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When Leaving is Persisting: Studying Patterns of Persistence in an Online Game-Based Learning Environment for Mathematics

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Abstract

We report on a large-scale, log-based study of the associations between persistence and success in an online game-based learning environment for elementary school mathematics. While working with applets, learners can rerun a task after completing it or can halt before completing and rerun it again; both of these mechanisms may improve the score. We analyzed about 3.1 million applet runs by N=44,323 1st–6th-grade students to have a nuanced understanding of persistence patterns, by identifying sequences of consecutive single applet runs (SoCSARs). Overall, we analyzed 2,249,647 SoCSARs and identified six patterns, based on halting and rerunning tasks, and their completion: 1) Single Complete, 2) Single Incomplete, 3) Some Incomplete and Single Complete, 4) Multiple Incomplete and No Complete, 5) Multiple Complete and No Incomplete, and 6) Multiple Complete and Some Incomplete. Expectedly, we found a positive correlation between SoCSAR length and success. Some patterns demonstrate low to medium positive associations with success, while others demonstrate low to medium negative associations. Furthermore, the associations between the type of persistence and success vary by grade level. We discuss these complex relationships and suggest metacognitive and motivational factors that may explain why some patterns are productive and others are not.

Notes for Practice

- When it is enabled by the game, students implement various mechanisms of re-engaging with educational games to increase their scores, and these behaviours — and their impact — differ by age.
- Generally, the halt-and-re-run mechanism is productive, while the complete-and-re-run mechanism is potentially counterproductive.

Keywords: Persistence, micro-persistence, game-based learning, log analysis, mathematics education

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1. Introduction

Persistence, which is the aspiration to successfully complete a process and achieve one's goals, has proven to be an important skill for learning and problem solving (Tran, 2019). However, achieving persistence is a significant challenge in online learning environments, due to various factors related to the learners, the settings, and the context in which learning occurs (Hart, 2012). Game-based, interactive learning environments, which have become very popular in recent years, are associated with increased student motivation (Abdul Jabbar & Felicia, 2015; Buckley & Doyle, 2016), which is closely associated with persistence (Vollmeyer & Rheinberg, 2000).

Examining persistence at the macro-level — that is, measuring the completion of a course or a program — may not reveal the whole picture of knowledge acquisition. Therefore, in the 1990s, it was suggested that persistence should be better measured for a single task (Cooley et al., 1994; Multon et al., 1991). This enables the study of micro-persistence, which is defined as persistence in each component of the learning process. Notably, measuring task-level behaviour may better explain learning at higher levels of the learning process (Baker et al., 2008b, 2013; Chung & Hsiao, 2020; Israel-Fishelson & Hershkovitz, 2020). However, micro-persistence has been mostly measured by the number of attempts to successfully

complete a task or by time-on-task, and a better understanding of processes involved with it is still lacking. This is the gap we aim to bridge.

In the study reported here — which is based on a secondary analysis of a previously used large dataset — we identified different patterns of task-level micro-persistence in an online learning environment for elementary school mathematics and explored their associations with success. We did so on a large-scale (N=44,323), taking a learning analytics approach while analyzing log files drawn from an online learning environment. Our research questions were the following: 1) What are the associations between the number of attempts to complete a task and success? and 2) What are the associations between the micro-persistence pattern and success?

2. Background

2.1. Persistence

Persistence is an essential skill for academic success. The literature offers various definitions of persistence, and identifies different variables that lead to student persistence, such as self-efficacy, intrinsic motivation, satisfaction, locus of control, and a sense of personal growth (Hart, 2012). Student persistence, however, is still a major challenge for both learners and educators, due to various course-, student-, and infrastructure-related factors. These factors are also associated with retention in online learning environments (Dalipi et al., 2018; Jung & Lee, 2018).

