Pegem Journal of Education and Instruction, Vol. 13, No. 1, 2022 (pp. 168-176)

RESEARCH ARTICLE WWW.PEGEGOG.NET

Digital Game-based Learning and Learning Analytics in Mathematics

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Abstract

The boom of the 4.0 industrial revolution and the Covid-19 pandemic have changed the teaching and learning process, where digital learning environments have become increasingly necessary and convenient. The application of game-based learning (GBL) provides many benefits, such as helping to improve the quality of the mathematics teaching and learning process. This paper describes digital GBL with the application of Learning Analytics (LA) in a primary school and how the LA approach can enhance learning with GBL. GBL allows students to have more practice in their learning, while LA allows the data on teaching and learning materials to be recorded. The recorded data allows the teachers to systematically analyze them to keep track of students' learning performance. The use of LA is also useful to researchers and game designers. This paper has also proven the importance of the cognitive load theory and its application in GBL. It allows the use of GBL-based application to present learning information to cater to students' cognitive needs. This study involved sixty-four students from a rural primary school who participated in a 10-week GBL-based intervention. The results show that digital GBL helped increase the students' achievement in mathematics. Moreover, the LA process could be used as a mathematics achievement prediction model. In this regard, data on login frequency, duration of use, and the score to predict could be used to predict the intervention's impact on mathematics achievements. The study concludes by discussing the findings and their implications towards GBL and LA-based research and practice in mathematics teaching and learning.

Keywords: Teaching/learning strategies, games, improving classroom teaching, data science application in education, 21st-century abilities

Introduction

The Covid-19 pandemic has changed the norms of human life around the world. This pandemic has resulted in many schools were forced to close, and the face-to-face teaching and learning process cannot be done as usual. In many parts of the world, schools have been closed for months to prevent the spread of the Covid-19 virus. As reported by a UNESCO, UNICEF and World Bank report in October 2020, it is projected that 1.5 billion students worldwide are affected by the Covid-19 pandemic as missing school for a prolonged period will significantly impact students' achievements (Kuhfeld et al., 2020).

During the lockdown, many efforts have been made worldwide to prevent students from missing out from learning, especially in learning mathematics. This is because students often consider mathematics as a challenging subject. It is perceived as uninteresting, difficult and unpleasant (Dele-Ajayi et al., 2019; Lai & Hwang, 2016; Tshewang, Chandra & Yeh, 2017). As missing out on mathematics lessons for a long period of time will increase students' risk of dropping out, teachers strive to continue teaching and learning during this pandemic era. Most teachers have shifted to the online platform and provide printed materials for the students to do at home for remote learning. The application of flexible digital technologies and tools in the learning process leads to students' digital literacy and their development in line with the needs of modern society (Papadakis & Kalogiannakis, 2020). However, questions arise about the effectiveness of the online or remote teaching approach used by teachers as teachers find it difficult to monitor the students' learning performance and cannot guide the students effectively.

In teaching 21st-century learners, teachers need to provide them with various learning techniques and methods in line with their cognitive development (Ingram et al., 2016). Therefore, teachers need to use various methods to facilitate the teaching and learning of mathematics in this new norm. The rapid and widespread development of technology has produced numerous technological tools and services that can be used in education (Papadakis & Kalogiannakis, 2020). One of the new developments in instructional learning is digital game-based learning (GBL). Studies have found that GBL can be used to increase the students' motivation. For instance, GBL has helped

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How to cite this article: Ramli ISM, Maat SM, Khalid (2022). Digital Game-based Learning and Learning Analytics in Mathematics. Pegem Journal of Education and Instruction, Vol. 13, No. 1, 2022, 168-176

Source of support: Nil.

Conflict of interest: None.

DOI: 10.47750/pegegog.13.01.19

Received : 11.04.2022

Accepted : 14.07.2022 **Published:** 01.11.2022

increase the students' intrinsic motivation when learning mathematics (Beserra et al., 2019; Kiili et al., 2018; Wang et al., 2018) as the technology-based GBL approach makes the learning process more interactive and engaging (Bakker et al., 2016; Wouters et al., 2017). Thus, the use of GBL is in line with the current learning needs of 21-st century learners, who are mostly exposed to sophisticated technological devices in their daily life.

