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Enhancing Mathematical Reasoning Skills Through Board Game Media and the Adaptive Problem-Based Learning Model

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ABSTRACT

Mathematical reasoning is often underemphasized in basic education due to students' difficulties in understanding mathematics. This study aims to develop and evaluate the effectiveness of board game media integrated with the Adaptive Problem-Based Learning (APBL) model in enhancing students' mathematical reasoning skills. A mixed-methods approach was employed using a sequential exploratory design, beginning with qualitative research followed by a quantitative phase. The study was conducted at SD Kristen Satya Wacana (UKSW Laboratory) Salatiga. The developed board game, APBL model, and instructional materials underwent expert validation, yielding very high feasibility ratings of 84%, 95%, and 90%, respectively. The board game was then tested with 30 students, and data were collected through pretests, posttests, and practicality assessments. The implementation results showed a significant improvement in students' mathematical reasoning skills. The average pretest score of 62 increased to 84 in the posttest, reflecting a 35.48% achievement gain. Additionally, teacher and student responses in the practicality test yielded a 92% practicality score, categorized as very high. The findings indicate that integrating board game media with the APBL model effectively enhances mathematical reasoning. The model provides an engaging and structured learning experience that supports higher-order thinking skills while maintaining a practical and enjoyable classroom environment. The study concludes that board game media with the APBL model is highly effective and practical for improving mathematical reasoning. It is recommended for broader application across different education levels and learning contexts to enhance mathematics instruction.

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1. INTRODUCTION

The Programme for International Student Assessment (PISA), administered by the Organisation for Economic Co-operation and Development (OECD), serves as a benchmark for evaluating students' ability to apply knowledge in real-world contexts. According to Mathias Cormann, Secretary-General of the OECD, PISA aims to identify the strengths of education systems that remain resilient even in times of crisis, such as a global pandemic. The assessment measures students' mathematical, scientific, and reading literacy, reflecting their ability to think critically, interpret information, and solve problems. However, Indonesia's performance in PISA 2022 remains concerning, ranking 68th with an average mathematics score of 379, science score of 398, and reading score of 371. Specifically, Indonesia ranked 73rd out of 79 participating countries, indicating that Indonesian students' competency levels remain in the lower category. A closer look at mathematical literacy reveals that Indonesian students predominantly perform at Level 2 on the six-level mathematical literacy scale, signifying basic proficiency with limited ability to solve complex problems.

Research suggests that low mathematics achievement is closely linked to weak reasoning skills (Resnick, Newcombe, & Goldwater, 2023). Reasoning ability is fundamental to understanding, analyzing, and evaluating mathematical concepts critically and logically (Hwang et al., 2020). Mathematics, as a discipline, involves well-defined objects and structured reasoning processes that allow students to analyze, transform, and derive logical conclusions (Agustyaningrum et al., 2019). Mathematical reasoning connects multiple facts and concepts, leading to valid conclusions (Jeannotte & Kieran, 2017). Thus, strengthening students' reasoning abilities is essential for improving problem-solving skills, as students with strong reasoning skills can better analyze problems and determine appropriate solutions (Ayal et al., 2016). Given that reasoning forms the foundation of mathematical thinking, it is critical to cultivate this skill from an early age, particularly in primary education.

In early education, learning is primarily play-based, interactive, and experiential, with a strong emphasis on concrete, hands-on activities (Mutia, 2021). Consequently, mathematics instruction at this stage requires tangible learning aids to ensure effective and meaningful learning experiences (Hamidi et al., 2024). One promising approach to address this need is the integration of board game media into mathematics learning. Mathematics board games provide a contextual, culturally relevant learning experience, making mathematical concepts more accessible and engaging for young learners. Furthermore, board games serve as a practical tool for reinforcing fundamental mathematical skills while promoting mathematical reasoning (Fathurrohman et al., 2022; O'Neill & Holmes, 2022). By incorporating Adaptive Problem-Based Learning (APBL) with board game media, students can actively engage in problem-solving activities that strengthen their reasoning abilities and foster higher-order thinking skills in an enjoyable and interactive manner.