Research has shown that game-based learning environments may prove effective in increasing learner motivation and engagement, hence reducing student dropout and increasing student persistence (Sümer & Aydın, 2018; Sun et al., 2023; Zhang & Yu, 2022). However, in online game-based learning environments, persistence in progressing in the game may come at the expense of investing in each of the game's levels, and vice versa. Therefore, we take a deeper look at persistence, that is, define and measure micro-persistence. This point of view is still not well studied; a literature review of student engagement in science education, published a few years ago, found that "many instruments assessed school or classroom-level engagement, with little attention to finer-grained, task-level variables" (Aker, 2016, p. 187). Previous studies of micro-persistence have demonstrated the importance of this level of investigation for better understanding student success (Fang et al., 2017; Israel-Fishelson & Hershkovitz, 2020). A highly relevant study of micro-persistence in a game-based learning environment has recently found two different types of micro-persistence behaviours: 1) persistence-challenge, i.e., repetition despite losing, and 2) persistence-reward, i.e., repetition after winning; the study also showed gender- and age-based differences in the frequencies of these behaviours (Zapata-Caceres & Martin-Barroso, 2021). Taken together, these studies emphasize the need to dive deeper in the exploration of micro-persistence in game-based learning environments.

2.2. Applets in Mathematics Education

Educational applets are resources that are usually limited in scope and have very specific learning goals under a particular topic. Such applets would most often incorporate visual elements, require some interaction from the learner (clicking on or dragging and dropping of graphical components, or choosing an answer for a multiple-choice question), and provide immediate feedback.

Certainly, the currently used applets are not a new idea, but rather an updated use of ideas and implementations that have been around for decades. However, the use of the new, online applets has tremendously grown in the last twenty years or so, as part of the overall increase in incorporating technology into the mathematics classroom. Due to their limited scope, they may be incorporated in many forms within the curriculum, according to the teachers' own pedagogical agenda, and may contribute to student achievement, motivation, and attitudes towards mathematics (Hershkovitz et al., 2021; Higgins et al., 2019). Importantly, despite them being rather simple in terms of game-based learning, such applets may yield more engagement and learning than more sophisticated games (Malkiewich et al., 2016).

3. Methodology

3.1. Research Field

The data we used was drawn from a commercial online learning environment that includes game-based applets for K–6 school mathematics (as per request of the company, we do not mention its name). Each applet consists of a few tasks, each of which allows for multiple attempts and is aimed at a certain math subtopic. For example, under the topic of fractions, different applets would each focus on skills like identifying fractions, representing fractions, naming fractions, comparing fractions, and so on. These applets usually require some user interaction, mostly dragging and dropping of visual elements, and provide immediate feedback. The current analysis covers all the topics for elementary school curricula in Israel, with almost 1000 applets.

Example applets are presented in Figure 1. Upon completing an applet run, a student would get a score between 0 and 5. Students could play an individual applet as many times as they wish. Also — and most importantly for the current research — they could halt an applet run before completing it, in which case no score would be registered for that particular run.

The software can be accessed through a browser or via a mobile app; it supports various operating systems (Windows 7 or higher, OS version High Sierra 10.13 or higher, OS version 13.0 or higher, Android version 7.10 or higher) and browsers (the latest versions of Chrome, Firefox, or Safari that are WebGL 1.0 or 2.0 capable, HTML 5 standards compliant, 64-bit, and WASM capable). It offers an individual or institutional subscription.

