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The Effect of the Use of Digital Gamification and Metacognitive Skills on Students' Mathematics Solving Ability

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Abstract

Mathematics is one of the essential subjects for students because it focuses more on the ability to remember, memorize, and interpret. In addition, gamification in mathematics is excellent since it promotes critical and creative problem-solving and enhances children's metacognitive abilities. This experimental study investigates the impact of digital gamification and metacognitive skills on the mathematical problem-solving capabilities of primary school students. This type of research is quasi-experimental with a pretest-posttest control group design. The number of samples used was 108 students consisting of 55 students in the experimental class and 53 in the control class. The research data was collected with the MAI (Metacognitive Awareness Inventory) instrument for metacognitive skills and problem-solving tests. The data analysis technique used is Two Way Anova. This study yielded several findings. Among them, there are significant differences in students' solving abilities based on the application of gamification in learning. Second, there is a significant difference in students' problem-solving abilities based on metacognitive skills. In addition, there is an interaction between digital gamification and metacognitive skills on students' mathematical problem-solving abilities.

Keywords: Gamification, Metacognitive, Education, Mathematics, Problem-Solving Skill

Introduction

Competency is one of the 21st-century skills required to ensure students are equipped for the future. It has four primary skills as described by the National Education Association (NEA), which include (Erdogan, 2019, pp. 113–124) 1) critical thinking and problem-solving, 2) creativity and innovation, 3) communication, and 4) collaboration. This means one of the skills needed mainly by school students is problem-solving (Tambunan, 2019, p. 293), which is why it is the focus of several subjects, such as mathematics. It is also an essential issue in learning mathematics in schools (Fasni et al., 2017, p. 2).

The core skill required for mathematics is problem-solving (Wangi et al., 2018, p. 1), which primarily focuses on the ability to remember, memorize, and interpret (Laksana, 2017, p. 80). Moreover, mathematics is a compulsory subject customarily used to train students to think logically, analytically, systematically, critically, and creatively (Yayuk, 2020, p. 1281). This is the reason related skills are necessary to solve mathematical problems. This shows that the primary goal of teaching mathematics at different stages of education is to improve the ability of students to solve problems (Al-Khateeb, 2018, p. 178).

It is important to note that there are limited opportunities for students in learning mathematics to explore and solve problems using different methods from those taught in class (Yayuk, 2020, p. 1281). Most classroom activities also apply novel problem-solving methods (Ali et al., 2010, p. 68). This is why educators need to innovate, for example, gamification's application in the learning process.

The use of appropriate and planned elements of this concept in learning activities was also reported to have the ability to motivate students to solve problems and improve their problem-solving skills (Annaggar & Tiemann, 2016). Another critical factor in learning mathematics is a metacognitive skill. It was observed that gamification elements such as randomness, artificial challenges, artificial assistance, exploratory or open-world approaches, and social cooperation could be improved. Meanwhile, the concept

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can provoke creative student learning methods with a subsequent tremendous effect on the increment in the level of learning independence and improvement of individual skills, specifically in mathematics (Udjaja et al., 2018, p. 3861).

This present study provides findings and insights concerning the use of gamification in learning mathematics and indicates scientific ideas based on the information retrieved from several relevant studies. This is necessary because a previous study showed that students' connections in solving mathematical problems were shallow and weak (Kenedi, 2019, p. 75). This can be improved through the use of elements of gamification in learning mathematics which is considered difficult and tedious for students, this is the purpose of this paper.

Literature Review

Gamification in Educational Institutions

Students are interested in something fun, which is why gamification is usually implemented as a learning approach. This involves using games or video games to motivate students and maximize their feelings of enjoyment to ensure they are engaged in the learning process(Kotob & Ibrahim, 2019). Moreover, incorporating game elements increases their enthusiasm and improves their participation in the learning process. It has also been discovered to have the ability to capture interesting things and inspire them to continue learning(Jusuf, 2016, p. 1).

Moreover, the practical application of gamification has been reported to have the ability to personalize student experience(Bell, 2018)by creating a fun and student-centred learning environment. According to Karl Kapp, this was also supported by the definition of gamification as "the use of game mechanics to make learning and teaching more enjoyable"(Kapp, 2012). Gamification is applied in the learning process of schools to promote learning motivation and improve student experience(Ilya et al., 2015, p. 76)]. However, making technology more attractive encourages users to engage in the desired behavior to assist them in solving problems(Middleton, 2009, p. 2).

