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The Effect of GEMAS on Mathematical Problem-Solving and Critical-Thinking Abilities

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ABSTRACT

This research focuses on the development of gamification-based mathematics teaching materials specifically designed to improve the problem-solving and critical mathematical thinking skills of junior high school students in the form of GEMAS (Junior High School Mathematics Game) and to test the product based on its validity, practicality, and effectiveness aspects. The ADDIE MODEL is used in the research and development of GEMAS. Previous research articles have discussed the stages of product development, validity testing, and practicality, so the focus mof this article only discusses its effectiveness test. Thus, the stages of the ADDIE model used in this article are also limited to the last two stages, namely Implementation and Evaluation. The study was conducted at two junior high schools in Sukabumi using a one-sample pretest-posttest design. The sample was 256 students from 10 study groups using cluster random sampling techniques. Data were collected through the Krulik-Rudnick problem-solving ability test instrument, the FRISCO critical-thinking ability test, and student response sheets that met the criteria of being very valid and highly reliable. Data were analyzed using a paired two-sample t-test at a significance level of alpha 5% and descriptive analysis. The results of the study showed that GEMAS met the criteria for effectiveness. This can be seen from the overall range of values between the average pretest and posttest of problem-solving ability which reached 43.75 and critical thinking ability which reached 47.00, as well as the n-gain value of both mathematical problem-solving ability and mathematical critical thinking ability of junior high school students has met the moderate improvement category (46-51%).

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A. INTRODUCTION

The independent curriculum is a curriculum whose learning is focused on developing 21st-century skills, including students' problem-solving and critical thinking skills (Anggraini et al., 2022). These skills are fundamental in everyday life because they can improve other thinking skills, such as decision-making skills and solving non-routine problems (Sari et al., 2021). Problem-solving ability is solving non-routine problems based on basic knowledge and mentality in the problem-solving process (Hakak et al., 2019a; Septian et al., 2022). Problem-solving ability is a complex cognitive and thinking ability, which includes activities of analyzing, interpreting, reasoning, predicting, evaluating, reflecting on information and previous knowledge, and implementing it in the problem-solving process or new and unknown situations (Adelia et al., 2020). Critical thinking is a process used to make reasonable decisions to obtain truth, which is considered good. This ability involves previous knowledge,

mathematical reasoning, and using cognitive strategies in generalizing, proving, or evaluating mathematical situations reflectively (Arisoy & Aybek, 2021; Samura & Darhim, 2023).

