

Development of numeracy-oriented questions based on digital simulation

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Abstract: This research aims to: (1) Develop numeracy-oriented mathematics questions based on digital simulation for junior high school students in mathematics learning; and (2) Measure the validity, reliability, and quality of the developed questions. The method used in this study is the 4D development model (Define, Design, Develop, Disseminate), which includes several stages: defining the problem, designing the questions, developing the questions, and disseminating the tested product. The content of the questions includes probability, data analysis, and algebra. The results of this study show that: (1) The developed questions meet the criteria for high content validity based on expert assessments; (2) The construct validity of the questions is good, with a significant correlation coefficient between the questions measuring numeracy skills in the same domain; (3) The reliability of the questions, measured using Cronbach's Alpha, resulted in 0.907, indicating that the questions are highly reliable; (4) The developed questions have varying levels of difficulty, but most fall within the medium category, with excellent discriminative power, effectively distinguishing students' abilities at different levels of competence.

Keywords:

Digital Simulation, Mathematics Questions, Numeracy skills, Questions quality

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1. Introduction

Mathematics is a crucial skill that plays a vital role across diverse areas, such as science, engineering, business, and the arts. It supports problem-solving, pattern identification, and the enhancement of logical and critical thinking abilities, all of which are key to learning and innovation. As emphasized in the Indonesian Ministry of Education and Culture's Regulation No. 21 of 2016, mathematics education aims to develop students' reasoning, creativity, and critical thinking (Kemdikbud, 2016).

However, many students struggle with mathematics, perceiving it as a difficult and abstract subject. This negative perception often leads to stress, low motivation, and poor academic performance, particularly in mathematics (Luttenberger et al., 2018; Mutodi & Ngirande, 2014; Wahyuni et al., 2024). One of the key reasons for this struggle is the traditional approach to teaching, which fails to promote critical thinking and problem-solving. Students are typically presented with routine, standardized questions that do not challenge

their analytical abilities, limiting their opportunities to engage in meaningful mathematical thinking (Anderha et al., 2021; Maulana et al., 2020).

Furthermore, there is a lack of numeracy-oriented questions that focus on applying mathematical concepts to real-life situations. This gap is compounded by the fact that many teachers do not develop or provide a variety of questions that can effectively enhance numeracy skills. As a result, students often fail to see the relevance of mathematics in their daily lives, which diminishes their interest and engagement with the subject (Asnawi et al., 2022; Damayanti et al., 2023; Fendrik et al., 2023; Suryawan et al., 2023).

Numeracy—the ability to apply mathematical reasoning in real-world contexts—is crucial for problem-solving and decision-making. However, Indonesia's performance in international assessments, such as PISA (Programme for International Student Assessment), reveals a significant deficiency in students' numeracy skills. According to PISA 2022, Indonesia ranked 72nd out of 78 countries in terms of mathematical literacy, with an average score of 366 points, far below the OECD average of 472 points (OECD, 2023). Moreover, only 18% of Indonesian students achieved at least Level 2 proficiency in mathematics, compared to the OECD average of 69% (OECD, 2023). This stark gap highlights the urgent need to address numeracy deficiencies and to develop numeracy-oriented tasks that challenge students to apply their mathematical knowledge in realistic contexts.

Digital simulations have emerged as a promising tool for addressing this issue. These simulations provide students with an interactive learning environment, allowing them to explore real-world problems and apply mathematical concepts in a practical, engaging manner. By incorporating digital simulations into mathematics education, students are encouraged to actively participate in learning, which can help improve their numeracy skills and overall mathematical proficiency (Fauzan et al., 2024; Mohamad et al., 2024; Suripah et al., 2024).

This research focuses on developing numeracy-oriented questions based on digital simulations for junior high school students. By aligning mathematical concepts with real-life contexts through digital simulation, this approach aims to enhance students' numeracy skills, making mathematics more relevant and accessible to them.

2. Methods

This study utilized the Research and Development (R&D) methodology, specifically the 4D model developed by (Thiagarajan, 1976). This model is structured and systematic, making it ideal for developing numeracy-oriented mathematics problems based on digital simulation. The model involves defining the problem, designing the problem, developing and disseminating the final product after testing its quality.

2.1 Participants

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2.2 Procedure

The development model employed in this study is 4D.

1. Define

In this phase, the fundamental needs for product development are identified and detailed.

The process includes:

- a. Front-end analysis to diagnose underlying issues in developing digital simulation-based questions.
- b. Learner analysis to observe the characteristics, abilities, and experiences of the participants.
- c. Task analysis to identify key tasks students must master.
- d. Concept analysis to determine the subject matter for the digital simulation-based questions.

