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PAPER

Gamification of Mathematics Teaching Materials: Its Validity, Practicality, and Effectiveness

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ABSTRACT

Gamification is a strategy for involving students by incorporating game elements into the learning process to improve specific abilities, involving students, optimizing learning, supporting behavior change, and socializing. This study aims to develop gamification-based mathematics teaching materials specifically designed to improve students' mathematical critical thinking and problem-solving abilities, as well as to test these products based on aspects of their validity, practicality, and effectiveness in the learning process in the classroom. The analysis, design, development, implementation, and evaluation (ADDIE) research and development model is used in this study. The sample used was 153 students from 3 junior high schools, namely Hayyatan Thoyyibah IT Middle School, Pelita YNH Middle School, and Tahfidz Qur'an Al-Fath Islamic Middle School, which were taken through the cluster random sampling technique. Data was collected through game validation sheets, FRISCO critical thinking ability test instruments, Krulik and Rudnick problem-solving ability test instruments, and student response sheets. Data were analyzed using a one-sample t-test, a two-sample paired t-test, and descriptive analysis. The results showed that gamification-based mathematics teaching materials met the valid, practical, and effective criteria for use in learning mathematics, significantly improving junior high school students' problem-solving abilities and critical mathematical thinking with moderate improvement categories.

KEYWORDS

gamification, teaching materials, validity, practicality, effectiveness

1 INTRODUCTION

The results of the TIMSS and PISA surveys on the mathematics abilities of Indonesian students for more than two decades have remained the same from the bottom seventh rank range. Both show that the ability of high school students in Indonesia in the cognitive domain of application and reasoning is still below 25% [1]. This data also reveals that the average high school student in Indonesia has yet

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to be able to use their basic abilities correctly or extract relevant information from the literature [2]. They are only able to recognize several basic facts. However, they have yet to be able to communicate, relate various topics, and apply complex and abstract mathematical concepts as a form of problem-solving and critical thinking ability [1]. This data is also supported by the results of everyday learning in class, which show that they are still not good at mathematical problem-solving abilities [3], mathematical critical thinking skills [4], reasoning and proof, oral and written communication, which are represented in writing, pictures, and mathematical expressions, as well as connections and representations of students when learning mathematics [5–7].

These facts contradict the demand that graduates must have many skills, such as problem-solving and critical thinking. That is partly caused by learning mathematics, which does not encourage students to improve problem-solving skills [8] and critical thinking [9]. Learning carried out in class is generally focused on things that are fundamental, theoretical, and yet to be applicable. This situation is, of course, not following what is suggested, that in facing global challenges, the school curriculum should be transformed to produce graduates who can think critically, are proficient in problem-solving, collaborate, and have the innovation skills needed for success in the era of globalization, such as mastering 21st century skills [10].

One implementation of learning that focuses on mastering 21st century skills is that it can be done through gamification techniques. Gamification is a learning approach where games and moving visualizations are specifically designed to teach specific skills to students so that the learning process motivates them to think and solve problems [11–15]. However, no specific research related to gamification in mathematics teaching materials simultaneously facilitates the improvement of students' mathematical critical thinking and problem-solving abilities. Therefore, this research focuses on developing gamification-based junior high school mathematics teaching materials to improve problem-solving skills and critical mathematical thinking. The quality is measured based on the validity of the content, practicality, and effectiveness of its use.

2 LITERATURE REVIEW

2.1 Mathematical problem-solving ability

Problem-solving can be interpreted as a cognitive process in achieving a goal that involves abilities and self-skills because problem-solving involves various processes, including analyzing, interpreting, reasoning, predicting, evaluating, and reflecting on information and previous knowledge that is implemented in producing alternative solutions or in new and unfamiliar situations [16] [17]. Problem-solving is crucial to applying and integrating mathematical concepts and making decisions. That is because problem-solving is applied to find solutions to unusual problems, thus encouraging a person to use their knowledge, skills, and understanding [18].