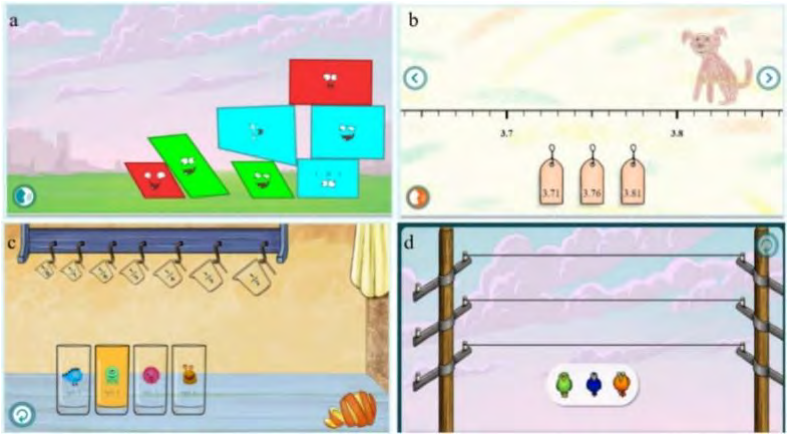

Figure 1. Applet examples where students are asked to: a) mark the polygons that are rectangles; b) locate labels on a line axis; c) pour juice equally into all glasses; d) drag birds to the wires to attain an overall given ratio of one type of bird to all the birds.

3.2. Research Population

Our data included records of all Israeli students who used the learning environment during the school year of 2017–2018 via their school-sponsored personal accounts. Overall, we had N=44,323 1st–6th-grade students, with the following distribution based on grade level: 1) n=7,663 (17%); 2) n=9,125 (21%); 3) n=9,363 (21%); 4) n=8,328 (19%); 5) n=5,856 (13%); and 6) n=3,988 (9%). We included only those students who had at least 10 applet runs logged in the dataset.

3.3. Research Tool

We used log files documenting every applet run in the platform. Recall that an applet usually consists of a few tasks, and that students could stop its use before completing it — the log files contain documentation of both completed and uncompleted applet-runs. Every row in the log files documents an applet run in three dimensions: 1) Who? (an anonymous student identifier and grade level); 2) When? (start time, end time, and total length); and 3) What? (identifier of the applet, whether it was completed, and total score). The original file included about 17 million records of 209,000 students from across Israel. This was a full sample of the Israeli students' activity in that learning environment in the 2017–2018 school year. Preprocessing included the removal of any data belonging to any of the following conditions: 1) students who used fewer than 10 applets; 2) students who were (mistakenly) logged in at multiple grade levels; and 3) activity during the national mathematics Olympics, as it did not represent authentic use of the learning environment, neither by content nor by persistence. Eventually we had N=44,323 students and ~3.1 million applet runs.

3.4. Research Variables

For having a deep understanding of learner behaviour related to persistence, we identified sequences of consecutive single applet runs (SoCSARs). An applet run can be halted by the learner while working on its tasks, and can be rerun immediately after halting or completing it; such halting and reruns are usually done to improve the student's score. We will refer to an applet run that is not immediately followed by any reruns as a SoCSAR of length 1. Table 1 demonstrates how SoCSARs are defined in a set of consecutive applet runs of a single learner. In total, we identified 2,249,647 SoCSARs.

3.4.1. Persistence at the sequence level

We measured two variables related to persistence in SoCSARs:

- ***Length (M=1.41, SD=0.60, N=44,323)***. For each SoCSAR, this was defined as the number of reruns within it (≥1).
- ***Persistence Pattern***. For characterizing a SoCSAR persistence pattern in a nuanced manner, and after initial exploration of the dataset, we defined six mutually exclusive categories, presented in Table 2. For each student, we calculated the percentage of their SoCSARs for each category, then averaged across all students.

3.4.2. Success at the sequence level

We measured two variables related to success in SoCSARs:

- ***Maximal Score [0–5, Null] (M=4.11, SD=0.67, N=44,216)***. We first documented maximal score [0–5] for each SoCSAR, then averaged for each student across their SoCSARs. Note that a SoCSAR with no completed applet runs would have a null value for that variable.
- ***Average Score [0–5, Null] (M=4.05, SD=0.69, N=44,216)***. Similar to Maximal Score, we computed the average score of completed applet runs — first at the SoCSAR level, then averaged at the student level.