The process of stimulating mathematical reasoning skills through board games needs a series of lessons that support the achievement of good mathematical reasoning. Therefore, a learning model is needed that is able to see the characteristics of students in order to create a learning process that originates from students. The concept adopts the concept of differentiated learning which is a learning approach that pays attention to individual student differences in accessing, understanding, and responding to learning materials (Thapliyal et al., 2022). In theory, differentiated learning is based on ecology, multiple intelligences, zone of proximal development (ZPD), and learning modalities. Through this basis, it can be seen that the learning process of each individual is influenced by various aspects, so it is irrelevant to look at the learning process classically without paying attention to the uniqueness of each individual in it.

Board games can be used in a learning model that conditions students to solve problems called problem-based learning model. Providing different problems based on students' abilities and providing material coverage based on students' ability levels and learning styles will optimize the development of students' mathematical reasoning skills. The learning model that uses the principle of differentiated learning is called the adaptive problem-based learning (APBL) model. Differentiated learning is a learning process that looks at the needs and uniqueness of each learner. The adaptive problem-based learning model produces an interrelated unity from the aspects of student learning needs and the learning process

applied. The uniqueness of learners is seen from the psychological aspect, namely the learning style of students. Therefore, the model is unique in providing a learning process that is relevant to each individual. The adaptive problem-based learning model integrated with local wisdom-based board games can optimize students' mathematical reasoning skills. Mathematical literacy, media literacy, logical thinking, critical thinking, creative thinking, board games, innovative learning models, and learning media development have been the focus of various previous studies related to mathematical reasoning based on higher order thinking skills (HOTS). Research by Kusuma et al. (2021) "Mathematic Creative Thinking Ability Based on Student Metacognition in Blended Learning Model with E-Module", highlighted the relationship between student metacognition and mathematical creative thinking ability in a blended learning model. Meanwhile, research by Darmastuti et al. (2020) "Board Game 'Narimo Ing Pandum' as Media Literacy for Consumptive Behavior of Adolescents in Central Java and Yogyakarta", discussed the potential of board games as an effective media literacy tool in shaping wise consumptive behavior in adolescents.

The novelty to be achieved in this research is to produce board game media applied in learning using the adaptive problem-based learning model to improve students' mathematical reasoning skills. Board games are part of tabletop games, which are games played on the table. Board games must be able to simulate real events so that people have a better understanding of learning through board games. Board games combine playing, learning, and communicating activities. Supporting research from this study has been explored by researchers in recent years with the scope of media literacy, mathematical literacy, PBL model, board game, and mathematical reasoning ability. Mathematical reasoning ability is related to problem solving, and the problems referred to are HOTS-level problems. Therefore, high-level thinking skills such as logical thinking, creative thinking, critical thinking, and problem solving can be instilled in basic education. The gap in this research is to develop reasoning skills by collaborating board game-based learning media with the APBL model, which familiarizes students through integrated learning activities.

This study aims to improve students' mathematical reasoning with an adaptive problem-based learning model integrated with board games. This research uses a mixed method approach with a sequential exploratory model, which begins with qualitative analysis as the initial and dominant stage in the research design. This approach is designed to describe students' mathematical reasoning skills in basic education, including the obstacles and characteristics faced. The analysis became the basis for designing educational board game media for adaptive problem-based learning. Furthermore, this research involves quantitative analysis to evaluate the effectiveness of board game media in adaptive problem-based learning model to improve mathematical reasoning. This research aims to design comprehensive learning by placing each individual as a unique learning subject, so that the learning process can meet their specific needs. This approach changes the paradigm from classical learning to individual learning through differentiated learning, which is expected to create an effective and understandable learning process. The objectives of this research include analyzing and mapping learning materials in basic education as well as the local wisdom of the Salatiga community and its surroundings that are relevant to mathematical concepts. In addition, this research aims to develop board game media using the adaptive problem-based learning model and test the validity, effectiveness and practicality of board game media in optimizing students' mathematical reasoning.