The boom of the 4.0 industrial revolution has changed the digital application of GBL in the teaching and learning process. Digital-based GBL with the application of Learning Analytics (LA) allows the data on teaching and learning materials usage to be recorded. Then, the recorded data could be analyzed systematically to help the teachers to keep track of students, performance during the learning process. Effective data analysis can project students' learning achievement (Wakelam et al., 2020). Various literature reviews have highlighted that GBL application with LA approaches has greater benefits than conventional teaching approaches (Ramli, Maat, & Khalid, 2019; Papamitsiou & Economides, 2014). Therefore, teachers need to be more creative when producing digital GBL materials with the application of LA for teaching and learning.

In addition, the production and use of digital GBL with the proper application of theory are important. The application of cognitive load theory by Sweller et al. (1998) enables the construction and use of digital materials considering students' cognitive load factors. In this regard, a good and effective learning process occurs when the learning materials used are on par with the students' cognitive design (van Merriënboer & Sweller, 2005). As the production of learning materials that are too complicated will increase the students' cognitive burden, the digital use of GBL could help present learning information in a simple way and according to the students' cognitive needs. This enables them to apply their cognitive resources more effectively (Plass et al., 2010).

The cognitive load strategies used in this study mainly focused on reducing the extraneous cognitive load to increase the quality of online learning courses (Caskurlu et al., 2020). This research aims to understand how digital GBL with LA and the application of cognitive load theory could affect students' learning and achievement in mathematics. Most studies in recent years have paid attention to LA at the higher institution level, specifically the learning process in universities rather than in schools. The review also indicated that most LA-based learning settings for mathematics are in the form of cognitive tutors, MOOC and LMS learning settings (Ramli, Maat, & Khalid, 2019).

Literature Review

Game-Based Learning (GBL) in Mathematics

The "edutainment era" describes the current learning trend, which exposes students to game-based learning approaches such as Math Blaster, Sim City EDU, and Minecraft (Farber, 2015). In learning mathematics, the application of GBL provides many benefits that help improve the quality of the teaching and learning process. Compared with the usage of traditional devices, the application of new interactive units provides the opportunity for more efficient learning (Kalogiannakis et al., 2021). Meanwhile, in terms of its application, setting clear learning objectives in line with the curriculum requirements and student-centred implementation makes GBL more effective (Farber, 2015; Tan, 2018).

Students will learn mathematics effectively when they successfully form the concept of mathematics independently in a constructivist manner. For this reason, the application of GBL in the teaching and learning of mathematics helps the students to build self-knowledge (Giannakas et al., 2018). This is where the students collaborate during their learning to achieve set learning objectives. GBL also provides an interactive technology-based learning process that will allow students to enjoy playing while learning. Subsequently, GBL forms a positive motivation and sense of self-efficacy towards mathematics. It also helps develop critical and creative thinking among students (Tokac et al., 2019). GBL application encourages the students to engage in problem-solving and self-learning to improve the students' competencies and self-efficacy (Eseryel et al., 2014; Wu et al., 2014). Ultimately, this application will help improve students' achievements in mathematics.

GBL encourages students to subconsciously learn a mathematical concept and develop good basic mathematical skills (Tokac et al., 2019) and (Okur & Aygenc, 2018). In this regard, students could acquire the basic mathematics concepts and skills as they play the game and complete the assignments in addition to other core skills like reading skills and problem-solving skills. Such interactions will facilitate learning and the acquisition of skills (Byun & Joung, 2018). This shows that GBL could help improve student's achievements in mathematics.

Learning Analytics (LA)

The LA approach is applied in education as a process of collecting, measuring, analyzing, and reporting students' learning in their own context. It is aimed to understand and optimize the teaching and learning process (Vladimir et al., 2019; Oyerinde, 2017; Niemelä et al., 2020). The application of LA in the teaching and learning process enables teachers to leverage the wealth of information to provide accurate feedback to their students. LA also provides valuable information to help teachers improve their teaching quality and allowing them to have a better understanding of the learning environment (Oyerinde, 2017; Siemens & Baker, 2012). LA could potentially provide informative feedback through data analysis. The application of LA in analyzing student learning data helps teachers to visualize the information and reflect the implementation of the teaching and learning process. LA allows teachers to analyze and frame data as a predictive model that could be adapted as educational data. This leads to an in-depth understanding of how learning takes place and allows teachers to identify students who may be facing problems and likely to drop out. These information help teachers formulate effective immediate actions (Ebner & Pronegg, 2015) and learning interventions to assist students and prevent dropouts (Faridhan et al., 2013).