Table 1. Characterizing SoCSARs for a Single Learner

Applet Runs				SoCSAR Characterization				
#	App. ID	Comp.	Score	#	Length	Max. Score	Avg. Score	Pattern
1	A1	No	.	1	3	5	4.5	Multiple Complete and Some Incomplete
2	A1	Yes	4					
3	A1	Yes	5					
4	A2	Yes	3	2	1	3	3	Single Complete
5	A3	Yes	3	3	2	4	3.5	Multiple Complete and No Incomplete
6	A3	Yes	4					
7	A1	No	.	4	2	.	.	Multiple Incomplete and No Complete
8	A1	No	.					

Table 2. Description and Distribution of the Different Persistence Pattern Values

Category	Characteristics	Description	Example*
Single Incomplete (n=678,425, 30%)	*Length*=1, incomplete	No immediate re-attempt to fully solve the applet.	I
Single Complete (n=1,131,234, 50%)	*Length*=1 complete	No immediate re-attempt to improve the score.	C
Multiple Incomplete and No Complete (n=116,992, 5%)	*Length*≥2 all incomplete	Leaving an applet run before completing it and immediately rerunning it is often done to improve the score; this sequence represents such attempts, however, without eventually succeeding.	IIII
Some Incomplete and Single Complete (n=203,499, 9%)	Length≥2 all applet runs incomplete (≥1) except for one completed (anywhere in the sequence)	After a single success, the student attempts to get a high score upon completing an applet run for the first time (compared with Multiple Incompletes and No Complete, which characterize failed attempts).	IIIIC
Multiple Complete and No Incomplete (n=86,579, 4%)	Length≥2 all applet runs completed	Immediate attempts to improve the score obtained for a completed applet run.	CCC
Multiple Complete and Some Incomplete (n=32,912, 2%)	Length≥3 at least 2 completed applet runs and at least 1 incomplete	Attempts to improve the score upon seeing it, with some difficulties (compared with Multiple Complete, No Incomplete, where such attempts faced no difficulties).	CCIC
Total N=2,249,647			

* I — Incomplete, C — Complete

4. Findings

Patterns of learning — vis-à-vis either cognitive, metacognitive, social, or affective processes — and patterns of actual use of a learning environment may change dramatically due to various age- and grade-related variables. Therefore, we checked for differences in our dependent variables based on grade level.

SoCSAR *Length* was positively associated with grade level; that is, the higher the grade level, the higher the SoCSAR lengths. Using the one-way ANOVA test, we found that the difference was significant, with $F(5;44,317)=339.0$, at $p<0.001$, and with all pairs compared in a post-hoc Scheffe test, which proved a significant difference at $p<0.01$. However, the overall effect size was small, $\mu^2=0.15$. Examining *Persistence Pattern* categories, we found overall that the rate of Single Incomplete SoCSARs significantly increased and the rate of Single Complete SoCSARs significantly decreased as grade level increased.

The two success variables demonstrated similar findings. *Maximal Score* decreased with grade level, with $F(5;44,210)=990.7$, and *Average Score* decreased too, with $F(5;44,210)=1119.8$, both at $p<001$. In both cases, all pairs of grade levels showed significant difference in a post-hoc Scheffe test, at $p<0.001$, except for grades 4 and 5 where the difference was not significant. These differences depict small effect sizes of $\mu^2=0.26$ and $\mu^2=0.28$, accordingly. Therefore, we decided to run all of our analyses for each grade level separately.

4.1. Length and Success

Testing for associations between SoCSAR *Length* and the two success variables, we get low positive correlations overall, in the range of $r=0.05–0.25$, at $p<0.01$. That is, the higher the length, the higher students' SoCSAR-based maximal and average scores. Considering that rerunning a single applet after either completing it or halting it is a way to improve the score, these associations are expected. Notably, these associations are the strongest in 2nd and 3rd grades, with $r=0.25$ and $r=0.21$ for *Maximal Score*, respectively, and $r=0.21$ and $r=0.16$ for *Average Score*, respectively. Findings are summarized in Table 3. Note that correlations of *Length* with *Maximal Score* are stronger than with *Average Score*, meaning that the overall contribution of long SoCSARs is local rather than global.