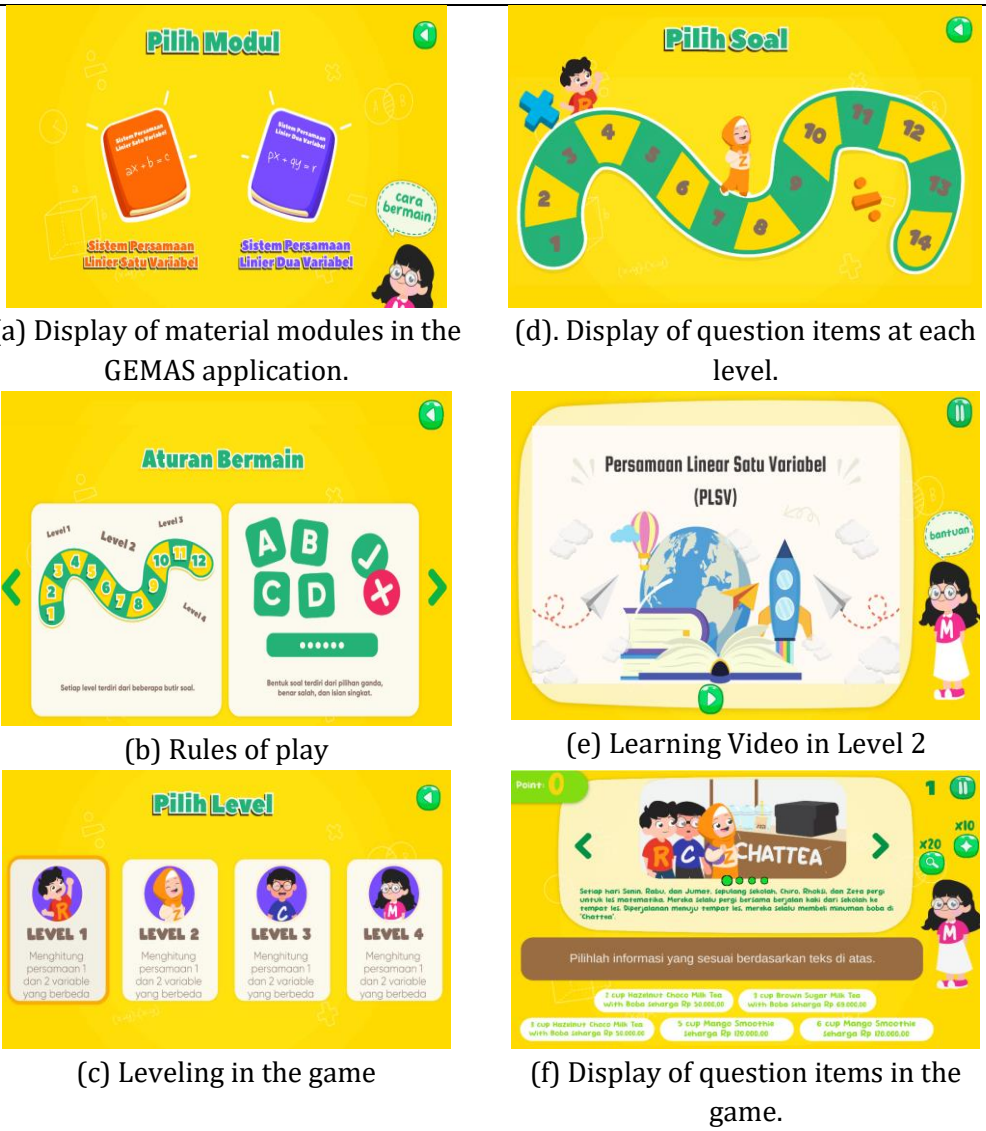
The problem-solving ability indicators used in this study are the five heuristic steps of Krulik and Rudnick, which consist of (1) reading and thinking, writing in own words about what is known and asked, and classifying important and unimportant information to be used as a way or strategy; (2) explore and plan, making a written plan or idea to solve the problem; (3) select a strategy, answering questions or solving existing problems based on previously made planning; (4) find an answer, writing the correct answer; and (5) reflect and extend, re-checking the correctness of the answers obtained and modifying them if possible. Meanwhile, the critical thinking ability indicators used in this study were put forward by Ennis (Almunawarah et al., 2023; Ennis, 2011), namely FRISCO (Focus, Reason, Inference, Situation, Clarity, and Overview). Focus is the ability to determine the focus of a given problem. Reason is knowing the reasons that support or oppose decisions based on relevant situations and facts. Inference is the activity of making reasonable conclusions that can be accounted for; Situation is the activity of applying previously owned knowledge concepts to solve problems in other situations. Clarity is the ability to explain the meaning or terms used. Moreover, an overview checks or re-examines the steps to solve the problem (Almunawarah et al., 2023; Ennis, 2011).

The benefits of having problem-solving skills include encouraging creativity, flexibility, and metacognitive thinking that are needed for professional needs and needs in everyday life (Alkhatib, 2019; Gunawan et al., 2020), while the benefits of having good critical thinking skills include (1) it is easier to evaluate the basis of the problem so that it can create the best solution (Tanty et al., 2022); (2) can manage and utilize information to survive in conditions that are constantly changing, uncertain, and competitive (Kurniawati & Ekayanti, 2020); (3) will be able to filter information, and also be able to express arguments with logical reasons (Maulidah et al., 2020); and (4) the quality of a person's thinking will increase because problems can be solved in a structured way and uphold intellectual values (Tanty et al., 2022).

However, Indonesian students' problem-solving and critical thinking abilities are still not optimal. This result can be seen from the OECD 2024, which states that the results of PISA in 2022, Indonesia's position is ranked 69th out of 80 countries below (Ayurachmawati et al., 2024; Bilad et al., 2024). This result shows that the average high school student in Indonesia is only able to recognize several basic facts, is not yet able to communicate, relate several topics, and apply complex and abstract concepts in mathematics as a form of problem-solving skills and critical thinking skills as (Hakim & Windayana, 2016; Masrurroh et al., 2024; Rahman et al., 2024). This low ability is one of the impacts of learning that is still fixated on things that are basic, theoretical, and not yet applicable. Therefore, classroom learning transformation needs to be carried out, one of which is through Gamification techniques. Gamification uses game design elements in a non-game context to attract attention, develop characters, or solve problems (Rienovita et al., 2024). Gamification is not about turning certain activities into games but redesigning them to make them more fun and interactive (Islam et al., 2025).