2. METHODS

This research uses a mixed method with a sequential exploratory model (Sugiyono, 2016), which begins with qualitative analysis to identify the characteristics, constraints, and mathematical reasoning abilities of students. The research subjects were students at Satya Wacana Christian Elementary School (UKSW Laboratory) Salatiga Grade 4 with similar mathematical skills. The results of this analysis became the basis for designing board game media using the adaptive problem-based learning (APBL) model to improve mathematical reasoning skills. In the next stage, quantitative analysis was conducted to evaluate

the effectiveness and practicality of the board game media in the APBL learning model developed. The scheme of this research is depicted in the following chart

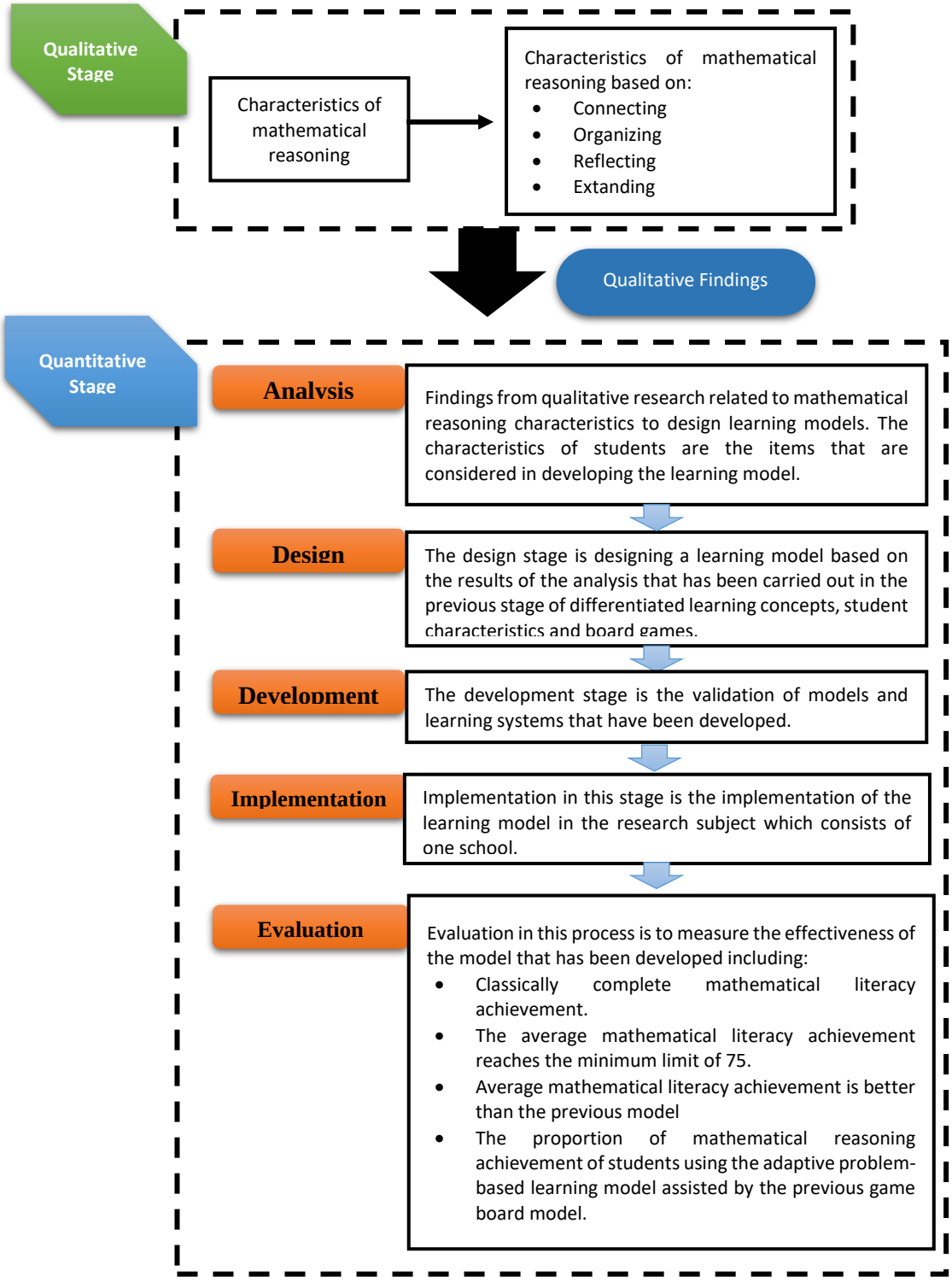

Figure 1. Stages of Exploratory Sequential Mixed Method Research

The quantitative flow in the research uses the ADDIE development steps described in the process of analysis, design, development, implementation, and evaluation. The qualitative stage aims to obtain findings, and then solutions are given using quantitative steps. The data collection instruments used in