The problem-solving ability indicators used in this study are Krulik and Rudnick's five heuristic steps, which consist of: 1) reading and thinking, writing in their own language about what is known and asked, and classifying essential and unimportant information to determine methods or strategies; 2) exploring and planning, making a written plan or idea to solve the problem; 3) selecting a strategy, answering questions, or solving existing problems based on plans that

have been made before; 4) find an answer; write down the correct answer; and 5) reflect and extend, re-checking the correctness of the answers obtained and modifying them if possible [18] [19].

Several studies have found that students need help to solve mathematical problems requiring complex procedures and applications in routine and non-routine questions [20]. To hone problem-solving skills, teachers need to internalize and develop students' skills in understanding problems, solving them, and interpreting solutions [20] so that students' mindsets related to mathematics slowly change from compulsion to necessity [21].

2.2 Mathematical critical thinking ability

Critical thinking ability is a process used to make reasonable decisions to obtain the truth that is considered good. This ability involves prior knowledge, mathematical reasoning, and using cognitive strategies to generalize, prove or evaluate mathematical situations reflectively [22]. Critical thinking skills underlie higher-order thinking skills, including creative thinking, problem-solving, and decision-making, so they must be mastered first [23]. Students need the ability to think critically because this ability will help them solve story problems or problems related to everyday life. Students who develop critical thinking skills will find it easier to solve the problems given [23]. That is because a critical thinker can determine the credibility of sources, distinguish between what is relevant and what is not, distinguish fact from judgment, identify and evaluate implicit assumptions, identify existing biases, identify viewpoints, and evaluate the evidence offered to support claims [24].

The indicators of critical thinking skills used in this study, namely focus, reason, inference, situation, clarity, and overview (FRISCO), were put forward by Ennis [25] [26]. Focus is the ability to determine the focus of a given problem. The reason is knowing the reasons for or against decisions based on relevant situations and facts. Inference is the activity of drawing reasonable and justifiable conclusions. 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, and overview is checking or reexamining the steps for solving problems [27].

2.3 The relationship between critical thinking and problem-solving ability

There is a link between critical thinking and problem solving. In solving problems, students need to understand the concepts correctly to obtain the right solution. At the stage of understanding the problem, students must be able to interpret it to understand the problem given precisely. In addition, students must also have evaluation skills to evaluate the correctness of their understanding of the problem. Furthermore, critical thinking skills are also needed in compiling and determining a problem-solving plan. At this stage of the problem-solving plan, students explore all the concepts and procedures they have learned to solve problems correctly. Thus, from understanding the problem to re-examining the results obtained, critical thinking skills are needed to test the truth of these results. Learning mathematics by solving problems will train students to think critically [28].

Critical thinking involves inductive and deductive thinking skills [29]. Inductive thinking includes recognizing relationships, analyzing open-ended problems, determining cause and effect, drawing conclusions, and calculating relevant data. Meanwhile, deductive thinking skills involve solving spatial and logical problems and distinguishing facts or opinions. Critical thinking contains mental activity in terms of solving problems, analyzing assumptions, giving rationale, evaluating, conducting investigations, and making decisions. The ability to search, analyze, and evaluate information is essential in decision-making. Thus, the two opinions make it clear that there is indeed a link between critical thinking skills and problem solving.

2.4 Gamification

Gamification uses game design elements in non-game contexts to attract attention, develop characters, or solve problems [30]. Gamification is not about turning certain activities into games but redesigning those activities to be more fun and interactive [31]. Gamification can be in the form of products, ways of thinking, processes, experiences, ways of design, and systems simultaneously involved in using game elements to solve non-game problems [32] [33]. Gamification has similarities with regular games in terms of playing a game. However, the concept of gamification and games in general is quite different. Ordinary games are only limited to specifically designed entertainment, starting with the rules, time, place, elements, and gameplay. In contrast, gamification is designed to attract someone to understand the context of the material contained in the gamification [33].

Several studies have shown that using gamification in the classroom can increase learning activities and motivation and improve student learning outcomes [34–37]. Gamification has a positive and significant effect on student learning outcomes, increasing student motivation and involvement and developing independent learning and critical thinking skills [30]. These results indicate a significant difference between the outcomes of the groups that attended the gamification-based active learning setup and those that did not. These skills are the ability to work in groups, the ability to listen to the opinions of others, the ability to learn independently, the ability to apply knowledge in practice, analytical skills, and the ability to synthesize information. In this way, gamification represents an educational tool capable of satisfying the interests of a digital society [30].