2. Design

After defining the needs, the design phase focuses on formulating the design of the numeracy-oriented questions based on digital simulation to enhance students' mathematical skills. This includes:

- a. Media selection to choose appropriate learning materials.
- b. Format selection for the presentation of the questions.
- c. Initial design is where the questions are drafted and reviewed by experts.

3. Develop

This phase involves two main activities: expert appraisal and developmental testing. Expert appraisal is conducted to validate the product's design and ensure its relevance, with feedback incorporated for revisions. Developmental testing follows, where the product is tested with real users, their responses are collected, and the product's quality is evaluated based on this feedback.

4. Disseminate

The final stage involves dissemination and adoption to ensure the product reaches the target users and is effectively utilized. This phase focuses on spreading the product to the intended audience and ensuring its adoption and practical use in the educational setting.

2.3 Data Analysis Method

Content validity in this study was assessed to ensure that the items in the instrument adequately represent the components of the domain being measured (Amin et al., 2018; Retnawati, 2016). Four experts in mathematics education and numeracy evaluated the questions using a four-point scale: (4) very appropriate, (3) appropriate, (2) inappropriate, and (1) very inappropriate. The results of the expert evaluations were analyzed using Aiken's index, which indicates high validity if the score exceeds 0.8, moderate validity if the score falls between 0.4 and 0.8, and low validity if it is below 0.4 (Putri et al., 2025; Retnawati, 2016).

For construct validity, Spearman's Rank Correlation Coefficient was employed to measure the strength and direction of the relationship between two variables that are not linearly related (Al-jabery, K., Obafemi-Ajayi, T., Olbricht, G., & Wunsch II, 2020). Furthermore, the Multitrait-Multimethod Matrix (MTMM) was used to evaluate the consistency of the measurement across different traits and methods. This method ensures that the questions accurately measure the intended construct and helps identify any potential biases in the measurement tools (Futri, 2020).

Reliability was assessed using Cronbach's Alpha, which measures the internal consistency of the questions. A score above 0.7 indicates that the questions are reliable and consistently produce dependable results (Futri, 2020). This is critical to ensure that the product yields consistent and repeatable outcomes during testing.

Item characteristics were analyzed using classical test theory through SPSS, focusing on difficulty levels and item discrimination. The difficulty level of each question was analyzed on a scale from 0.00 to 1.00, with a good question falling between 0.3 and 0.7 (Rafi et al., 2023). Item discrimination, which measures the ability of a question to distinguish between high and low-achieving students, was also analyzed. A positive discrimination value above 0.2 indicates that the question effectively differentiates between different student performance levels, while values below 0.2 suggest the question is ineffective in this regard.

3. Results and Discussion

This study aims to develop numeracy-oriented questions based on digital simulation, with a focus on evaluating their validity, reliability, and item characteristics, including difficulty level and item discrimination.

3.1 Participants

Front-end analysis highlights that students' numeracy levels are low due to a lack of appropriate questions, and digital simulations are proposed as an effective solution. Learner analysis focuses on eighth-grade students who have studied basic concepts in probability, data analysis, and algebra and have access to smartphones, although teachers still use traditional methods. Task analysis aims to develop questions that engage students in applying these concepts through interactive tasks. Finally, Concept analysis addresses the challenges students face with topics like probability, data analysis, and algebra, with digital simulations chosen to help them better understand and apply these concepts in real-world situations.

3.2 Design and Develop

The media selected for this development is Desmos Classroom web, chosen for its easy accessibility across PC, Android, and iOS devices without the need for installation, making it convenient for students to access the questions and learning materials on various devices. Desmos offers an interactive platform where students can manipulate variables and observe real-time results, which enhances their understanding of mathematical concepts related to probability, data analysis, and algebra. The structure of the digital simulation-based questions includes four main components: an introduction to provide context, a simulation where

students manipulate variables, observation to analyze the results, and questions to assess their understanding.