the qualitative analysis stage are a questionnaire sheet on the perception of the learning process and the results of classroom observations and interviews. The data collection instruments used in the quantitative analysis stage were the validity test assessment rubric and the rubric of the initial measurement and the final measurement in the form of pretests and posttests used to measure the level of optimization of mathematical reasoning with the adaptive problem-based learning model using board games. The instrument for measuring reasoning ability is measured using a test, with the standard that students meet the criteria for completeness if they have a minimum score of 75. The data analysis technique uses categorical descriptive analysis techniques and percentages. The category range consists of 5 categories, namely Very High (VH), High (H), Fair (F), Low (L) and Very Low (VL).

3. FINDINGS AND DISCUSSION

3.1. Qualitative Analysis

Efforts to optimize mathematical reasoning skills basically rest on the initial analysis, namely the characteristics of mathematical reasoning in basic education, so that theoretical findings are obtained, which can then be mapped into a mathematical reasoning framework in basic education. The results of the qualitative analysis show that the stigma of mathematics that develops is that mathematics is difficult to understand, has many difficult problems, and has many formulas that must be memorized. As a result, the formation of mathematical reasoning skills has not been prioritized. The mathematical reasoning ability of students at the basic education stage has some distinctive characteristics. Students are generally able to recognize simple patterns and understand basic relationships between numbers or shapes. However, these abilities still depend on visual representations or concrete objects, which help them understand abstract concepts. The main concept found is the limitation of students in explaining their thinking or reasoning process verbally, even though they can find the correct answer. Another factor affecting reasoning ability is the reliance on teacher guidance and context relevant to daily life.

The findings indicate the importance of contextualized and experiential learning to overcome obstacles and support the development of students' mathematical reasoning ability. Mathematical reasoning in grade 4 students is still not optimally formed, and the majority are still in the memorization stage, not optimizing reasoning skills. In accordance with Piaget's theory of cognitive development, it shows that children at the age of 7-10 are still in the concrete operational stage of development, which requires learning tools that students can see, hold, and practice directly. Research Febriyanti et al., (2018) dan Holm & Kajander (2020) conveyed that in optimizing mathematical reasoning of children aged 7-10 years requires learning media that can be used directly by children to elaborate understanding gradually from concrete to abstract levels.

The results of the initial analysis on students at SD Kristen Satya Wacana (UKSW Laboratory) Salatiga found to be the basis for designing board game media with adaptive problem-based learning model. The APBL model is a more comprehensive learning model and is able to facilitate individual differences in accessing, understanding and responding to material, which implies an increase in students' mathematical reasoning skills. The APBL model collaborates with board games with the aim of accommodating learning in basic education, namely playing and learning.

3.2. Quantitative Analysis

3.2.1 Analysis

The analysis stage in this research begins with identifying the learning needs and constraints experienced by elementary school students, especially in developing mathematical reasoning skills. The characteristics of students at the basic education stage show that they tend to learn through concrete experiences, have high curiosity, and more easily understand abstract concepts with visual

aids or manipulative objects. However, initial analysis revealed that mathematics learning is often less relevant to these characteristics.

Observations show that there is a stigma that mathematics is a difficult subject, many complicated problems, and full of formulas that must be memorized. This creates a big challenge in the formation of students' mathematical reasoning skills. In addition, learning interactions in the classroom are still dominated by the lecture method, which is not contextualized, so students are less motivated to learn and understand the material in depth. Therefore, the characteristics of students who depend on concrete learning and teacher guidance are the main concerns in designing board game media using an innovative learning model, namely the adaptive problem-based learning (APBL) model.