Previous research on gamification only focused on using gamification to increase student motivation [38–40], foster student learning outcomes [41] [42], communication and collaboration skills [43], routine problem solving [44], participation and a learning experience [45], and improve academic performance [40]. Existing educational games usually have character selection, conflicts or problems that must be solved to level up, material content, and strategies used to complete the game according to needs [46], specifically designed for the development of problem-solving skills [47] [48]. This study also developed a similar application, but more specifically related to gamification in mathematics teaching materials, which facilitates the improvement of students' mathematical critical thinking and problem-solving abilities. The difference between this research and previous research is that the application developed is to improve critical thinking skills or problem-solving skills and enhance both further. In addition, games are designed not only to place questions

from easy to difficult, but questions also direct students to construct their understanding. There are learning videos to confirm student understanding, and questions are available for reinforcement.

3 METHOD

This study uses the analysis, design, development, implementation, and evaluation (ADDIE) research and development model [49]. The research procedure is described in Figure 1.

3.1 Analysis

In this stage, preliminary study activities include field surveys, learning observations, and literature studies. This activity aims to map the problems faced by junior high school students in learning mathematics, analyze needs, design alternative solutions, and map research variables.

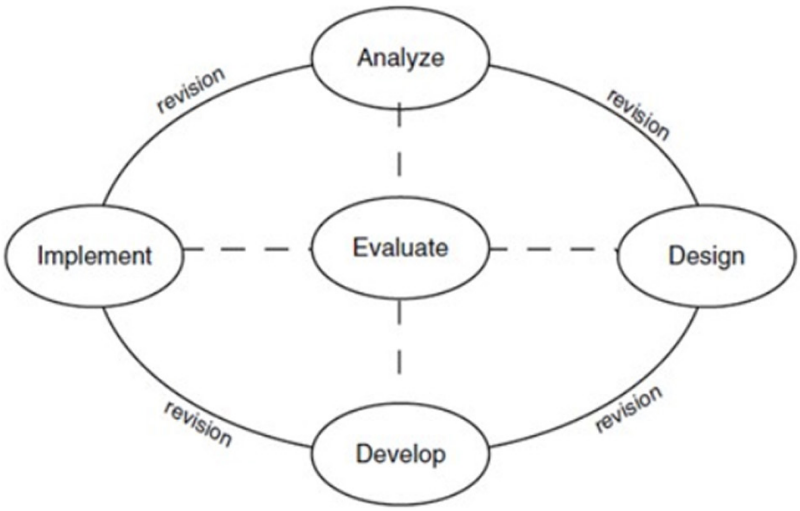

Fig. 1. Stages of the ADDIE model

3.2 Design and development

The activities carried out at this stage include: 1) reviewing the curriculum and content of junior high school mathematics learning materials; 2) designing learning scenarios in the form of level games adapted to indicators of problem-solving abilities and critical mathematical thinking; 3) making a layout or display design for teaching materials in the form of a game which can be seen in Figure 2; 4) designing learning video content that will be displayed in the game; 5) compiling and developing gamification-based teaching materials following predetermined layouts using game applications; and 6) assessing the validity of the content of five experts in Mathematics education and information and communications technology.