This method has been confirmed to be a good step in improving cognitive abilities and motivation in children, specifically in the current digitalization era characterized by the use of more technology (Marisa et al., 2020, p. 104).

Problem Solving and Metacognitive Skills in Learning Mathematics

In metacognitive skills, gamification can help students build their knowledge, determine strategies to be used in problem-solving, and control learning outcomes.(Tang & Kay, 2014). This was further confirmed by the findings of a previous study that gamification, which involves using the web as a platform and utilizing its elements such as rewards, levels, and challenges, can be used to increase students' learning motivation(Wols et al., 2020, p. 2) (Panis et al., 2020, p. 4). Moreover, combining mobile devices and gamified learning offers potentially new activities to enrich student engagement and learning experiences. It is important to note that it is necessary to design the gamification mechanism to align with the desired learning outcomes(Zhang, 2015). The application of gamification increases students' motivation and allows learning by interacting through games to improve learning and training. It can further improve cognitive and problem-solving abilities for certain subjects when conducted continuously.

The Usage of Gamification Design in Mathematics

Mathematics learning focuses on the ability to think logically, systematically, and analytically to solve problems. Kirisci further explained that the core of mathematics is problem-solving ability(Kirisci et al., 2020, p. 1). This means the primary goal of teaching mathematics at different education stages is to improve students' problem-solving abilities(Al-Khateeb, 2018, p. 178). Moreover, the National Council of Teachers of Mathematics showed that problem-solving is essential to all subjects and should not be an isolated part of the lesson, unit, or curriculum but integrated into the experience of students and connected to different processes and material descriptions(Baldeon et al., 2015, p. 2). It is possible to integrate new experiences for students through gamification strategies.

Developing student experience through gamification strategies makes learning mathematics more fun, precisely the essential aspect. This is possible because students can participate in games and work in groups(Baldeon et al., 2015, p. 7). It is important to note that the determination of the gamification elements should be applied in learning mathematics, specifically in solving problems.

Method

This study uses a quantitative approach with a quasi-experimental type using a pretest-posttest control group

Tables 1: Research Design

Group	*Pre-Test*	*Treatment*	*Post-test*
Experiment	O1	X1	O2
Control	O1	X2	O2

design(Creswell, 2018). The data collection technique used is a reasoning ability test. The research design can be seen in the table 1.

Participant

The sample in this study amounted to 108 students consisting of an experimental class of 55 students and a control class of 53 students at Muhammadiyah Ponorogo Elementary School. The purposive Random Sampling technique is used because it takes two classes that are homogeneous (assumption test) in their abilities and can represent the characteristics of the population. Furthermore, students will be grouped based on metacognitive groups tested using MAI (Metacognitive Awareness Inventory) (Pramusinta et al., 2019). The distribution of data is as follows:

Tables 2: Distribution of Research Subjects Based on MAI

Metacognitive Skills	*Frequency*	*Percentage*
High	38	35.19%
Middle	35	32, 41%
Low	35	32, 41%

Analysis of Data

After being given treatment for the experimental and control classes, the data will be analyzed. Research data were analyzed using descriptive statistics, prerequisites, and hypothesis testing using Two Way Anova.

Result and Finding

The data of this study were obtained through learning activities in the experimental and control classes. However, before that, students were given a pretest to determine their initial condition and a posttest after treatment to measure the students' problem-solving abilities. Before the data was tested using ANOVA, the research data had to meet the requirements for normality using the Kolmogorov-Smirnov test and homogeneity with Levene's test. The results of the normality test can be seen in the following table.

Tables 3: Tests of Normality Kolmogorov-Smirnov

Variable	Tests of Normality Kolmogorov-Smirnov				Result
	Experiment		Control		
	Pretest	Posttest	Pretest	Posttest	
Problem Solving	0.200	0.200	0.078	0.062	Normal

Based on the results of the normality test, it was found that the alpha value was more significant than the significance value of 0.05; it can be said that the data were normally distributed. Then the homogeneity test was carried out using Levene's Test. The results can be seen in the following table.