3.2.2 Design

The design stage in this research focuses on designing board game media and adaptive problem-based learning (APBL) models based on the results of analyzing the characteristics of students in the learning concept of differentiation. The learning media design integrates interactive and fun game elements. This approach aims to attract students' interest and create a more enjoyable and effective learning experience. The board gameconcept developed is inspired by popular games, then modified to accommodate mathematical learning needs. The following is the appearance of the board game media.

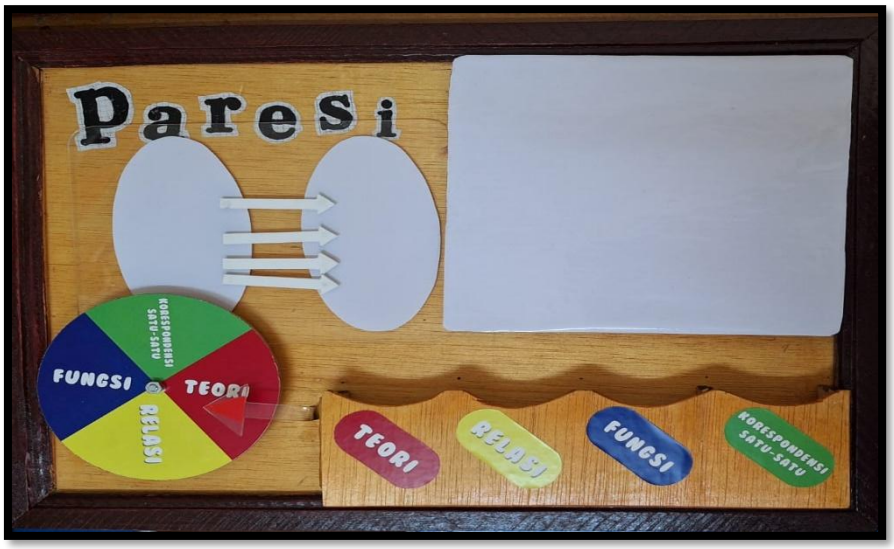

Figure 2. Board Game Display

The board game design is designed to resemble an educational adventure in the form of a game board with an attractive visual design to motivate students in learning, where students must solve mathematical challenges at each step of the game. The challenges include activities such as recognizing patterns, understanding relationships between numbers, and solving mathematical problems. The interactive board game is designed as the main media in learning to improve the mathematical reasoning ability of elementary school students through the application of the adaptive problem-based learning (APBL) model. The syntax of the adaptive problem-based learning (APBL) model can be seen in Table 1 below.

Table 1. Syntax of Adaptive Problem-Based Learning (APBL) Model

Syntax	Activities	Objective	Output
Orientation and Problem Identification	1. The teacher gives an introduction to the learning topic. 2. The teacher presents a complex, authentic (real-world context) problem. 3. The teacher helps students understand the problem and map information needs (problem analysis). 4. Small group discussion is initiated for further problem identification.	Motivate students and orient them to the main relevant issues.	1. Students understand the main problem. 2. Students are able to identify what is known and what needs to be known (prior knowledge & knowledge gaps)
Adjustment (Adaptation) of Learning Strategy	1. The teacher facilitates students in choosing a learning strategy (individual/group). 2. Students choose appropriate learning methods, for example, group discussions, reading reference sources and simple experiments. 3. Teachers provide*adaptive scaffolding* according to students' needs by providing additional instructions for students who need help and providing additional challenges for students who already understand the concepts.	Customize learning strategies according to students' needs and learning styles.	Plan learning strategies that suit individual/group needs.
Inquiry and Exploration	1. Students search and analyze information from various sources (books, internet, experiments, interviews). 2. The teacher provides feedback and assistance if needed. 3. Students collaborate to share findings with the group. 4. Students try to solve the problem by using the information obtained.	Students conduct independent investigations to find problem solutions.	The results of student exploration are new concepts, data, or understanding related to the problem.

Solution Development	1. Students discuss and develop the best solution based on the results of the investigation. 2. Teacher guides students to organize the presentation of their solutions in various forms of: written reports, oral presentations, prototypes or products. 3. Students evaluate their own solutions with the help of a teacher-provided rubric.	Encourage students to come up with innovative and applicable solutions to problems.	The solution has been developed, tested, and is ready to be presented.
Reflection and Evaluation	1. Students reflect individually or in groups on the process and results of learning regarding what has been learned and what remains a difficulty. 2. The teacher provides formative and summative evaluations of the process and student-generated solutions. 3. Joint discussion to formulate improvements or next learning steps.	Evaluate the learning process and the results achieved.	1. Deep understanding of the learning process. 2. Improved critical thinking, collaboration and problem-solving skills.