LA could improve students' teaching and learning of mathematics (Lu et al., 2018) by helping teachers predict students' future achievements (Hue et al., 2015). The predicted results will help teachers to plan and take proactive initial steps to help the students master the skills being learned. Teachers could use these data to encourage at-risk or low performing students by reflecting on the learning strategies practised (Huang & Fang, 2013). Teachers will be able to review the teaching methods implemented. Furthermore, it also students room to evaluate the learning that has been applied and whether it is effective or not. As a result, the teaching and learning process will always be improved from time to time, ensuring that the learning objectives could be achieved.

The literature review showed that the application of LA in anticipating students' achievements requires a set of data. Thus, teachers need to identify the type of data required for each variable needs to warrant the accuracy of the prediction. This is because the data set for each variable could increase the correlation value and ultimately ensure a high expectation accuracy. However, just using data from different variables does not guarantee the accuracy of the precision (Huang & Fang, 2013). Therefore, this study used several variable data verified in the literature review to predict students' achievements, namely use duration, login status and game score.

The data collected on GBL and LA digital applications are on the usage duration (Hue et al., 2015; Román-González et al., 2018), login frequency (Chu et al., 2017; Cohen, 2017; Dani & Nasser, 2016; Kim et al., 2018; Kim et al., 2016) and game score (Kim et al., 2016; Romero-Zaldivar et al., 2012; Tomkin et al., 2018). In this study, the researcher recorded the amount of time the students' use the GBL digital applications. Furthermore, the study collected the frequency of students logging in to the application, while the data on the game scores were obtained based on the scores the students obtained when they use the GBL digital application.

Description of the GBL

In this paper, a GBL application was used as an educational software that provides games and drills to allow students to learn and practice mathematics skills through self-learning. These games allow students to learn independently and have fun at the same time while the teacher acts as a mentor. The GBL application provides an immediate feedback function that could be used to monitor students' learning. Immediate feedback can also motivate students and encourage them to strive to the next level. The GBL application is also equipped with learning analytics potential where data on students' use of the application could be recorded and analyzed systematically to predict students' achievement. For this study, the types of data recorded are login frequency, usage time, and game score.

In this study, the GBL application covers the topics of multiplication and division. The researcher has chosen these basic mathematical operational skills as they are the fundamental skills in developing mathematically-minded students and the effective application of mathematics concepts in their daily life. There are eight levels of play and learning in this application, four levels for multiplication and four levels for division. For the players, the ultimate goal is to reach the castle, and they can only proceed to the next level after passing each level successfully.

Research Questions

The purpose of this research was to identify how the digital GBL application could affect the students' mathematical achievements. The data recorded by the digital GBL application was used in the LA process and is able to predict the students' performance. The aims of this study were to answer the following questions:

- Is there a difference in mathematics achievement between the groups of students using a digital GBL application with groups of students using conventional methods?
- Is there a contribution made by time period data, log in frequency data and score data towards the mathematics achievements based on the group of students who use the digital GBL application in anticipation of mathematics achievements?

The hypotheses related to the research questions are as follows:

- H1: There is significant difference in the mean score of mathematics achievements based on the group of students using the digital GBL application and the group of students using conventional methods.
- H2: There was significant contribution from the time period data, log in frequency data and score data related to the mathematics achievements based on the group of students using the digital GBL application.

Method

A quasi-experimental study was conducted to determine the impact of the use of GBL digital applications through the application of LA in relation to improving student achievements. The application of LA allowed the GBL digital application usage data to be recorded and analyzed to help the teachers anticipate the student achievements. Studies employing experimental designs with control groups provided empirical evidence for the positive impact in mathematics achievement when using technology compared to standard classroom practice (Papadakis et al., 2021).

The sample consisted of 64 students from 2 primary schools from a rural area in Miri, Sarawak. The students in the experimental group attended classes and learnt mathematics using digital game-based learning apps. The participants in the control group attended classes as normal class with the use of resources such as mathematics textbooks through the conventional approach. Both groups lasted for 2 hours each week for 10 weeks.

The instrument used in this study was the mathematics achievement test. The mathematics achievement test consisted of 16 items include two basic operations in mathematics, namely multiplication and division. The test given is intended to measure the level of learning mastery gained after a learning experience is revealed (Creswell & Creswell, 2018).