Previous research on Gamification has only focused on the use of Gamification to increase learning motivation (Jueru et al., 2020; Nurjannah et al., 2021; Omar et al., 2022), improving learning outcomes (Nurtanto et al., 2021; Permata & Kristanto, 2020; Qiao et al., 2022), Communication and collaboration skills (Farooq et al., 2022), problem-solving routine

problems (Hakak et al., 2019b), participation and learning experiences (Nair, 2022) and improved academic performance (Hakak et al., 2019; Setiawan et al., 2020). However, no gamification research has simultaneously facilitated the improvement of students' problem-solving and mathematical critical-thinking skills. In addition, the game is designed not only to place questions from easy to difficult but the questions also direct students to form an understanding related to the material being studied. There are learning videos to confirm students' knowledge, and questions are available for reinforcement. Therefore, this study aims to develop gamification-based mathematics teaching materials specifically designed to improve junior high school students' problem-solving and mathematical critical thinking skills and to test the product based on its validity, practicality, and effectiveness. This research lasted for three years and produced gamification-based mathematics teaching materials in the form of the GEMAS game which was proven to be valid, practical, and effective in improving junior high school students' problem-solving and mathematical critical thinking skills in limited-scale testing (Agustiani et al., 2022; Agustiani et al., 2023, 2024; Lukman et al., 2022; Setiani et al., 2023, 2024). The design results are shown in the following Figure 1.



(a) Display of material modules in the GEMAS application.

(d). Display of question items at each level.

(b) Rules of play

(e) Learning Video in Level 2

(c) Leveling in the game

(f) Display of question items in the game.

Figure 1. Design and Appearance of Gamification-Based Teaching Materials

Therefore, to see the consistency of GEMAS' effectiveness in problem-solving and mathematical critical thinking skills, a large-scale test was conducted this year involving 256 users from 2 junior high schools in Sukabumi. This article will only discuss the testing of GEMAS' effectiveness on junior high school students' problem-solving and mathematical critical thinking skills.

B. METHODS

This study uses the type of research and development of the ADDIE model (Lukman, Setiani, et al., 2023). However, in this article, the discussion is more emphasized on the last two stages, namely *implementation* and *evaluation* (figure 2), to measure the quality of gamification-based mathematics teaching materials (GEMAS) on the problem-solving and critical-thinking abilities of junior high school students based on their effectiveness aspects. The stages of the activity are described as follows.