3.2.3 Development

The next stage is the development of board game media and learning models that have been designed through a validation process to ensure product quality and feasibility. Validation is carried out by experts, namely learning model experts, media experts, and material experts, to assess aspects of accuracy, suitability, and ease of implementation. The validation results are in Table 1 below:

Table 1. Validation Test Results

Validation Test	Score Obtained	Percentage	Category
Learning Model	42	84%	Very High
Media	38	95%	Very High
Material	45	90%	Very High

Based on Table 1, it is known that the model validation test results obtained a score of 42 with a percentage of 84%, the media validation test results obtained a score of 38 with a percentage of 95% and the material validation test results obtained a score with a percentage of 90%. This shows that the board game learning media with the adaptive problem-based learning model has a very high category, so it is declared very valid. The components used in the study have met the eligibility criteria set.

3.2.4 Implementation

The implementation stage is the application of board game media using the adaptive problem-based learning model in the learning process to 30 students at SD Kristen Satya Wacana (UKSW Laboratory) Salatiga. The board game media is used by the teacher as an additional training tool after delivering the

material. Students practiced both in groups and independently using the board game that had been provided. The observation results show that students are very enthusiastic and challenged to complete each level of the game presented in the learning media. Each challenge in the board game is designed to hone mathematical reasoning skills, by presenting structured problems ranging from simple patterns to higher levels of complexity. At this stage, after testing the product, then testing the students' mathematical literacy achievement from the learning outcomes after using the board game media. To assess the practicality of the board game media in improving mathematical reasoning, teachers and students fill out a practicality questionnaire to assess the extent to which this media is effective and practical to use in learning. The challenge in implementing the APBL model and board game learning media is the need for careful monitoring by teachers in each group of students who learn to use the media. The goal is that the learning flow of the APBL model can run according to plan and achieve according to the target to be aimed at in learning.

3.2.5 Evaluation

The evaluation stage in this process aims to measure the effectiveness of the model that has been prepared, including classically complete mathematical literacy achievement and the average mathematical literacy achievement reaching the minimum limit of 75. The measurement of student learning outcomes in optimizing mathematical reasoning can be seen in Table 2 below:

Table 2. Pretest and Posttest Results

	Average Mathematical Literacy Achievement	Description	Percentage
Pretest	62	Below are the Minimum Completion Criteria	35.48%
Posttest	84	Above the Minimum Completion Criteria	

Based on Table 2, the average achievement of mathematical literacy in the pretest was 62, not meeting the minimum limit 75, while in the posttest it increased to 84, exceeding the minimum limit 75. The percentage increase in learning achievement results is 35.48%. This shows that board game media with adaptive problem-based learning model is effective in improving mathematical reasoning. Meanwhile, the practicality aspect of board game media with an adaptive problem-based learning model was assessed based on teachers' and students' responses to the implementation of learning. Based on the results of the practicality test, a practicality percentage of 92% was obtained, which was classified in the very high category. This percentage reflects that this board game learning media is easy to implement in the classroom, in accordance with student needs, and is able to create an interesting and interactive learning atmosphere. Thus, besides being effective in improving mathematical reasoning ability, this board game media also has a high level of practicality, so it has the potential to be implemented more widely in various learning contexts at the basic education level.