In addition, to make sure that the digital GBL application supports the industry revolution 4.0 phenomenon especially in big data, this application is equipped with an LA application. The data from the use of the digital GBL application includes the students' log in frequency data, the user usage time and the user score. The data will be analyzed to predict the students' mathematics performance.

Results

The results are presented as being relevant to the students' mathematics achievements. The results also indicate the LA process used to predict the students' mathematical performance.

Mathematics Achievements

The descriptive statistics for the pre-test and post-test for the mathematics achievement test were implemented based on the group of students using the digital GBL application and the group of students using conventional methods as shown in Table 1. For the group of students using the digital GBL application, the pre-test mean was 25.606 and this increased to 87.513 in the post-test. The mean pre-test for the group of students using the conventional method was 25.225 and this increased to 52.356 in the post-test.

Next, an independent t-test was performed to determine the difference in the mean score of the mathematics achievement based on the group of students using the digital GBL application and the group of students using the conventional method. There was a significant difference in the mathematics achievement of the group using the digital GBL application (mean = 87.5125, s.d. = 13.097) and the group using the conventional method (mean = 52.3562, s.d. = 21.524); ($t = -7.893$, $p = 0.000$). The strength of the difference in the magnitude of the mean mathematics achievement score based on the group of students using the digital GBL application and the group of students using conventional methods was large at 50.1%.

Students' Mathematics Performance Prediction

Multiple linear regression analysis was performed to see if there was a contribution concerning time period data, log in frequency data and score data concerning mathematics achievement based on the group of students using the digital GBL application in prediction of their mathematics achievements.

The findings of the multiple linear regression analysis are as shown in Table 2. Based on Table 2, the R-square value is 0.842 which means that 84.2% of variation of the dependent variable of mathematical achievement can be explained by the independent variables of log in frequency data, usage time and score. The findings of this analysis show that the expected mathematics achievement of the students through the visitor status data, time of use and score has a strong expectation or prediction strength as it contributes around 84.2% of the variation in mathematics achievement.

Next, the ANOVA Table in Table 3 shows that the regression equation is significant. This indicates that at least one parameter of the model is significant.

Therefore, based on Table 4, the model for the expected achievement of mathematics is built through the following regression equation:

$$\hat{Y}=a+b1X1+b2X2+b3X3$$

Where
$\hat{Y}$=the predicted score of student
a=the random error is usually neglected
b1.be,b3=regressopm coefficient value
X1,X2,X3=predoctor scre value

Table 1: Descriptive statistical analysis results for the pre-test and post-test

	Pre-Test		*Post Test*	
Variables	*Control*	*Experiment*	*Control*	*Experiment*
Achievement Test				
Mean	25.225	25.606	52.356	87.513
Standard deviation	17.502	18.681	21.524	13.097

Table 2: Findings of the multiple linear regression analysis

R	*R Square*	*Adjusted R Square*	*Std. Error*
0.917a	0.842	0.825	5.48286

Table 3: Findings of the ANOVA analysis

	Sum of Squares	*df*	*Mean Square*	*F*	*Sig.*
Regression	4475.786	3	1491.929	49.629	0.000

Table 4: Coefficient Value

	B	*Std. Error*	*Beta*	*t*	*Sig*
(*Constant*)	70.207	14.743		4.762	0.000
Log in frequency	-0.846	0.101	-0.869	-8.366	0.000
Usage Time	0.046	0.016	0.276	2.819	0.009
Score	0.028	0.006	0.350	4.313	0.000

Table 5: Five student variables

X1	*X2*	*X3*
46	735	1195
49	894	1011
74	1065	1107
78	1046	1217
93	988	902

Table 6: Regression results for the inputted values and the actual mathematics achievement results

Total Visitor Status Data	*Total Usage Time Data*	*Total Score Data*	*Prediction Mathematics Achievement*	*Actual Mathematics Achievement*	*Differences Between the Actual and Predicted Achievements*
(X1)	*(X2)*	*(X3)*	*($\hat{Y}$)*		
46	735	1195	98.7	100	1.3
49	894	1011	98.4	100	1.6
74	1065	1107	87.8	87.5	-0.3
78	1046	1217	86.6	87.5	0.9
93	988	902	62.4	62.5	0.1

(X1 = total log in frequency data, X2 = total usage time data, X3 = total score data)

As a result, the predicted model of mathematics achievement obtained is as follows:

$$\hat{y}=70.207+(-0.846+X1+(0.046)X2+(0.028)X3$$

Table 5 shows the variables of five students that we used in the model to predict their performance in mathematics.