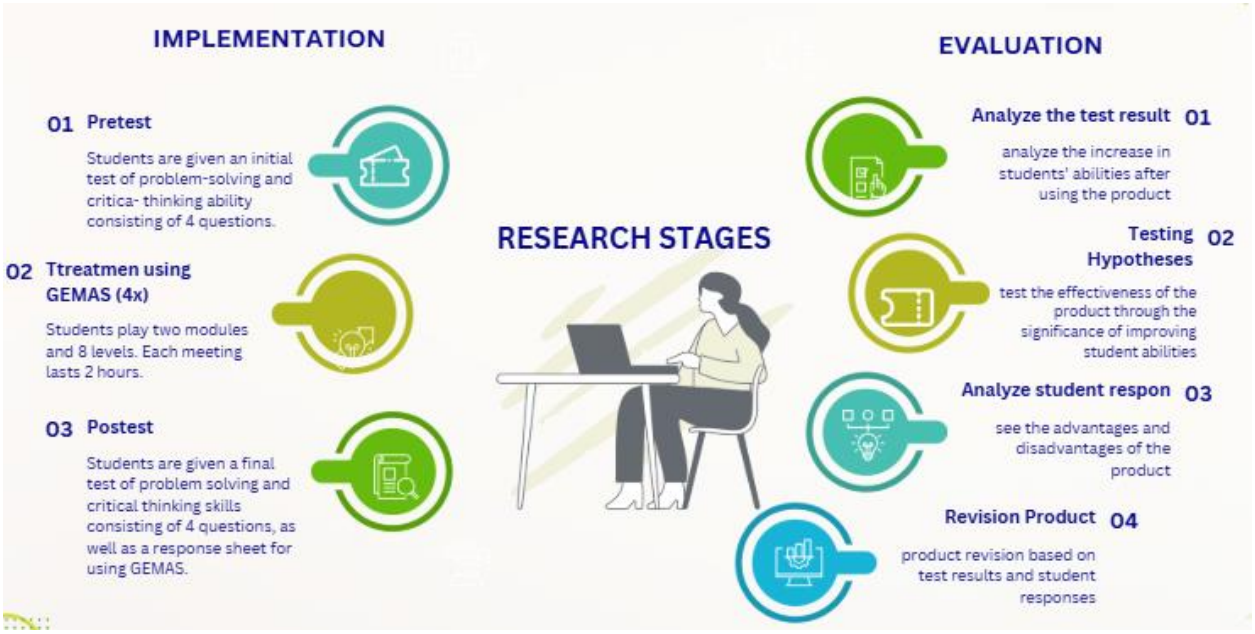


Figure 2. Research Stages

1. Implementation

The activities carried out at the implementation stage are user trials, namely junior high school students. Using a one-group pretest-posttest design, this trial involved 256 students from two schools in Sukabumi. For each school, 3-6 sample groups were selected randomly through the cluster random sampling technique; from this process, 10 selected study groups (groups) were produced. Furthermore, all study groups were given treatment for six meetings (each meeting takes 2 hours), consisting of a pretest, four meetings using the GEMAS, and a post-test and student response sheets.

2. Evaluation

The evaluation was conducted based on expert validation data to see product validity, limited trials to measure practicality test, and user trials to see the effectiveness of gamification-based teaching materials developed on junior high school students' mathematical problem-solving and critical-thinking abilities. The results of product validity and practicality test of this gamification-based teaching material have been discussed in the previous article. They show that the GEMAS game has a content validity of 4.55, a very valid category; 81% is practical for classroom learning and is effective in improving problem-solving and critical mathematical thinking skills, with a moderate category in limited-scale testing (Lukman et al., 2023). The evaluation focused on this article includes an analysis of the effectiveness of user trial activities involving 256 students in 2 junior high schools. Activities at this stage are analysing assessment results, testing hypotheses, describing, interpreting, measuring advantages and disadvantages, and making improvements to products that have been developed based on suggestions from expert validators and users.

3. Data Collection Techniques and Research Instruments

Data collection in this study was carried out using student response sheets, Krulik-Rudnick problem-solving ability test instruments, and FRISCO mathematical critical thinking ability test instruments which had met the criteria of very valid (4.55) and high reliability (0.90) (Lukman et al., 2023). The student response sheet consists of 19 student response statements regarding students' appearance, ease, suitability, and interest in using the GEMAS game. In contrast, the mathematical problem-solving and critical thinking ability test instruments consist of 4 pretest questions and four post-test questions using Krulik-Rudnik and FRISCO indicators. Data from the pretest and post-test in the trial were analyzed using a paired two-sample t-test with a significance level of 5%. In addition, the increase in learning outcomes in both abilities before and after using the game was measured through the N-gain test, the conversion of which is presented in Table 1.

Table 1. N - Gain Conversion Categories

Score Range	Category
$N - Gain \geq 0{,}70$	High
$0{,}30 \leq N - Gain < 0{,}70$	medium
$N - Gain < 0{,}30$	Low

C. RESULT AND DISCUSSION

The GEMAS Effectiveness Test results in the four schools discussed focused on three things: the effectiveness of GEMAS on problem-solving skills, critical mathematical thinking skills, and student responses to GEMAS products. The three analysis results are described below in detail.

1. Mathematical Problem-Solving Ability

The GEMAS game effectiveness test results on students' mathematical problem-solving abilities were conducted using a paired 2-sample t-test at a 5% test significance level and the N Gain test, with the following Hypothesis. H_0 is GEMAS cannot improve junior high school students' mathematical problem-solving abilities; and H_1 is GEMAS can improve junior high school students' mathematical problem-solving abilities.