Table 4: Tests of Homogeneity Levene's Test

	Tests of Levene's Test		
Variable	*Pretest*	*Posttest*	*Result*
Problem Solving	0.255	0.492	Homogeneous

Based on the homogeneity test results, the number 0.255 for the pretest and the number 0.492 for the posttest, so the data obtained is in the homogeneous category.

After getting the findings of the study of normality and homogeneity in the pretest results and including them in the regular and homogeneous categories, as shown in Table 5 below, the sample size may be calculated.

Tables. 5 : Test the difference in the results of the pretest problem-solving ability of the experimental class and the control class.

		t-test for Equality of Means	
Sig. (2-tailed)			*Result*
Pretest	Equal variances assumed	.846	No Difference
	Equal variances not assumed	.846	

In this study, it is necessary to calculate the normality test for students' metacognitive skills on the posttest results of students' problem-solving abilities, as for the data as follows.

Tables 6: Posttest Normality Test based on Metacognitive Skills

	Test of Normality Kolmogorov-Smirnov	
Indicator	*Sig.*	*Result*
High	0.119	Normal
Middle	0.062	Normal
Low	0.069	Normal

Based on the results of the normality test of metacognitive skills on the post-test ranging from high to low indicators, a number greater than 0.05 is obtained, which means that it is normally distributed. Then test the homogeneity of metacognitive skills on the post-test results, for the results as follows.

Tables 7: Posttest Data Homogeneity Test on Metacognitive Skills

	Test of Homogeneity of Variance	
	Sig.	*Result*
Post-test	0.326	Homogeneous

Based on the homogeneity test results, the number 0.326 means that the value is more significant than 0.05, with the conclusion that the data is homogeneous.

Hypothesis Testing

The Influence and Interaction of Digital Gamification and Metacognitive Skills on Students' Problem Solving Ability

In this study, three hypotheses were set to be tested. Testing the hypothesis of this research which has been formulated as follows: (1). There are differences in problem-solving abilities of students who use digital gamification, (2) There are differences in problem-solving abilities of students who have high, medium, and low metacognitive skills, (3) There is an interaction between the use of digital gamification and metacognitive skills on students' solving abilities. The results of the two-way Anova test can be seen as follows in Table 8:

From the test results using ANOVA in Table 8 above, it can be explained that the first hypothesis shows a calculated F value of 5.231 with a significance value of 0.024, which means the value is smaller than 0.05. Based on these results, it can be concluded that H0 is rejected and Hypothesis H1 is accepted.

Furthermore, the second hypothesis test shows the calculated F value of 47.963 with a significance value of 0.000, which means that the value is smaller than 0.05. Based on these results, it can be concluded that H0 is rejected and Hypothesis H1 is accepted. The third hypothesis test shows the calculated F value of 7.649 with a significance value of 0.001, which means that the value is smaller than 0.05. Based on these results, it can be concluded that H0 is rejected and Hypothesis H1 is accepted.

Discussion

The Effect of Digital Gamification on Problem Solving Skills

In general, the results of research that have been carried out show that the use of digital gamification significantly affects problem-solving abilities in students' mathematics subjects. It is necessary to know that learning mathematics does require high concentration and accuracy. Several problems are observed to be existing in learning mathematics, specifically at the school level. Examples include less achievement of learning objectives, less motivation for students to study mathematics because it is considered boring, and difficulties in teaching mathematics conceptually (Subarinah, 2011).

Several students learned through the conventional methods of memorizing to answer questions. This can be boring and unpleasant even though it is considered very good become there is no fun in the learning process. Teachers must be creative and innovative while parents provide adequate support to ensure their children learn mathematics successfully (Ramani & Scalise, 2020, p. 79). The review also showed the importance of early development of math skills in students because it is a strong and stable predictor of their later math achievement PESTLHE A gamified and mystery-driven approach for facilitating problem based learning in a postgraduate strength and conditioning module May 2018 29 20 credit, module, students were introduced to an organisation they believed to be real and asked to compile a presentation for that organisation providing suggestions in relation of athlete development. A series of mystery packages were then delivered to the students over a four week period, as the central element of the module, providing information that was potentially relevant to their problem scenario. This

Table 8: Test Results of the Effect of Independent Variables on Dependent Variable