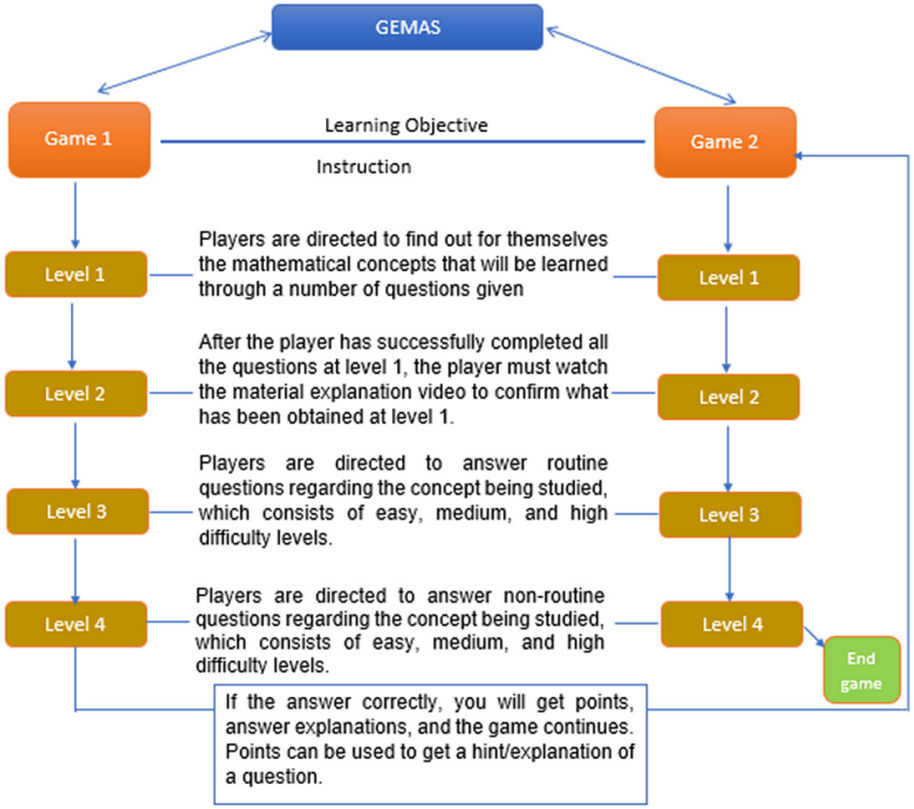

Fig. 2. Hypothetical design of gamification of mathematics teaching materials

3.3 Implementation

Activities carried out at the implementation stage are using teaching materials in class through laboratory and limited trials. The laboratory trial used a single one-shot case study design on two sample groups from SMP IT Hayyatan Thoyyibah. The two sample groups were selected through the cluster random sampling technique. The first group consists of 19 students, and the second group consists of 16 students. The two groups were then given treatment in six meetings, which consisted of giving a pre-test, four meetings using the GEMAS game, and a post-test and response sheets for using the game.

The limited trial involved 118 students from three schools: Hayyatan Thoyyibah IT Middle School, Pelita YNH Middle School, and Tahfidz Qur'an Al-Fath Islamic Middle School, using a one-group pretest-posttest design. Two sample groups were taken from each school, which were randomly selected using the cluster random sampling technique. Similar to the laboratory trial, the six groups were then given treatment in six meetings, which consisted of giving a pre-test, four meetings using the GEMAS game, and a post-test.

3.4 Evaluation

The evaluation was based on expert validation data, laboratory trials, and limited trials to see the validity, practicality, and effectiveness of the gamification-based teaching materials based on junior high school students' problem-solving abilities and critical mathematical thinking. Activities at this stage are analyzing the

assessment results, testing hypotheses, describing, interpreting, measuring strengths and weaknesses, and making product improvements that have been developed based on the suggestions of expert validators and users.

This study collected data using game content validation sheets, student response sheets, the FRISCO critical thinking ability test, and the Krulik-Rudnick problem-solving ability test. Overall validity assessments of game content and student responses were analyzed descriptively using a scale of 1–5, with categories including 1 (not good), 2 (quite good), 3 (good), 4 (very good), and 5 (excellent). To clarify the assessment, in assessing content validity, a scale of 1–5 is given a description of the criteria adapted from [50] as follows: a scale of 1 if less than 20% of the criteria are met; a scale of 2 if 21%–40% of the criteria have been met; a scale of 3 if 41%–60% of the criteria have been met; scale of 4 if 61%–80% of the criteria have been met; and a scale of 5 if 81–100% of the criteria have been met. Furthermore, the overall average rating is converted according to Table 1. The conversion of the practicality assessment derived from student responses is adapted from [51] and presented in Table 2. While the data comes from the pre-test and post-test in laboratory and limited trials, it was analyzed using a one-sample t-test and a two-sample paired t-test with a significance level of 5%. The N-gain test is used to see the effectiveness of the media through learning outcomes before and after using the game. The N-Gain score conversion is presented in Table 3.