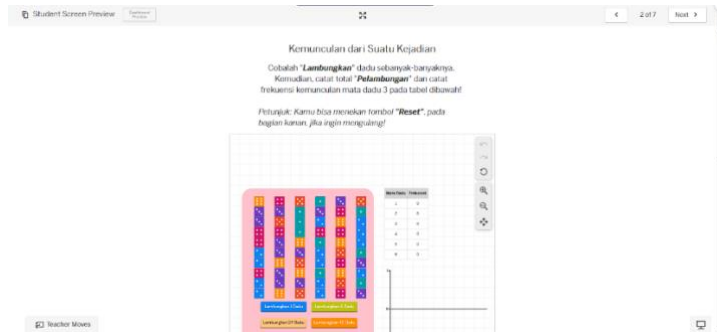
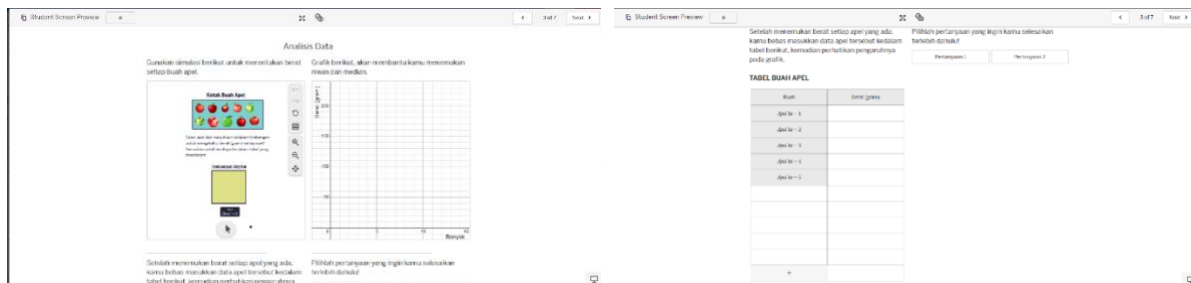


Figure 1. Dice Experiment Simulation

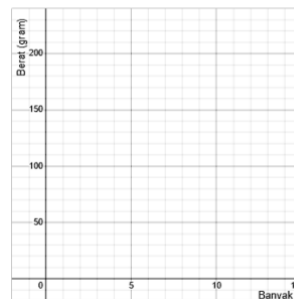
The first set of questions centers around probability simulations (see Figure 1), where students are asked to perform dice-throwing experiments. In this simulation, students can select the number of dice to roll, ranging from one to sixty. As the dice are rolled, the results are automatically collected and displayed in a table showing the frequency of each die face. This table is updated in real-time as more dice are rolled, allowing students to observe how the experimental probabilities approach the theoretical probabilities as the number of trials increases.



(i)

(ii)

Grafik berikut, akan membantu kamu menemukan mean dan median.



(iii)

Figure 2. The Data Analysis

The Data Analysis task focuses on working with data to calculate key statistical measures. Students are provided with a simulation where they measure the weight of different apples using a digital scale (Figure 2 (i)). The students then input these

measurements into a table within the Desmos environment (Figure 2 (ii)). As they do so, the table and accompanying graphs update dynamically (Figure 2 (iii)), providing visual representations of how the data changes and how the calculated mean and median evolve as more data points are added. The task requires students to manipulate the data and answer questions such as adjusting the data to achieve a particular mean or to compare the relationship between the mean and median. This task allows students to engage with theoretical and practical data analysis aspects.

For the Data Analysis task, students are presented with questions that guide them to adjust the data. These questions require students to engage with the data actively, reinforcing their understanding of how the mean and median are calculated and how they can manipulate data to meet specific objectives.

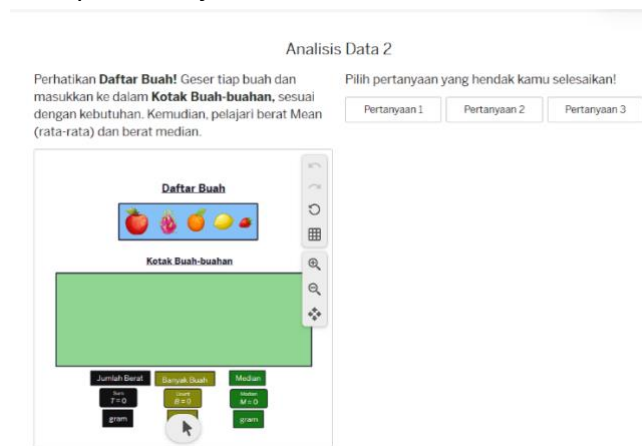
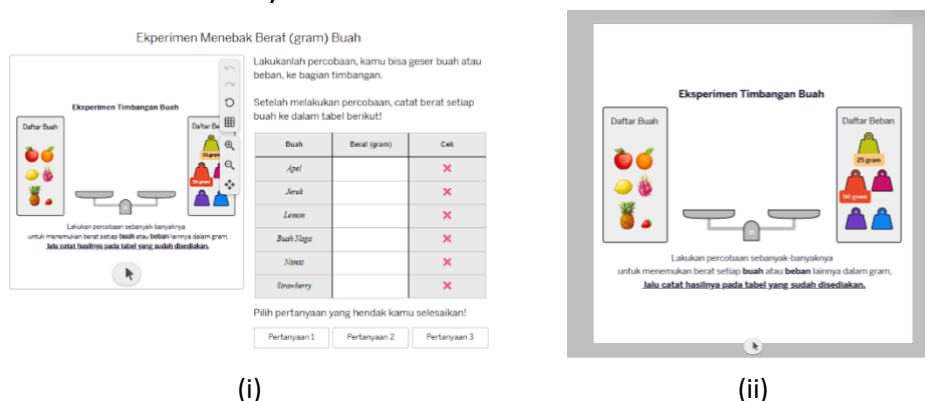