Table 3. Description and Distribution of the Different Persistence Pattern Values

Grade	Correlation with *Max. Score*	Correlation with *Avg. Score*	N
1	0.14**	0.09**	7,643
2	0.25**	0.21**	9,100
3	0.21**	0.16**	9,352
4	0.16**	0.12**	8.314
5	0.11**	0.05**	5,845
6	0.16**	0.12**	3,962

** $p<0.01$

4.2. Persistence Patterns and Success

When testing for associations between Persistence Pattern and success variables, we get a deeper understanding of the impact of various categories of these patterns and of the differences between grade levels. Overall, there were small to medium correlations; however, they varied in direction and strength between categories and between grade levels (see a summary of the findings in Table 4).

4.2.1. Low–medium positive associations: Some Incomplete and Single Complete

This pattern refers to sequences in which there were a few incomplete runs of one applet, with a single completion of it. As we explained above, this is a common behaviour for students who submit a wrong response in an applet task and would like to improve their overall score for that applet — doing so by halting and rerunning it again. As our findings suggest, the higher the rate of implementing this pattern, the higher the scores — with correlations ranging between 0.25 and 0.33 — which means that this mechanism is productive in improving scores. This association is the strongest among 2nd and 3rd graders.

4.2.2. Low positive associations: Multiple Incomplete and No Complete

This pattern had low positive associations with the success variables, with correlation coefficients ranging between 0.07 and 0.24, and the strongest correlations observed for grades 3 and 4. This pattern refers to multiple reruns and halts of an applet with no completion of it. Intriguingly, our findings suggest that the higher the rate of this pattern, the higher the scores, especially in mid-elementary school grades.

4.2.3. Low–medium negative associations: Single Incomplete

This pattern — which refers to cases in which there was only one applet run, and this run was halted — was negatively associated with the success variables. As our findings suggest, expectedly, the higher the use of this pattern, the lower the achievement, with correlations ranging between –0.17 and –0.34, the highest of which was observed in grades 5 and 6.

4.2.4. Low negative associations: Multiple Complete and No Incomplete Multiple

This pattern — which refers to multiple completed reruns of an applet, a pattern mostly associated with attempts to improve the score — is overall, surprisingly, negatively associated with the success variables, with correlation coefficients ranging between –0.04 and –0.21. That is, the higher the rate of completed re-attempts, the lower the student scores. This is mostly evident for upper elementary school students (grades 4–6).

4.2.5. Mixed weak associations: Single Complete, Multiple Complete and Some Incomplete

The Single Complete pattern refers to cases in which there was a single applet run that was completed. For 2nd, 3rd, and 4th grades, it has negligent correlation coefficients, which range between –0.07 and 0.05, not all of which are significant. However, for 1st, 5th, and 6th grades, we observed higher, positive — and quite expected — correlations of 0.1–0.2. That is, for either very young or relatively old elementary school students, the higher the rate of single complete runs, the higher their scores, however, to a low degree. Similarly, Multiple Complete and Some Incomplete — which characterizes a mix of re-attempts to improve the score and halting to get a higher score — is weakly, if at all, associated with the success variables.

Table 4. Persistence and Success Correlations

Category	Grade[a]	Correlation with… Max. Score	Avg. Score	Category	Grade[a]	Correlation with… Max. Score	Avg. Score
Single Incomplete	1	–0.26**	–0.26**	Some Incomplete and Single Complete	1	0.25**	0.25**
	2	–0.27**	–0.27**		2	0.33**	0.33**
	3	–0.17**	–0.17**		3	0.30**	0.30**
	4	–0.22**	–0.21**		4	0.25**	0.26**
	5	–0.33**	–0.33**		5	0.28**	0.29**
	6	–0.34**	–0.33**		6	0.25**	0.26**
Single Complete	1	0.11**	0.15**	Multiple Complete and No Incomplete	1	–0.04**	–0.12**
	2	0.01	0.05**		2	0.02	–0.10**
	3	–0.07**	–0.03**		3	–0.04**	–0.13**
	4	–0.02	0.05**		4	–0.08**	–0.17**
	5	0.16**	0.20**		5	–0.13**	–0.21**
	6	0.16**	0.19**		6	–0.11**	–0.20**
Multiple Incomplete and No Complete	1	0.08**	0.07**	Multiple Complete and Some Incomplete	1	0.03**	–0.02
	2	0.17**	0.17**		2	0.07**	0.01
	3	0.24**	0.24**		3	0.06**	–0.01
	4	0.20**	0.20**		4	0.02	–0.05**
	5	0.16**	0.15**		5	–0.07**	–0.15**
	6	0.13**	0.14**		6	0.03**	–0.05**

