwin, Ma Victoria Q Almeda, Ryan S Baker, and Anna V Fisher. The Variable Relationship Between On-task Behavior and Learning. *Proceedings of the 38th Annual Meeting of the Cognitive Science Society*, pages 812–817, 2016. URL http://www.upenn.edu/learninganalytics/ryanbaker/Godwin{('_')}Cogsci{('_')}2016{('_')}Final.pdf.

Rachel Ryan Shaun Rachel Baker, Brent Evans, Qiujie Li, Bianca Cung, Christian Fischer, Zachary A. Pardos, Rachel Ryan Shaun Rachel Baker, Joseph Jay Williams, Padhraic Smyth, Renzhe Yu, Stefan Slater, Rachel Ryan Shaun Rachel Baker, Mark Warschauer, Dragan Gasevic, Jelena Jovanovic, Abelardo Pardo, and Shane Dawson. Does Inducing Students to Schedule Lecture Watching in Online Classes Improve Their Academic Performance? An Experimental Analysis of a Time Management Intervention, volume 60. Springer Netherlands, 2019. doi:10.1007/s11162-018-9521-3. URL https://doi.org/10.1007/s11162-018-9521-3.

Tal Soffer, Tali Kahan, and Rafi Nachmias. Patterns of students’ utilization of flexibility in online academic courses and their relation to course achievement. *International Review of Research in Open and Distance Learning, 20*(3): 202–220, 2019. doi:10.19173/irrodl.v20i4.3949.

Mohammad Khalil and Jacqueline Wong. The Essence of Time: Taking a Look at Learning Sessions in MOOCs. *Proceedings of 2018 Learning With MOOCS, LWMOOCS 2018*, (September):131–133, 2018. doi:10.1109/LWMOOCS.2018.8534681.

Yijun Ma, Lalitha Agnihotri, Ryan Baker, and Shirin Mojarad. Effect of student ability and question difficulty on duration. *Proceedings of the 9th International Conference on Educational Data Mining, EDM 2016*, pages 135–142, 2016.

Yan Li, Boqin Feng, and Qinjiao Mao. Research on path completion technique in web usage mining. *Proceedings - International Symposium on Computer Science and Computational Technology, ISCSCT 2008*, 1:554–559, 2008. doi:10.1109/ISCSCT.2008.151.

Karrie E Godwin, Ma Victoria Q Almeda, Ryan S Baker, and Anna V Fisher. The Variable Relationship Between On-task Behavior and Learning. *Proceedings of the 38th Annual Meeting of the Cognitive Science Society*, pages 812–817, 2016. URL http://www.upenn.edu/learninganalytics/ryanbaker/Godwin{('_')}Cogsci{('_')}2016{('_')}Final.pdf.

Rachel Ryan Shaun Rachel Baker, Brent Evans, Qiujie Li, Bianca Cung, Christian Fischer, Zachary A. Pardos, Rachel Ryan Shaun Rachel Baker, Joseph Jay Williams, Padhraic Smyth, Renzhe Yu, Stefan Slater, Rachel Ryan Shaun Rachel Baker, Mark Warschauer, Dragan Gasevic, Jelena Jovanovic, Abelardo Pardo, and Shane Dawson. Does Inducing Students to Schedule Lecture Watching in Online Classes Improve Their Academic Performance? An Experimental Analysis of a Time Management Intervention, volume 60. Springer Netherlands, 2019. doi:10.1007/s11162-018-9521-3. URL https://doi.org/10.1007/s11162-018-9521-3.

Tal Soffer, Tali Kahan, and Rafi Nachmias. Patterns of students’ utilization of flexibility in online academic courses and their relation to course achievement. *International Review of Research in Open and Distance Learning, 20*(3): 202–220, 2019. doi:10.19173/irrodl.v20i4.3949.