Table 1. Conversion of validity assessment scores

Score Range	Category
$\bar{x} > 4.20$	Very Valid
$3.40 < \bar{x} \leq 4.20$	Valid
$2.60 < \bar{x} \leq 3.40$	Valid Enough
$1.80 < \bar{x} \leq 2.60$	Less Valid
$\bar{x} < 1.80$	Invalid

Table 2. Conversion of practicality assessment scores

Score Range	Percentage (%)	Category
$\bar{x} > 4.20$	84–100	Very Practical
$3.40 < \bar{x} \leq 4.20$	68–83	Practical
$2.60 < \bar{x} \leq 3.40$	52–67	Pretty Practical
$1.80 < \bar{x} \leq 2.60$	36–51	Less Practical
$\bar{x} < 1.80$	< 36	Impractical

Table 3. N-Gain conversion

Score Range	Category
$N - Gain \geq 0.70$	High
$0.30 \leq N - Gain < 0.70$	Medium
$N - Gain < 0.30$	Low

4 STATISTICAL ANALYSIS

Following the research objectives, the statistical data analysis in this study was also grouped into three discussions: testing the validity of game content, practicality testing, and testing product effectiveness. In detail, the results of each analysis are described in the following sections.

4.1 Game content validity test

The validity of the game content measured in this study includes five criteria, namely the feasibility of the content, the appropriateness of the use of language, the suitability of the items with the Krulik-Rudnick indicators, the suitability of the items with the FRISCO theory indicators, and the suitability of the game components. A team of five experts in mathematics education carried out this validity test. The results of content validity testing can be seen in Table 4.

Table 4. GEMAS game content validity analysis from the expert team

Criteria	Average Expert Team Rating	Validity Category	Percentage of Achievement of Criteria
Content Eligibility	4.60	Very valid	92% of the criteria in each indicator have been met
Appropriate Use of Language	4.33	Very Valid	86.60% of the criteria in each indicator have been fulfilled
Conformity of Items with Krulik and Rudnick Indicators	4.51	Very Valid	90.20% of the criteria in each indicator have been fulfilled
Compatibility of Items with FRISCO Theory	4.61	Very Valid	92.20% of the criteria in each indicator have been met
Game Component Compatibility	4.70	Very Valid	94% of the criteria in each indicator have been met
GEMAS Game Validity Rating Average	**4.55**	**Very Valid**	**91% of the criteria in each indicator have been fulfilled**

The validity assessment of gamification-based teaching materials obtained an overall average rating of 4.55. These results indicate that 91% of the GEMAS game content validity indicators that have been developed have been fulfilled and are classified as very valid criteria so that they are suitable for use in classroom learning.

4.2 Practicality test

The data analyzed in the practicality test are derived from laboratory trials. This data includes an analysis of students' responses and the testing of hypotheses regarding the attainment of students' problem-solving abilities and students' mathematical critical thinking. The results of the student response analysis are presented in Table 5.

Table 5. Analysis of student responses to the GEMAS game

Criteria	Item Number	Average Response Score	Percentage of Achievement of Criteria	Category
Display and game design	1–8	4.16	83% of the criteria in each indicator have been met	Practical
The speed of understanding and adding knowledge	9–11	4.13	83% of the criteria in each indicator have been fulfilled	Practical
Improved Learning Outcomes	12–19	3.83	77% of the criteria in each indicator have been met	Practical
Rating Average		4.04	81% of the criteria in each indicator have been fulfilled	Practical

Based on Table 5, 83% of students' responses in both classes to the appearance and design of the GEMAS game, as well as the speed of understanding and adding knowledge after using the GEMAS game, are classified as very good. In addition, 77% of students responded that the GEMAS game could improve their learning outcomes. Thus, the overall response of students to the use of the GEMAS game, 81%, is classified as good and fulfills the practical category used in the learning process in class.

In addition to response analysis, the practicality of the GEMAS game can also be seen based on whether there is an increase in students' critical thinking skills and mathematical problem-solving skills before and after using the GEMAS game. The results of testing the hypothesis for these two abilities are presented in Tables 6 and 7.