Figure 3. The Data Analysis 2

The Data Analysis 2 task extends the previous concepts by introducing a more complex scenario with multiple types of fruit (see Figure 3). Students place fruits into a digital fruit box, where the system automatically calculates the total weight and number of fruits. As students add or remove fruits, they can see how these changes affect the total weight and the number of fruits, which enables them to calculate the mean and median. This task helps students apply statistical concepts to larger data sets, offering real-time updates to visualize the distribution and central tendency of the data.



(i)

(ii)

Figure 4. Guessing the Weight of Fruit

In the "Guessing the Weight of Fruit" experiment (Figure 4), students are tasked with estimating the weight of a fruit by balancing it against known weights using a digital scale (Figure 4 (ii)). The simulation provides students with combinations of known weights (e.g., 25 grams and 50 grams) and asks them to determine the weight of an unknown fruit by experimenting with different combinations. The task encourages students to test different possibilities and adjust their inputs until they achieve the correct weight. This simulation develops their problem-solving skills and encourages an understanding of measurement and estimation in a digital environment.

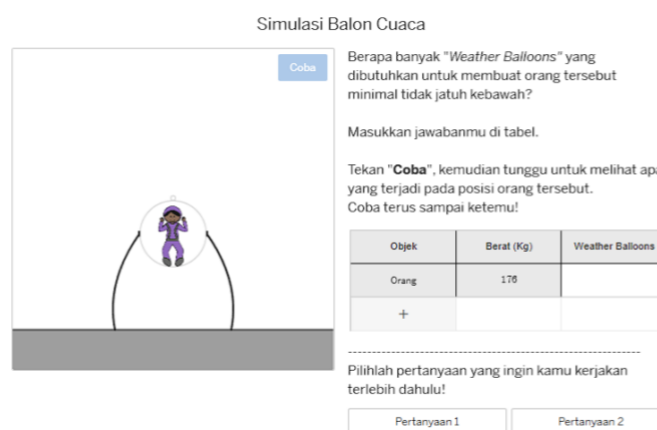


Figure 5. The Weather Balloon Simulation

Lastly, the Weather Balloon Simulation asks students to determine how many weather balloons are needed to lift a person weighing 176 kg (see Figure 5). In this task, students input the person's weight and adjust the number of balloons required for lifting. The digital simulation updates in real time, providing feedback on the students' calculations and helping them understand the relationship between weight, force, and number of balloons. The task integrates algebraic reasoning with practical applications, providing students a real-world context for applying their mathematical knowledge.

3.3 Assessing Test Quality

Assessing the quality of a test involves evaluating several key components that ensure the test accurately measures what it intends to measure and performs consistently.

1. Content validity

Two specialists established Content validity through expert judgment and analyzed it using the Aiken method. The results confirmed that all test items had high validity ratings.

2. Construct validity

a. Probability

Construct validity for the probability items was established using Spearman's correlation between Probability Question 1 ($P1_U$) and Probability Question 2 ($P2_U$), yielding a significant positive correlation of 0.763 (p -value = 0.000) (Table 1). This result indicates a strong relationship between the two questions, supporting the construct validity of the probability items.

Table 1. Formatting Rules

	$P1_U$	$P2_U$
$P1_U$	1	0.763
$P2_U$	0.763	1

b. Data analysis and algebra

Construct validity for Data Analysis and Algebra items was assessed using the multitrait-multimethod (MTMM) approach (see Table 2). The validity was evaluated based on the content areas (traits), specifically Algebra (A) and Data Analysis (AD), and the item formats (methods), which included multiple-choice (PG), complex multiple-choice (PGK), short-answer (IS), and descriptive (U) questions. High correlations were found between items measuring the same trait with different methods, such as $Algebra_{IS}$ and $Algebra_{PG}$ (0.728) and $DataAnalysis_U$ and $DataAnalysis_{IS}$ (0.710), indicating good convergent validity. Items measuring different traits using the same method, like $Algebra_U$ and $DataAnalysis_U$ (0.455), showed lower correlations, confirming discriminant validity. An exception was found between $Algebra_{IS}$ and $DataAnalysis_{IS}$, with a correlation of 0.743, which can be explained by the nature of short-answer items that often require similar numerical skills. Overall, the items exhibited strong convergent and discriminant validity, ensuring that the test accurately measures distinct content areas and item formats.