NOTE: Grey background denotes a medium correlation.
[a] n_1=7,643; n_2=9,100; n_3=9,352; n_4=8,314; n_5=5,845; n_6=3,962
** $p<0.01$

It is interesting to compare both sets of correlations, that is, of the rate of each category of *Persistence Pattern* with *Maximal Score* and with *Average Score*. In most cases, these sets are quite similar. In two cases, they behave differently. However only one of these is interesting, due to the correlation coefficient values. For Multiple Complete and No Incomplete, correlations with *Average Score* are generally stronger (more negative) than with *Maximal Score*, which may be indicative of the way this pattern is unsuccessful in improving scores overall.

5. Discussion

In this large-scale, log-based study, we defined and studied two measures of persistence in an online learning environment for elementary school mathematics, while focusing on SoCSARs; that is, sequences of consecutive runs of a single applet. The prominence of such sequences that are greater in length than 1 — with a total of about 20% of all the sequences — and the

types of behaviours they depict, are an indication of the ways young students navigate their learning in online environments used as part of their formal curriculum. Young learners are driven by various motivations for learning, either internal or external, and our analysis sheds light on such behaviours, on the motivations that drive them, and on their impact on learning.

We will first note that the distribution of student behavioural patterns was different across grade levels. Specifically, SoCSAR length increased with grade level, and the rate of Single Incomplete sequences increased while the rate of Single Complete ones decreased. It was previously shown that while elementary school students use an online learning environment, the time dedicated for learning decreases and the pace of learning increases with age (Ben-Zadok et al., 2010); our findings add to that notion a more sophisticated understanding of the mechanisms of this phenomenon. As the very existence of SoCSARs with length greater than 1 may indicate students' strategic behaviour in aiming to maximize their scores, we suggest that different metacognitive mechanisms are being implemented at different grade levels, in a way that emphasizes changes in cognitive engagement (Richardson & Newby, 2006). We showed that sequence length was positively associated with achievements, mostly in mid-elementary school grade levels. However the effects of implementing various mechanisms in online learning may also extend to satisfaction from learning and to the ability to transfer (del Valle & Duffy, 2009). Therefore, it is important to support students in areas that go beyond mere learning of content. The latter point becomes more concrete when we look at the different persistence pattern types — which may suggest what has driven student behaviour — and their association with success.

Two patterns proved to be productive in improving scores: Some Incomplete and Single Complete, and Multiple Incomplete and No Complete. Both patterns depict cases in which students halt applet runs to obtain a high — hopefully the highest — score in a consecutive rerun; that is, once they submitted a wrong solution to a task within the applet. While Some Incomplete and Single Complete may suggest a successful implementation of this strategy, Multiple Incomplete and No Complete suggests an unsuccessful implementation. That both cases were found to be positively correlated with overall success makes us realize the importance of the halt-and-re-run behaviours, which may be looked at as a particular case of gaming the system; that is, attempting to succeed in an educational environment by exploiting properties of the system rather than by using knowledge to answer correctly (Baker, 2004b). Students may decide to game the system for various reasons, mostly associated with negative affective states, either disliking the subject matter, technology, or learning environment, or feeling frustrated or unmotivated to learn (Baker et al., 2008a). However — and most relevant to our study — gaming the system is not always harmful, specifically not in the short run (Baker, 2004a, 2008b; Cocea et al., 2009). In our case, the positive contribution of the halt-and-re-run mechanism may be a result of learning from errors, which is a desirable learning behaviour (Metcalfe, 2017), and was found to be effective in game-based learning (Langlands & Moralles-Trujillo, 2023).