Table 6. Results of hypothesis testing of students' mathematical critical thinking ability

Trial Class	N	Pretest Average	Posttest Average	Standard Deviation	T Count	df	T Table	Conclusion
L1	19	26.91	44.21	16.24	4.65	18	2.552	H_1 accepted _(Students' mathematical critical thinking skills after using the GEMAS game are better than before)
L2	16	32.03	52.27	5.97	13.55	15	2.602	H_1 accepted _(Students' mathematical critical thinking skills after using the GEMAS game are better than before)

Table 7. Hypothesis testing results of students' mathematical problem-solving ability

Trials	N	Pretest Average	Posttest Average	Standard Deviation	T Count	df	T Table	Conclusion
L1	19	26.84	49.01	18.27	5.29	18	2.552	H_1 accepted _(Students' mathematical problem-solving abilities after using the GEMAS game are better than before)
L2	16	33.67	61.80	9.87	11.39	15	2.602	H_1 accepted _(Students' mathematical problem-solving abilities after using the GEMAS game are better than before)

Based on Tables 6 and 7, both male and female classes have an average value of critical thinking skills and mathematical problem-solving abilities after using the GEMAS game, which is significantly better than before.

4.3 Effectiveness test

The data analyzed in the effectiveness test are data from limited trials. This data includes an analysis of hypothesis testing regarding improving students' mathematical critical thinking and problem-solving abilities, an analysis of increasing students' mathematical critical thinking and problem-solving abilities, and student response sheets. The detailed results are presented in Tables 8–10.

Table 8. Results of the hypothesis testing of students' mathematical critical thinking ability in 3 junior high schools

Class Code	N	Pretest	Posttest	N-Gain	Category	Standard Deviation	T Count	df	T Table	Conclusion
A1	19	22.76	39.61	0.212	Low	18.872	3.890	18	1.734	H_1 accepted GEMAS games can improve students' critical thinking skills
A2	16	24.22	42.34	0.231	Low	12.298	5.895	15	1.753	H_1 accepted GEMAS games can improve students' critical thinking skills
B1	20	23.625	31.5	0.098	Low	18.905	1.863	19	1.729	H_1 accepted GEMAS games can improve students' critical thinking skills
B2	22	3.409	12.614	0.1	Low	13.960	3.093	21	1.721	H_1 accepted GEMAS games can improve students' critical thinking skills
C1	16	15.156	54.688	0.463	Medium	16.437	9.620	15	1.753	H_1 accepted GEMAS games can improve students' critical thinking skills
C2	25	19.300	82.600	0.779	High	19.628	16.125	24	1.711	H_1 accepted GEMAS games can improve students' critical thinking skills
All	118	17.733	44.725	0.326	Medium	27.083	10.826	117	1981	H_1 accepted GEMAS games can improve students' critical thinking skills

Table 8 shows that the six male and female classes have an average value of critical thinking skills that have increased significantly after using the GEMAS game. This improvement category differs in each class. Four classes have a low improvement category, one class has a medium improvement category, and one class has a significant improvement category. The overall results of the data analysis also show that using the GEMAS game can improve critical thinking skills significantly in the medium improvement category.

Table 9. Results of hypothesis testing of students' mathematical problem-solving ability in 3 SMP

Class Code	N	Pretest	Posttest	N-Gains	Category	Standard Deviation	T Count	df	T Table	Conclusion
A1	19	22.89	41.32	0.233	Low	20.399	3.936	18	1.734	H_1 accepted GEMAS games can improve students' problem-solving skills
A2	16	24.69	55.94	0.402	Medium	16.608	7.526	15	1.753	H_1 accepted GEMAS games can improve students' problem-solving skills
B1	20	23.25	31.875	0.112	Low	17.761	2.172	19	1.729	H_1 accepted GEMAS games can improve students' problem-solving skills
B2	22	3.409	14.886	0.1	Low	14.973	3.595	21	1.721	H_1 accepted GEMAS games can improve students' problem-solving skills
C1	16	15.156	55	0.466	Medium	16.316	9.768	15	1.753	H_1 accepted GEMAS games can improve students' problem-solving skills
C2	25	18.500	82.800	0.780	High	20.710	15.524	24	1.711	H_1 accepted GEMAS games can improve students' problem-solving abilities
All	118	17.585	47.415	0.361	Medium	27.243	11.895	117	1981	H_1 accepted GEMAS games can improve students' problem-solving abilities

Table 9 shows that the six classes, both male and female, have an average score of problem-solving abilities that have increased significantly after using the GEMAS game. This improvement category differs in each class. Three classes have a low improvement category, two classes have a medium improvement category, and one has a significant improvement category. The overall results of the data analysis also show that using the GEMAS game can improve critical thinking skills significantly in the medium improvement category.