The results of the hypothesis testing show that the pretest average is 14.03, the post-test average is 57.78, and the standard deviation is 20.20. The overall range between the average pretest and post-test reached 43.75. This shows an increase in the value of problem-solving ability before and after using GEMAS. However, a hypothesis test was conducted to see whether the increase was significant. The hypothesis test results showed that the calculated T value (34.61) is greater than the T table value (1.65), so H_0 is rejected, or H_1 is accepted. Thus, it can be concluded that using the GEMAS game has significantly improved junior high school students' mathematical problem-solving abilities. Furthermore, the n-gain value reaching 0.51 shows a moderate increase in students' mathematical problem-solving abilities. In addition to the overall increase, the data analysis also focused on increasing each indicator of problem-solving abilities. The results of the data analysis are presented in Figure 2.

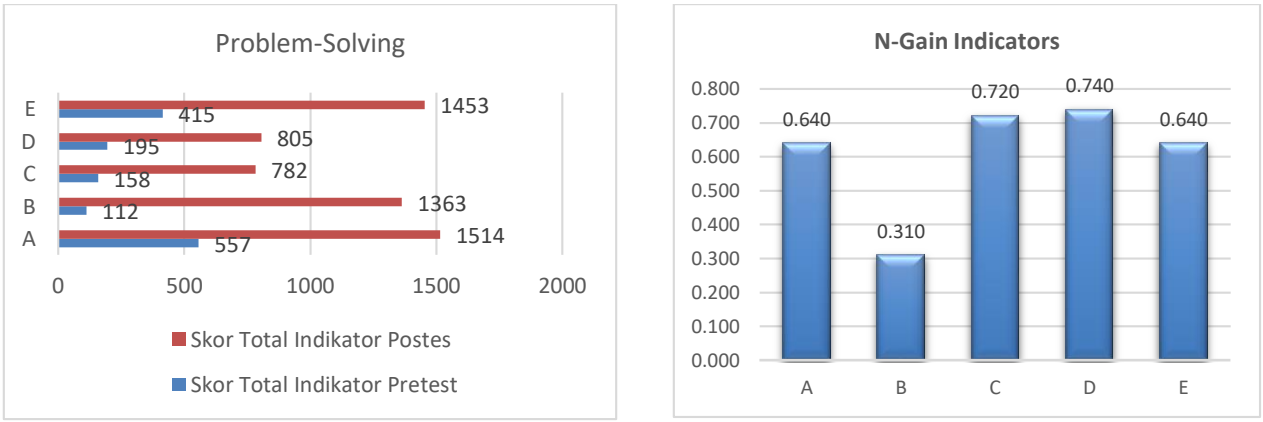


Figure 2. Pretest, post-test, and N-Gain Values for Each Problem-Solving Indicator

Indicators Description:

a. Read and think (A)
b. Explore and plan (B)
b. Select a strategy (C)
c. Find an answer (D)
d. Review and discuss (reflect and extend) (F)

Based on Figure 2, the GEMAS game can improve every indicator of problem-solving ability. This can be seen from the range between the pretest value of problem-solving ability before using GEMAS and the post-test value of problem-solving ability after using GEMAS, which is quite large. The highest increase was in the indicator of finding an answer with an n-gain value of 0.74, and the lowest increase was in the explore and *plan* indicator with a value of 0.31.

2. Mathematical Critical-Thinking Ability

The GEMAS game effectiveness test results on students' mathematical critical thinking skills were carried out using a paired 2-sample t-test at a 5% test significance level and the N Gain test, with the following Hypothesis. H_0 is GEMAS cannot improve junior high school students' critical mathematical thinking skills; and H_1 is GEMAS can improve junior high school students' critical mathematical thinking skills. The results of the hypothesis testing show that

the pretest average is 17.04, the post-test average is 64.04, and the standard deviation is 22.12. The overall range between the average pretest and post-test reached 47. This result shows increased students' mathematical critical thinking skills before and after using GEMAS. However, a hypothesis test was conducted to see whether the increase was significant. The hypothesis test results showed that the calculated T value (33.99) is greater than the T table value (1.65), so H0 is rejected, or H1 is accepted. Thus, it can be concluded that using the GEMAS game has been proven to significantly improve junior high school students' mathematical critical thinking skills. Furthermore, the n-gain value reaching 0.46 shows a moderate increase in students' mathematical critical thinking skills. In addition to the overall increase, the data analysis also focused on increasing each indicator of critical thinking skills. The results of the data analysis are presented in Figure 3.