Tests of Between-Subjects Effects

Dependent Variable: Troubleshooting

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Corrected Model	4532,439a	5	906.488	24,065	.000
Intercept	577649,078	1	577649,078	15335,388	.000
a	197.045	1	197.045	5,231	.024
b	3613,343	2	1806,672	47,963	.000
a*b	576,230	2	288.115	7,649	.001
Error	3842,107	102	37,668		
Total	592847,000	108			
Corrected Total	8374,546	107			

a. R Squared = .541 (Adjusted R Squared = .519)

was followed by two tutorial sessions prior to presentation of the student work. Following completion of the module, students participated in focus group interviews. Focus group interviews, analysed using thematic analysis, revealed that students believed the approach was interesting, interactive, developed new skills and was vocationally relevant. However, students felt confused by the approach, perceiving this to be negative, unaware that the confusing elements were designed to prompt deeper learning. These results seem to indicate that a PBL approach, using some aspects of gamification, via role play and mystery, via receiving 'mystery' packages can add value to the postgraduate experience. Despite this, the approach trialled in this study can be challenging to employ. Academics and practitioners need to be aware that the student perception of confusion the process can create is initially negative but is an important element to better answer causal questions, diagnose and solve problems, and demonstrate application of acquired knowledge." (Duncan et al., 2018). The problems mostly explored concerning children's natural interest in mathematics tend to apply theoretical and abstract approaches that do not focus on the context (Al-Khateeb, 2018). Usually leads to stress for the children due to their inability to understand the mathematical materials, which can interfere with their mental health(Vejdemo-Johansson et al., 2019, p. 1080). This means there is a need to find exciting and fun ways of solving mathematical problems (Bellos, 2010).

Giving extrinsic and intrinsic motivation is needed in training problem-solving skills because of its ability to improve individual performance, as reported by a study entitled "The role of games can change the mindset of playing games can help motivate students in learning" (Wols et al., 2020, p. 9). Meanwhile, only intrinsic motivation directly affects the improvement of creativity, learning outcomes, and positive involvement in an activity (Kalogiannakis & Papadakis, 2021, p. 4). External motivation is also very much needed, specifically for subjects considered difficult for children. This shows that gamification can stimulate children's learning abilities and motivation through various processes, such as educating and playing games to support problem-solving abilities (Ibrahim et al., 2021, p. 115).

Gamification in learning can function as a process of using game-based mechanics, thinking, and aesthetics to engage and motivate students toward learning and acquiring problem-solving skills (Yamani, 2021, p. 19).

The concept was also explained to be a creative learning method with tremendous influence on the increment in the level of independent learning and skills improvement, specifically in practical mathematics lessons (Udjaja et al., 2018, p. 3861). The use of gamification in the learning process is one of the innovative solutions expected to assist teachers, specifically those in charge of mathematics subjects, and also to serve as a very effective model to internalize critical cognitive processes for students.

The findings from a previous study showed that an average of 66.9% of students became more interested and happy to learn mathematics due to gamification, which contributed 75.4% to their learning achievement(Udjaja et al., 2018). PESTLHE A gamified and mystery-driven approach for facilitating problem based learning in a postgraduate strength and conditioning module May 2018 29 20 credit, module, students were introduced to an organisation they believed to be real and asked to compile a presentation for that organisation providing suggestions in relation of athlete development. A series of mystery packages were then delivered to the students over a four week period, as the central element of the module, providing information that was potentially relevant to their problem scenario. This was followed by two tutorial sessions prior to presentation of the student work. Following completion of the module, students participated in focus group interviews. Focus group interviews, analysed using thematic analysis, revealed that students believed the approach was interesting, interactive, developed new skills and was vocationally relevant. However, students felt confused by the approach, perceiving this to be negative, unaware that the confusing elements were designed to prompt deeper learning. These results seem to indicate that a PBL approach, using some aspects of gamification, via role play and mystery, via receiving 'mystery' packages can add value to the postgraduate experience. Despite this, the approach trialled in this study can be challenging to employ. Academics and practitioners need to be aware that the student perception of confusion the process can create is initially negative but is an important element to better answer causal questions, diagnose and solve problems, and demonstrate application of acquired knowledge (Duncan et al., 2018, p. 29) also reported that a problem-solving approach implemented using several aspects of this concept, such as role-playing and receival of the "mystery" package was able to add value to the learner's experience. This means it is essential to apply every element of gamification in order to ensure meaningful learning is provided. This is in line with