Table 10. Analysis of student responses to the GEMAS game in 3 middle schools

School Code	N	Student Response Assessment			Average	Percentage of Achievement of Criteria	Category
		Appearance and Design	Understanding Speed	Learning Outcomes			
Hayyatan Thoyyibah IT Middle School (A)	35	4.16	4.13	3.83	4.04	81% of the criteria in each indicator have been fulfilled	Very good
YNH Pelita Middle School (B)	42	3.93	3.77	3.79	3.83	77% of the criteria in each indicator have been met	Good
IT Al-Fath Middle School (C)	41	4.21	4.16	4.16	4.18	83% of the criteria in each indicator have been fulfilled	Very good
Average		4.10	4.02	3.93	4.02	80% of the criteria in each indicator have been fulfilled	Good
Percentage of Achievement of Criteria		82% of the criteria in each indicator have been met	80% of the criteria in each indicator have been fulfilled	78% of the criteria in each indicator have been met	80% of the criteria in each indicator have been fulfilled		
Category		Very good	Good	Good	Good		

Based on Table 10, the overall response of students in three schools regarding the appearance and design of the GEMAS game is in the very good category. Student responses to the speed of understanding and adding knowledge after using the GEMAS game are in a good category, and student responses to improving their learning outcomes after using the GEMAS game are in a good category. Thus, the overall response of students to developing and using the GEMAS game significantly improves their problem-solving skills and critical mathematical thinking, which is 80% in the good category.

The implementation of the GEMAS game applied to 118 samples has fulfilled the criteria of effectively increasing the problem-solving abilities and critical mathematical thinking of junior high school students, with a moderate improvement category.

5 RESULTS AND DISCUSSION

5.1 Analysis

Activities at the analysis stage include field surveys and literature studies to analyze the need for developing gamification-based teaching materials on junior high school students' problem-solving abilities and critical mathematical thinking. The results obtained in this activity are adjusting the mathematics curriculum in gamification, determining the material, and mapping the indicators to be used.

5.2 Design and development

After analyzing the needs and reviewing the curriculum and content of junior high school mathematics learning materials, the following steps are: 1) designing learning scenarios in the form of level games; 2) designing a test instrument for problem-solving skills and critical mathematical thinking with low, medium and high difficulty levels; and 3) designing learning video content that will be displayed in the game. This activity produced test instruments for problem-solving abilities and critical mathematical thinking at medium, low, and high levels and seven animated learning videos.

After designing content for games, the next step is to create storyboards and develop teaching materials for GEMAS games (Junior High School Mathematics Educational Games). In summary, the results obtained are presented in Figure 3.

a) Front View | b) Module Menu | c) Levels Menu

d) Question Item Display | e) Question View | f) Games Rule Menu

Fig. 3. *(Continued)*

g) Video View h) Leaderboard i) Question Illustration

Fig. 3. The GEMAS game

5.3 Implementation and evaluation

Based on the content validity analysis results, the GEMAS game meets the very valid criteria, thus indicating that the GEMAS game is suitable for use in learning. That is because the display of teaching materials is designed in the form of a game that requires the active involvement of students. Visualizations and illustrated images can trigger student motivation for learning, direct specific skills, especially problem-solving skills and critical thinking, and adapt to the character of junior high school students. Furthermore, the results of expert content validation also showed that the characteristics of the items used in the game followed the indicators of students' problem-solving abilities and critical mathematical thinking and were declared very valid. This result is in line with [49] that suitable teaching materials must support the improvement of the quality of one's knowledge. So that experts assess that teaching materials are following the objectives of gamification, namely involving games or moving visualizations designed to teach specific skills to students so that the learning process motivates students to think and solve problems [11–14] by prioritizing enjoyment and engagement [52] [53].