Discussion

This research is a follow-up of several previous studies that are correlated with each other, namely mathematical literacy, higher-order thinking skills, critical thinking, creative thinking, media literacy, innovative learning media development, and board games. Reasoning ability is the ability to use logical logic, critically to understand, analyze, and evaluate information and situations whereas the ability to reason mathematically is characterized by the ability to interpret (thinking process) which functions in forming a conclusion or statement that is true and then known as a fact/reality (Hwang, 2019). Mathematical reasoning plays a central role in solving mathematical problems and their applications

in everyday life so that the better students' ability to reason, the easier it will be for students to solve problems (Jeannotte & Kieran, 2017). Mathematical reasoning skills can be developed through media literacy and mathematical literacy wrapped in mathematical reasoning skills and broken down into three processes namely formulate, employ and interpret. The three concepts have basically been studied by the research team and the results obtained that literacy skills must basically be based on appropriate reasoning skills first (Kusuma et al., 2022). Media literacy and mathematical literacy realized in contextual problem solving are very useful for developing problem solving skills and mathematical reasoning skills. Contextual problems can also develop logical thinking, critical thinking and creative thinking skills.

The discussion of the findings in this study focuses on optimizing the mathematical reasoning ability of basic education students through the application of the adaptive problem-based learning (APBL) model collaborated with local wisdom-based board games. Qualitative analysis revealed that the characteristics of students' mathematical reasoning ability at the basic education stage tend to rely on a visual or concrete object approach, with a high dependence on teacher guidance and learning contexts relevant to everyday life. Based on these findings, board game media with an adaptive problem-based learning model is designed to provide contextualized learning experience, actively involve students, and utilize board game media as a means to increase mathematical engagement and understanding.

The validation results of the learning model, media, and materials show a "very high" category, with percentage scores of 84%, 95%, and 90% respectively. This data indicates that the learning components have met the eligibility standards for implementation. At the implementation stage, the quantitative results showed a significant increase in students' mathematical reasoning ability, where the average pretest score of 62 (has not met the minimum completeness criteria) increased to 84 (exceeded the minimum completeness criteria) after learning, with a percentage increase of 35.48%. This finding shows that board game media with adaptive problem-based learning model is effective in supporting the development of students' mathematical reasoning ability. This finding is in line with the research of Anggraeni et al. (2023) which confirmed the superiority of problem-based learning in improving analytical skills. In addition, the results of the practicality test obtained from teacher and student responses obtained a percentage of the practicality of 92%, which is classified in the very high category. These results are consistent with studies showing that the integration of educational game media can increase student motivation and engagement in the learning process.

The implication of this finding is that board game media with adaptive problem-based learning (APBL) learning model not only improves students' mathematical reasoning ability but can also reduce the negative stigma towards mathematics. By providing a fun and relevant learning experience, students are more motivated to understand mathematical concepts deeply (Lin & Cheng, 2022). The challenge in the implementation of the APBL model and board game learning media is to ensure that student learning activities are in accordance with the learning flow in the APBL learning syntax. Boardgame learning media provides a different learning atmosphere with game collaboration and integrated learning, but it needs careful observation by the teacher so that the series of learning activities towards the learning objectives, namely mathematical reasoning. The achievement of mathematical reasoning ability centres on the achievement of learning syntax that is carried out optimally by utilizing board game media. So that the APBL learning model and board game media is a unity of learning activities that are integrated and cannot be separated in improving students' mathematical reasoning skills. In addition, this approach can be an alternative to learning mathematics in basic education that accommodates individual student learning needs.

4. CONCLUSION

Based on the results of research and discussion, it can be concluded that the board game media with adaptive problem-based learning model is valid, effective and practical in optimizing

mathematical reasoning in elementary school students. The results of the learning model expert validation test obtained a percentage score of 84% with a very high category, the results of the media expert validation test obtained a percentage score of 95% with a very high category, the results of the learning material validation test with a percentage score of 90% with a very high category. The effectiveness of board game media with adaptive problem based learning (APBL) model in improving mathematical reasoning is reflected in the significant increase in students' mathematical literacy achievement, with a percentage increase in pretest to posttest results of 35.48%. Based on the results of teacher and student responses, it is stated that this model is very practical to use with a percentage score of 92%. It can be concluded that by integrating a problem-based learning approach and educational game media based on local wisdom, this board game media is able to overcome the obstacles of learning mathematics at the basic education level, while increasing student motivation and involvement in the learning process. Suggestions in future research are that the APBL learning model can be implemented at other levels of education with adjustments to learning activities. Then, for learning media, it is necessary to adjust to the characteristics of students and also the learning material presented, so that it is appropriate and optimal to improve mathematical reasoning.

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