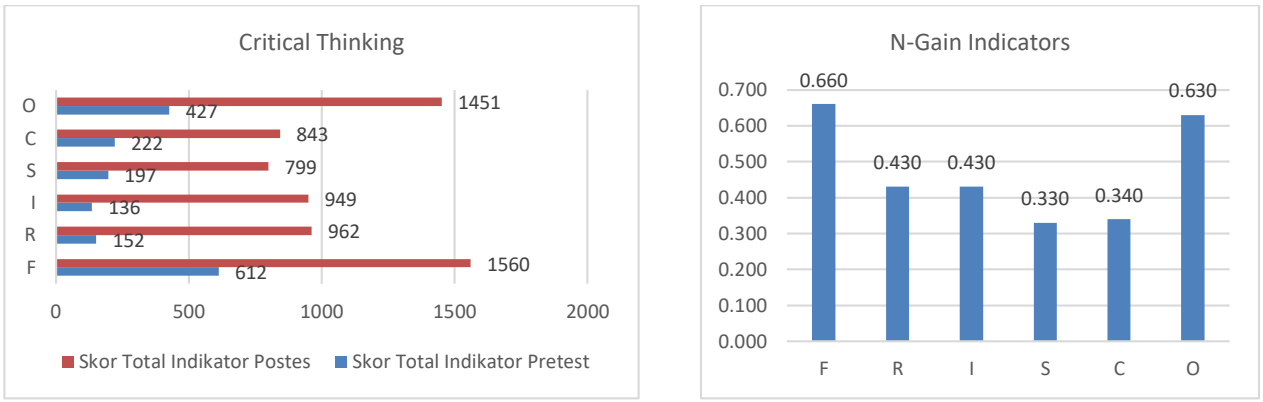


Figure 3. Pretest, Post-test, and N-Gain Values for Each Critical-Thinking Indicator

Indicator Description:

a. Focus (F): Understand the given problem.
b. Reason (R): Provide reasons based on appropriate facts/evidence at each decision or conclusion step.
c. Inference (I): Writing the correct mathematical model
d. Situation (S): Using all the correct information with the problem.
e. Clarity (C): Solve the problem with the correct procedure
f. Overview (O): Double-check the entire solution from start to finish correctly.

Based on Figure 3, the GEMAS game can improve every indicator of junior high school students' mathematical critical thinking skills. This result can be seen from the range between the pretest value of critical thinking skills before using GEMAS and the post-test value of critical thinking skills after using GEMAS, which is quite large. The highest increase is in the indicator of understanding the given problem (Focus), with an n-gain value of 0.66. The lowest increase is in the indicator of using all the correct information with the problem (Situation), with a value of 0.33.

3. Student Response

The response of all students in all schools to using GEMAS in mathematics learning is 81% in the outstanding category. This result can be seen based on the assessment of the appearance criteria and game design according to all students in the outstanding category, the speed of understanding and addition of knowledge after using GEMAS is in the outstanding category, and the increase in learning outcomes, especially in problem-solving skills and critical mathematical thinking felt by students is also in the good category. The complete results can be seen in Table 2 as follows.

Table 2. Recapitulation of Student Responses

Criteria	Item Number	Average Response Score	%	Category
Game Appearance and Design	1-8	4.13	83%	Very good
Speed of understanding and addition of knowledge	9-11	4.06	81%	Very good
Improving Learning Outcomes	12-19	3.90	78%	Good
Average (256 students)	all	4.03	81%	Very good

Based on the three results of the GEMAS effectiveness test on students' problem-solving, critical thinking, and response abilities, it can be concluded that the use of GEMAS in mathematics learning in the classroom has proven to be effective in improving junior high school students' mathematical problem-solving and critical thinking abilities with a moderate, consistent increase category. Based on the results of the effectiveness analysis, students' critical mathematical thinking skills after using the GEMAS game increased significantly with a moderate increase category. This result is in line with several research results showing that learning with a gamification approach can improve problem-solving skills (Xavier & T.C, 2024; Zheng, 2019), improve students' critical thinking skills, especially in the indicator of compiling critical questions (Ratnawati et al., 2020), and improve critical mathematical thinking dispositions, such as metacognition, persistence, and impulsivity regulation (Bunt & Gouws, 2020). In more detail, research by Heliawati et al. stated that Gamification could improve students' critical mathematical thinking skills, with the highest indicators being Reason (85.29%), Situation (83.82%), Inference (82.35%), Focus (76.47%), Overview (75.00%) and the lowest on Clarity (73.53%) (Heliawati et al., 2022).