In addition to being seen from the appearance, content, and gamification objectives, high validity can also be seen from the suitability of the GEMAS game components used, such as clear rules, character appearance, leveling, scores, and question items that are tailored to the development of problem-solving skills and students' mathematical critical thinking. That is in line with [54], which suggested that with designs starting from the learning side, it is possible to model the learning process to learning outcomes and then integrate game elements iteratively into instructional design. These elements include game logic, rules, characters, levels, scores, and other game patterns with learning activities and outcomes.

Based on the practicality analysis results, the GEMAS game fulfills the applicable criteria with a practicality percentage of 80%. That shows that after being used in classroom learning, the display quality and game design follow the characteristics of junior high school students. The speed of understanding and adding knowledge after using the game is quite good and has shown an increase in student learning outcomes in problem-solving abilities and critical thinking. However, even though it is classified as a practical category, this game needs to be improved, especially in writing undefined mathematical symbols, adding audio features that can be turned on and off, and the leaderboard, which still cannot save if there is the same account. Therefore, before being used in a limited trial, the game was revised first.

Based on the results of the effectiveness analysis, students' mathematical problem-solving abilities and critical thinking abilities after using the GEMAS game significantly increased in the moderate improvement category. That is in line with several research results that show that learning with a gamification approach can improve problem-solving abilities [55], improve students' critical thinking

skills, especially in indicators of compiling critical questions [56], and increase critical thinking dispositions such as metacognition, persistence, and managing impulsivity [57]. Gamification can improve students' critical thinking skills, with the highest indicators being reason (85.29%), situation (83.82%), inference (82.35%), focus (76.47%), overview (75.00%), and clarity (73.53%) [58].

Even though it is classified as a valid, practical, and effective category for improving students' mathematical critical thinking and problem-solving abilities based on expert assessments and their implementation in the field, the GEMAS game still requires improvement in several respects, including: 1) The system is not stable, and the scoring is still there and not saved automatically. The system often exits suddenly, requiring students to repeat the game from the beginning. 2) Automatic point addition occurs when repeating the same question with the correct answer; it is better not to add points if the question is done repeatedly. 3) The system does not yet support IOS users, it is best if the breadth of features is added so that they can be used on Android and IOS. 4) Game soundtracks are extended in duration or change songs, so do not get bored. 5) Some of the problem images appear small on the cellphone screen, depending on the type of user's cellphone screen, so it is necessary to add a zoom in zoom out the menu so that it can be used on various types of cellphones with different screen sizes; 6) The offline feature also needs to be available to make it easier to use when internet service is not available.

Although the use of games in learning shows positive results, several problems arise. When introducing educational games, teachers must control the classroom in a gamified teaching environment and avoid gaming addiction and learning ignorance [55]. That is because gamification affects users differently based on their personality traits. The previous research results show that gamification's effect depends on the user's specific characteristics, in this case, their extrovert-introvert nature. Introverted students who use gamification are more actively involved, and the ratings obtained are better than those of extroverted students [59]. That is the limitation of this research. It has not measured the negative effects or the level of addiction arising from the games developed, both from the perspective of gender and the extroverted and introverted characteristics of students. Therefore, it is necessary to carry out further research regarding the negative effects arising from the use of this GEMAS game.

6 CONCLUSION

Based on the results of data analysis on content validity assessment, gamification-based junior high school mathematics teaching materials in GEMAS games have a content validity of 4.55 and are classified as very valid categories. Based on the practicality analysis, the GEMAS game has a practical value of 81% and belongs to the practical category. Meanwhile, based on the results of the effectiveness analysis, it was found that the GEMAS game significantly increased problem-solving abilities and critical mathematical thinking, with moderate improvement categories. Therefore, the GEMAS game meets valid, practical, and effective criteria for use in classroom learning and significantly improves junior high school students' problem-solving and mathematical critical thinking abilities by increasing problem-solving abilities and critical thinking, which are classified as moderate categories.

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