From Table 6 showing the values, it can be concluded that the predicted model for the mathematics achievement of the students through log in frequency data, time of use and score has a strong expectation or prediction strength in terms of how it contributes to mathematics achievements. This is because the difference between a student's actual mathematics achievement and the student's expected achievements in mathematics is small.

Discussion

Interpretation of Mathematics achievement findings

The findings of the study show that the use of the digital GBL application has successfully improved the achievement of mathematics. This can be seen through the comparison of the mathematics achievement based on the group of students using the digital GBL application and the group of students using the conventional method. The former has showed a significant improvement in the post-test thus indicates that the use of the digital GBL application based on the GBL approach successfully meets the learning needs of the students in this era. Furthermore, the use of the digital GBL application makes learning more active and enable teachers to diversify their pedagogical approaches instead of merely relying on conventional methods. As a result, students' learning becomes more assisted and guided hence making teaching process more effective as noted by Steinmaurer et al (2020) that a GBL-based learning approach and technology helps to build mastery of the learning concept in a manner that is easier to understand for students.

A reasonable explanation of the digital impact of the GBL application particularly in terms of how it helps to improve the student's mathematics achievement is related to its potential to encourage the students to practice solving mathematics questions more than the conventional approach. Usually, the students are only able to complete six to eight mathematics questions in the designated mathematics teaching and learning time. However, the digital GBL application has motivated the students to complete more than thirty mathematics questions in one mathematics teaching and learning session. On top of that, the integration of mathematics learning with digital GBL application allows the students to learn either directly or indirectly. This is because the GBL approach is able to encourage the students to solve problems and engage in self-learning (Saudelli & Ciampa, 2016), thus enabling them to learn a mathematics concept without realizing it. As a result, the students' self-competence and abilities can be improved

(Eseryel et. al, 2014; Wu, Richards & Saw, 2014), thus helping to improve their achievements in mathematics.

In addition, the digital success of GBL applications in terms of helping to improve the students' mathematical achievements can be further explained through the concepts in cognitive load theory. Sweller et al (1998) stated that during the construction of the digital GBL application, this theory allows researchers to take into account the cognitive load factor of the students. This is important because a good and effective learning process occurs when the learning materials used are on par with the cognitive design of the students (van Merriënboer & Sweller, 2005). Additionally, this theory also provides a guide to arrange learning information according to the cognitive needs of the students. The arrangement lets students to engage in progressive learning ranging from easy to difficult. Consequently, GBL application's digital users can follow a structured learning scheme through a learning process that is appropriate to the student's conceptual developmental stage. The implication is that the digital use of the GBL application has succeeded in improving their achievements in mathematics.

The interpretation of the students' mathematic performance and the prediction findings

Time period data, log in frequency data and score data due to the use of the digital GBL application by the students are the data that provides many benefits to the teachers. The influx of the data enables the implementation of LA through the process of collection, measurement, analysis and reporting related to the students in their own context with the aim of understanding and optimizing the teaching and learning process (Vladimir et al., 2019; Oyerinde, 2017; Siemens & Baker, 2012).

The findings illustrate that the time data, log in frequency data and score data from the use of the digital GBL application make a strong contribution to the expected mathematical achievements. This shows that the function settings used for recording this data in the digital GBL application has successfully helped to anticipate the students' achievements. The results of this data analysis prove that the LA application in relation to the digital GBL application allows the teaching and learning process to be seen clearly (Ruiperez et al., 2015). The LA digital GBL application process provides a visualization for the teachers which give rooms for the teachers to reflect on their implementation of the teaching process. The results of the LA process also enable the teachers to leverage the wealth of data to help them in providing accurate feedback to the students. It also offers valuable information to the teachers on how to improve the quality of their teaching as well as to help them in understanding the learning environment more clearly (Oyerinde, 2017; Siemens & Baker, 2012). As a result, the teachers are able to identify students who are potentially having problems or who are likely to drop out. These students can be assisted by formulating effective immediate action (Ebner & Schön, 2013) and providing learning interventions (Faridhan et al., 2013).