The improvement of these two abilities is also supported by the features and mature goal setting of the game being developed. The game is developed in the form of a leveled game ranging from easy to difficult using questions that have been adjusted to the FRISCO critical thinking indicators and Krulik Rudnik problem solving. In addition, the game features use interesting illustrations with the characteristics of junior high school students and use animated videos that can be repeated so that they can improve students' understanding of the material being studied. This is in accordance with several studies that state that Another theory that is often associated with gamification is the goal-setting theory. Goals that are straightforward, specific, make sense, and not too tricky to effectively increase performance and engagement. Designing a gamification application by applying the goal-setting theory principles would require the indication of progress, some challenges, levels of achievement, a type of feedback, and some sort of competition (Kalogiannakis et al., 2021). In addition, GEMAS

is also equipped with a leaderboard feature that creates challenges for students to compete. The leaderboard can be used to compare the results of all players, serves as feedback for social competition, and can increase participant engagement. Through this leaderboard, players show their overall ranking and are updated regularly so that players can compete for a higher position. Therefore, it indirectly motivates students to improve their problem-solving and critical thinking skills. However, some research results do not agree with displaying the leaderboard. This is because the transparency triggered by the leaderboard may not always be an ideal solution, as users can easily feel weak compared to people in better positions and as a result may face higher levels of stress (Schlömmer et al., 2021).

Although it is categorized as valid, practical, and effective in improving students' mathematical problem-solving and critical thinking skills, based on expert assessments and its implementation in the field, this gamification-based teaching material (GEMAS) still needs improvement in several areas, including (1) the system does not support IOS users, so the breadth of features needs to be increased so that it can be used on Android and IOS; (2) some question image displays look small on the cellphone screen, depending on the type of user's cellphone screen, so a zoom in - zoom out menu needs to be added so that it can be used on several types of cellphones with different screen sizes; and (3) offline features also need to be available to make it easier to use when there is no internet service available.

One of the limitations of this study is that it has not measured the adverse effects or levels of addiction caused by the games developed, both from the perspective of gender and the extrovert and introvert nature of students. Although the use of games in learning shows good motivation and learning outcomes, several studies show that Gamification influences users differently based on their personality traits. The effects of Gamification depend on specific user characteristics, such as extrovert-introvert traits. Introvert students who use Gamification are more actively engaged, and their learning outcomes are better than those of extrovert students (Smiderle et al., 2020). Therefore, further research will be conducted to determine the adverse effects of developing gamification-based mathematics teaching materials.

D. CONCLUSION AND SUGGESTIONS

The results of the GEMAS effectiveness test on problem-solving abilities, mathematical critical thinking, and student responses involving 256 students in 2 schools show that the GEMAS is significantly effective in improving problem-solving abilities and mathematical critical thinking of junior high school students with a medium increase category. From the indicators of problem-solving ability, the highest increase was in the indicator of finding an answer with an n-gain value of 0.74, and the lowest increase was in the explore and *plan* indicator with a value of 0.31. From the critical-thinking indicators, the highest increase is in the indicator of understanding the given problem (Focus), with an n-gain value of 0.66. The lowest increase is in the indicator of using all the correct information with the problem (Situation), with a value of 0.33. Although there is an increase in students' problem-solving and critical mathematical thinking abilities, it is still in the moderate category, so further research is needed to determine the causal factors (both internal and external) and their solutions so that the use of this GEMAS game can improve students' critical mathematical thinking abilities in the high category.

This research is still limited between two material topics, namely one variable linear equations and systems of linear equations in two variables and only measures the mathematical problem-solving and mathematical critical thinking ability. Therefore, further research is needed to explore the improvement of these two abilities in other material topics, as well as the need to analyze internal and external factors that influence the improvement of these two abilities to be consistent and more optimal. In addition, the GEMAS developed is a two-dimensional application that has limited features, especially in generating descriptive questions or short answers, so it is necessary to update the features into three dimensions to make it more interesting and challenging to complete the mission, and it is also necessary to add features that can measure students' answers in the form of descriptions.

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