the findings of Reiguluth that learning experience through this method requires both direct engagement and meaningful learning activities(Beatty & Myers, nd, p. 272)to affect the learning outcomes positively. Another study also showed that the learning model combined with the approach enhanced the ability of the multisensory in children to increase their performance and potential and to activate their involvement to trigger specific emotional responses in educational games(Covaci et al., 2018).This approach is more comprehensive and provides additional guidance on supporting students through the actual problem-solving process(Charles M. Reigeluth, nd). It was observed to improve mathematical problem-solving skills as expressed by NCTM which focuses on applying and adapting appropriate strategies to solve problems(NCTM, 2003). Moreover, the elements contained in gamification were reported to make learning more fun(Juric et al., 2021, p. 285).

Interaction of Using Digital Gamification and Metacognitive Skills

Furthermore, this integration process can provide learning feedback to students, track their progress in knowledge acquisition, and allow a child to learn the process of breaking down questions and problems into smaller parts for easy explanation. This is described through a learning concept used in Means-Ends Analysis (a problem-solving technique) by Biloch & Löfsted as stated in Fig. 1, which involves breaking down the problem into three stages, including the current state, sub-goal, and goal state (Biloch & Löfstedt, 2013). The problem is further divided into three at the sub-goal stage, which includes defining the problem (learning), defining the use (creating), and defining success (processing) (Andrzej Marczewski, 2017).

The gamification element is very influential in this stage, and this is the reason it is essential to select the appropriate elements to obtain support from external factors such as behavior, motivation, interest, curiosity, and responsibility to improve the problem-solving skills and support the metacognitive skill of the children, specifically through the avoidance of stress as indicated in Fig. 1.

The effectiveness of this learning also depends on other factors, such as metacognitive skills, namely, at the cognitive level of understanding and applying concepts. At the cognitive level, it explains that knowledge of how many cognitive abilities students have is not enough to be the basis for compiling ideal learning(Schraw & Moshman, 1995). A study shows that problem-solving methods can develop metacognitive skills(İDawati et al., 2020).

This is in line with the findings of Vanessa Wan Tse that the elements in gamification, such as story-telling, challenges, and Random games, can be used to improve children's problem-solving skills(Cheng et al., 2019). It is also possible for students to obtain information on their achievements through this gamification concept. However, designing the games to demonstrate their effectiveness in supporting metacognitive skills while formulating new models to support problem-solving skills development is essential.

These data showed that using gamification to learn mathematics, specifically solving problems, is compelling. The gamification design framework can be implemented in the study room through technology's support to increase students' enthusiasm for learning(Verbruggen et al., 2021). The appearance of the learning process using gamification is generally presented as indicated in the following Fig. 1.

Most of the data retrieved showed the positive effect of using gamification to learn mathematics on learning motivation. For example, it was observed to be improving problem-solving skills due to the hours spent applying the concept learned through the games (Turan et al., 2016, p. 64). However, it is essential to note that the implementation does not always lead to success due to several problems, confirmed by several studies that showed its ineffectiveness due to improper use. For example, Jan Broer reported that its effect on motivation or participation is much lower than the hype people previously believed (Broer, 2014, p. 393). This is based on several factors associated with both educators and students, with the most visible observed using these games for leisure while others use them for learning purposes(Broer, 2014). Ismail reported a similar finding that students were less motivated using the gamification method because they felt unprepared to use this new method (Ismail et al., 2018, p. 2).

Students' lack of motivation in learning will doubtful affect the effectiveness of the application of gamification, even though the correct use of entertainment content in the form of video games has been shown to improve mood, increase motivation, and reduce stress or emotional release (Ibrahim et al., 2021, p. 144). Therefore, what needs to be considered when applying gamification is *first* to identify the learning