Table 1. The MTMM matrix

	AD_U	AD_{IS}	AD_{PGK}	A_U	A_{PG}	A_{IS}
AD_U	1	0,710	0,455	0,455	0,504	0,613
AD_{IS}	0,710	1	0,436	0,680	0,613	0,743
AD_{PGK}	0,455	0,436	1	0,271	0,313	0,262
A_U	0,455	0,680	0,271	1	0,622	0,695
A_{PG}	0,504	0,613	0,313	0,622	1	0,728
A_{IS}	0,613	0,743	0,262	0,695	0,728	1

3. Reliability

The data were transformed into z-scores to enhance measurement accuracy. The obtained Cronbach's Alpha value of 0.907 indicates that the test items are reliable.

4. Item Characteristics

a. Difficulty level

Most test items, including essay, short-answer, multiple-choice, and complex multiple-choice, were of moderate difficulty. The difficulty indices ranged from 0.29 (difficult) to 0.70 (moderate), ensuring a balanced level of difficulty across the test.

b. Item discrimination

All items demonstrated strong discrimination, with values ≥ 0.30 . Essay and short-answer questions showed excellent discrimination (0.457 to 0.855), while multiple-choice items ranged from 0.384 to 0.579, ensuring the items effectively differentiate

student proficiency.

The results of this study indicate that the developed numeracy-oriented questions based on digital simulation meet high standards of validity, reliability, and item quality. The high content validity confirmed through expert judgment suggests that the items are well aligned with the intended learning objectives and numeracy constructs. This finding is consistent with previous studies emphasizing the importance of expert validation in ensuring the appropriateness and relevance of assessment instruments in mathematics education (Alibraheim, 2023; Kurniawan et al., 2023; Lestari et al., 2023; Setyaningrum et al., 2024). Furthermore, the strong construct validity, supported by significant correlations and MTMM analysis, demonstrates that the items effectively measure the intended domains of probability, data analysis, and algebra.

In terms of reliability, Cronbach's alpha indicates a high level of internal consistency among the test items. This suggests that the developed instrument yields stable, consistent results when used to measure students' numeracy skills. Similar findings have been reported in previous research, where high reliability values indicate that assessment instruments are dependable and suitable for evaluating students' competencies (Kusaeri et al., 2018; Reffiane et al., 2021). The transformation of data into z-scores also contributes to improving measurement precision, ensuring that the results accurately reflect students' abilities across different item formats.

Moreover, the item characteristics analysis indicates that most questions fall within the moderate difficulty range and have strong discriminative power. This balance is essential in assessment design, as it allows the instrument to effectively distinguish between students with different levels of ability while still being accessible to most learners. Previous studies have highlighted that well-designed test items should maintain a moderate level of difficulty and high discrimination indices to ensure both fairness and effectiveness in measuring learning outcomes (Herawaty et al., 2021; Silmi Juman et al., 2022). The inclusion of various item types, such as essay, short-answer, and multiple-choice questions, further enhances the assessment's comprehensiveness.

In addition, integrating digital simulations through platforms such as Desmos provides an interactive and meaningful learning context that supports the development of numeracy skills. Digital simulations enable students to explore mathematical concepts dynamically, fostering deeper understanding and engagement. This finding aligns with prior research indicating that technology-enhanced learning environments can improve students' problem-solving abilities and conceptual understanding by linking abstract mathematical ideas to real-world applications (Nugroho, 2024; Nugroho et al., 2024). Therefore, the developed questions not only meet psychometric quality standards but also contribute to more effective and engaging mathematics learning experiences.

4. Conclusion

This research successfully developed numeracy-oriented questions based on digital simulations for 8th-grade mathematics, demonstrating strong content and construct validity,

and high reliability. The test items effectively assess key numeracy skills in probability, data analysis, and algebra, offering a dynamic and interactive approach to learning.

The findings suggest that these digital simulations can be applied across various educational levels, including primary, secondary, and higher education, with adjustments to content. Future research could further validate these items in different subjects and educational stages, exploring their impact on student engagement and long-term learning outcomes.

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- Additional Information : -

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