Contrary to that, we found that two patterns were negatively associated with success: Single Incomplete, and Multiple Complete and No Incomplete. In a sense, these two patterns may seem very different from each other, as the former refers to cases in which a student is giving up on completing an applet run on their first attempt — that is, seemingly pointing to lack of motivation — and the latter refers to cases in which there are attempts to improve the score — that is, seemingly pointing to the existence of motivation. That both these patterns were negatively associated with success echoes Vu et al.'s recently suggested research agenda on motivation–achievement cycles, in which they emphasize that these complex relationships may be mediated by self-regulation and actual behaviour (Vu et al., 2022).

Moreover, we emphasized the role of age in the associations between persistence and success. The use of Some Incomplete and Single Complete behaviours was mostly productive in the lower grades of elementary school; Multiple Incomplete and No Complete were mostly productive in the middle grades; and Single Incomplete was mostly counterproductive in the upper grades. This is in line with previous studies that showed differences between age groups in the associations between motivation and achievement (Bećirović & Remzija Hurić-Bećirović, 2017; Schwabe et al., 2015).

Taken together, we found that regarding achievements, the halt-and-re-run persistence mechanism (portrayed by Some Incomplete and Single Complete, Multiple Incomplete and No Complete) is productive overall, while the complete-and-re-run persistence mechanism (portrayed by Multiple Complete and No Incomplete) is potentially counterproductive. This is an important addition to the existing literature, which recently suggested that micro-persistence showed a somewhat positive contribution to learning (Fang et al., 2017; Israel-Fishelson & Hershkovitz, 2021; Auvinen et al., 2015; Delen & Liew, 2016; Kovanović et al., 2016; Motz et al., 2019; Nguyen, 2020).

Our main limitation in this study is in studying a single learning platform with students from a single country, which may have biased our findings educationally, technologically, or culturally. However, our atypically large data set is comprehensive enough to be characterized by a high variety in many personal measures; hence we believe that we can add an important, unique contribution to the literature, and that our study has valuable implications. In any case, it is advised to replicate this study in other learning environments, and in other geographical and cultural settings.

6. Conclusions and Future Work

To summarize, by analyzing micro-persistence in a digital game-based learning environment for mathematics, we found that when students can halt and rerun a task, they often utilize this option; by doing so, they often improve their score. By

distinguishing between different patterns of such persistence-related behaviours, we showed that some of them may be productive for learning while others are harmful.

Halt-and-re-run can be productive when students learn from errors, hence our recommendation to educators is to encourage a culture where it is okay to make mistakes, as such mistakes would reveal misconceptions, knowledge gaps, and unfruitful practices from which students could learn and grow (Basu et al., 2020). On the other hand, halt-and-re-run can be harmful when student motivation or self-regulation do not support completing the task. As metacognition and motivation are key to successful learning, it is advised that educators and learners would pay close attention to these aspects. It has been shown that student awareness of their behaviour in online learning may help in changing such behaviour (Auvinen et al., 2015; Delen & Liew, 2016). However more research is needed to test for the impact of interventions inspired by our suggested actions.

Educational software developers can consider persistence-related behaviours part of an ongoing evaluation within digital learning environments. Automatically identifying persistence-related behaviours — and responding to them — may be helpful in navigating students towards productive persistence. This is a fascinating avenue for further research.

Our study also has important methodological implications, adding to the cumulative evidence on the need in refining the ways by which engagement in online learning is measured (Kovanović et al., 2016; Motz et al., 2019; Nguyen, 2020). Overall, it makes us reconsider the very term "persistence" and highlight that "leaving" is not necessarily an antonym of it.

Declaration of Conflicting Interest

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