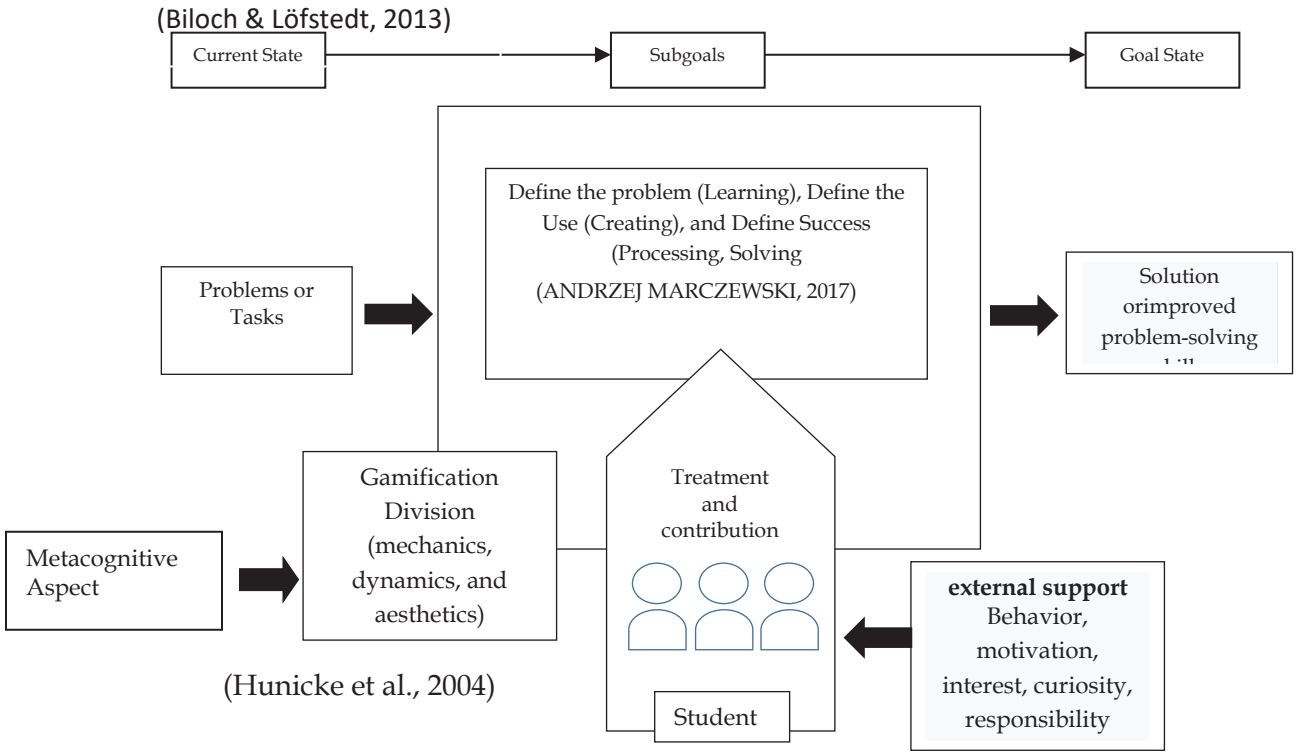

Fig. 1: Design on the Application of Digital Gamification to improve Mathematical Problem-Solving Skills and Metacognitive.

objectives that will be carried out; *second*, identifying the technology and game mechanisms is considered effective in achieving learning objectives and reflecting the characteristics of students (Persephone Rizvi, 2019); *third*, the combination of fun game mechanics as well as the provision of valuable and meaningful gameplay motivates students to keep playing and learning (Chairul, nd); *fourth*, consider the accuracy in inserting gamification elements into gamification-based applications and selecting appropriate elements to increase learning activity and motivate students to be actively involved in the learning process (Alsubhi & Sahari, 2020, p. 16).

Conclusion

The use of application-based gamification for learning mathematics can serve as a way to develop learning innovations and assist students in improving their problem-solving skills, which is one of the mandatory indicators for acquiring mathematical knowledge. Metacognitive skills are also an important factor that cannot be separated from problem solving, because students become more focused on their learning through metacognitive skills. Of course, these two variables were also observed to have the ability to improve and restore children's mental health based on the dependence of games on strategies that can relieve stress. Thus, this study concludes: there are significant differences in the problem-solving abilities of students who learn mathematics using digital gamification, also those who have high, medium, and low metacognitive skills and there is an interaction between the use of digital gamification and metacognitive skills on students' mathematical problem-solving abilities.

For further research, researchers should add one more variable that supports this research, namely mental health, because several sources explain the relationship between gamification elements that support children's mental health.

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