The collection of log in frequency data and time period data is useful to analyze the contribution of GBL application time usage to the total score obtained by the students. This is because the frequency of students in applying a learning material will contribute to the students mastery skill as they spend more time using the material. The application of GBL in learning often motivates students to learn. This often contributes significantly to the amount of time period data, log in data frequency so as to affect the data score.

Among the factors contributing to this large amount of data is the setting of immediate feedback in GBL applications that has the potential to motivate students to strive for the next levels. This allows students to complete exercises independently while playing, answer questions and accomplish activities and then receive a display of learning progress as well as reinforcement of positive comments throughout learning. As a result, students can learn freely without worrying of making mistakes. Therefore, the more often students log in to the GBL application, the longer the duration of the GBL application usage and the more often students receive learning feedback.

The contribution of the time period data, log in frequency data and score data from the use of the digital GBL is beneficial in anticipating students' achievement. The digital GBL's ability to anticipate students' achievement gives the teachers an opportunity to review their teaching methods that have been implemented. They can then evaluate the effectiveness of their teaching and whether the learning objectives have been achieved. As a result, the teaching and learning process will always be improved from time to time, learning objectives will be optimally achieved, students' achievements continue to enhance and there will be a reduction in the number of students who are at risk of dropping out. The impact of the LA process through the type of data used is parallel with other previous studies which reported that LA helped teachers to understand the development of student learning processes in mathematics (Bertacchini et al., 2018; San Pedro et al., 2017; Kim et al., 2016; Ruipérez- valiente et al., 2015; Sivaranjani et al., 2015). The benefits of LA have also helped teachers to predict their students' achievements in mathematics and to identify possible students who are at risk of dropping out through detailed data analysis (Román-González et al., 2018; Xing et al., 2017; Dani & Nasser, 2016; Romero-Zaldivar et al., 2012).

Limitations and future work

The findings of this study indicate that the digital GBL application has succeeded at improving the students' mathematics achievements. However, the findings of this study are only limited to one class of students as quasi-experimental design was used. The study on the digital effectiveness of the GBL application can be improved by strengthening the methodology. The selection of a much larger study samples may be able to provide broader findings related to the impact and contribution of the GBL digital application in the teaching and learning of mathematics.

Apart from that, the comparison made in the current study is between the experimental group that is set to use the digital GBL application and another group that does not use the application. Future research can be established to compare between a group that uses the digital GBL application actively with another group that uses the digital GBL application passively.

In addition, LA in the current study is a systematic process of data management, collection, and analysis that will help to anticipate the students' achievements in mathematics. The variables used in the application of LA in this study are the time period data of use, log in frequency data and score data. To further increase the students' achievement expectations, learning response variables received by the students each time that they use the digital GBL application can be considered. It is claimed that learning responses will help to improve their mastery of their learning. Therefore, the addition of the learning response variables that the students receive can be done as part of helping to improve the quality of the student achievement expectations in mathematics.

Conclusions

The results of this study prove that the digital application of the GBL application in the process of teaching and learning mathematics has successfully improved the students' achievement and triumphed at providing students' achievement expectations. For this reason, the digital application of the GBL application and LA are particularly suitable to be applied in the new post-pandemic norms of Covid-19. Also, it permits the teachers to monitor the student's learning performance through the data on the student's learning application usage. The LA process as part of the GBL application's digital usage data in mathematics learning provides useful information to the teachers about the development of the students' learning process. The teachers can then formulate effective strategies to ensure that the students do not lag behind in their learning due to the Covid-19 pandemic factors. In conclusion, the digital application of the GBL application and LA in the learning process should be applied in the process of teaching and learning mathematics as an effort to improve the quality of teaching and the effectiveness of the students' learning.

Statements on Open Data, Ethics and Conflict of Interest

The data that support the findings of this study are available on request from the first author. The data are not publicly available due to them containing information that could compromise privacy of the participants.

This research was carried out under the ethical guidelines. We took an experiment in a primary school and we informed all the participants the basic information about the research, and we got the permission to use these data for our research. To ensure confidentiality, students' personel identifiers were removed prior to processing the data.

Acknowledgments: This research was supported by a grant from the Faculty of Education, Universiti Kebangsaan Malaysia; GG-2020-026.

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