

# Building Numeracy Interest and Ability: The Effectiveness of Digital Simulation Media for Junior High School Students

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## ABSTRACT

Low numeracy skills and declining learning interest among junior high school students represent a critical challenge in modern mathematics education. Traditional teaching methods often fail to bridge the gap in student engagement within increasingly digital learning environments. While digital simulations offer significant interactive potential to address these issues, their focused development and empirical testing for specific numeracy interventions remain insufficient. This study aimed to develop digital simulation media and evaluate its validity, practicality, and effectiveness in improving numeracy skills and learning interest independently. Using a Research and Development (R&D) approach with the ADDIE model, the media was tested on 32 eighth-grade students at an Indonesian public junior high school. Data were collected through numeracy tests, interest questionnaires, practicality assessments, and expert validation sheets. After confirming the normality assumption via Shapiro-Wilk, data analysis was conducted using paired sample t-tests and N-Gain scores. The results indicated that the media was deemed highly valid by both material and media experts. Teachers and students rated the media as "very practical" and "practical," respectively. Furthermore, the intervention independently improved both numeracy skills ( $p < 0.001$ ; N-Gain = 0.62, medium category) and learning interest ( $p < 0.001$ ; N-Gain = 0.31, medium category), with 75% of students achieving the minimum mastery standard. This study concludes that the developed digital simulation media is a valid, practical, and effective tool for enhancing students' cognitive numeracy skills and fostering their affective learning interest. It is recommended for broader implementation and further development.



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## A. INTRODUCTION

The imperative to enhance learning outcomes in secondary education has driven global innovation in educational technology. In the domains of Science, Technology, Engineering, and Mathematics (STEM), digital tools have demonstrated significant potential. A recent meta-analysis confirms that the use of digital tools, including dynamic simulations, can substantially improve learning outcomes in mathematics and science at the secondary level, with effect sizes in the moderate to large range (Hillmayr et al., 2020). This effectiveness is further supported by research on digital game-based learning in STEM, which shows similar positive effects (Huang et al., 2023). These digital interventions are not merely delivery mechanisms; well-designed simulations can create immersive, interactive environments that facilitate deeper conceptual understanding (H. Lee & Park, 2025). However, global evidence alone is insufficient without addressing local educational constraints.

In the Indonesian context, a persistent gap exists between the potential of digital tools and student competency in foundational skills. According to the Programme for International Student Assessment (PISA) 2022 results, Indonesian students ranked 70th out of 81 participating countries in mathematics literacy, with an average score of 366, significantly below the OECD average of 472 (OECD, 2023). Numerous studies highlight that Indonesian secondary school students continue to struggle with core numeracy skills, including mathematical operations, problem-solving strategies, and result interpretation, as evidenced by analyses of PISA-based problems (Marhami et al., 2024). This challenge is compounded by a broader issue of low literacy and numeracy skills observed even at the elementary level (Rakhmawati & Mustadi, 2022). The Indonesian Ministry of Education and Culture has responded by prioritizing numeracy as a critical competency in the Kurikulum Merdeka which emphasizes flexible, project-based learning and the development of foundational literacy and numeracy (Kemendikbudristek, 2022). Despite this policy shift, classroom implementation remains uneven, and teachers often lack access to validated, contextually relevant digital learning media. These local challenges point to a specific gap in the literature.

Before explaining this gap, it is necessary to define the two key variables addressed in this study. Numeracy skills refer to the ability to formulate, apply, and interpret mathematics in various contexts, including reasoning quantitatively, using mathematical concepts, procedures, facts, and tools to describe, explain, and predict phenomena (OECD, 2023). In this study, numeracy skills are operationalized through core Grade VIII aspects: number sense, data interpretation, and pattern recognition. Learning interest is defined as a psychological state characterized by focused attention, intrinsic curiosity, emotional engagement, and persistence in mathematics learning activities (Hidi & Renninger, 2006). It encompasses three indicators: cognitive interest (curiosity about mathematical problems), affective interest (enjoyment of mathematical activities), and behavioral interest (voluntary engagement with mathematical tasks). The relationship between these two variables is bidirectional: students with stronger numeracy skills tend to develop greater confidence and interest in mathematics, while higher learning interest motivates students to engage more deeply with numeracy tasks, creating a positive feedback loop (Schukajlow et al., 2017). However, many interventions target only one dimension, missing the opportunity to address both simultaneously.

While systematic reviews note a growing body of research on mathematics learning media (Hanifah et al., 2024), and specific studies in Indonesia show the effectiveness of digital media in improving science achievement (Nurhidayah et al., 2024) and interest in mathematics (Kaafah et al., 2024), several limitations persist. First, most existing studies focus on either cognitive outcomes (e.g., test scores) or affective outcomes (e.g., interest or motivation), but rarely both. Second, the majority of digital media developed for Indonesian classrooms lack rigorous empirical testing of validity and practicality alongside effectiveness. Third, Desmos-based simulation media have been studied in Western educational settings (Chechan et al., 2023), but their application in the Indonesian context with its unique curriculum, cultural characteristics, and technological infrastructure remains underexplored. Fourth, no previous study has integrated multiple platforms (Google Sites, Desmos, Disqus, and Google Forms) into a single, cohesive web-based numeracy learning environment and tested its simultaneous impact on both numeracy skills and learning interest. Therefore, this study aims to fill this gap.

The urgency of this research is underscored by three converging factors. First, the post-COVID-19 learning crisis has exacerbated numeracy deficiencies, with evidence of significant learning losses in mathematics across schools worldwide (Donnelly &

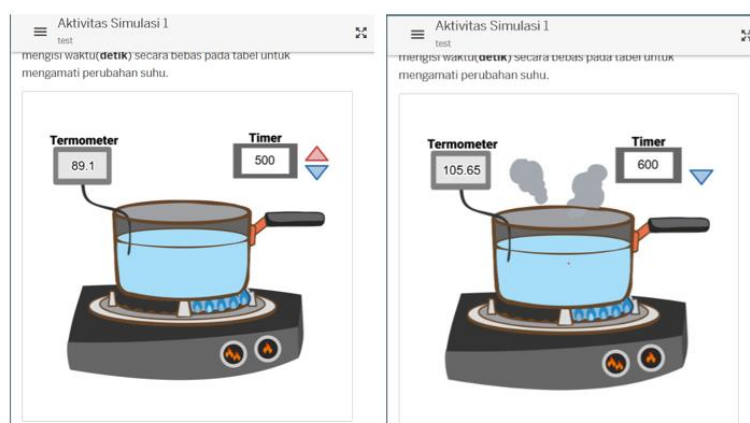
Patrinos, 2022). Second, modern curricula increasingly require teachers to integrate technology and contextualized learning, but most educators lack ready-to-use, validated digital resources. Third, Generation Z and Alpha students are digital natives who respond more positively to interactive, simulation-based learning than to traditional lecture methods (Prensky, 2001). Without targeted development of digital simulation media that is both pedagogically sound and locally relevant, the gap between policy aspirations and classroom realities will continue to widen.

The purpose of this research is to develop and evaluate digital simulation media based on the ADDIE model, assessing its validity, practicality, and effectiveness in improving the numeracy skills and learning interest of junior high school students. The novelty of this study lies in three aspects: (1) the integration of interactive simulations with a web-based learning portal, discussion forums, and assessment tools into a single numeracy learning environment; (2) the empirical testing of validity, practicality, and effectiveness on both cognitive (numeracy) and affective (interest) outcomes within the same intervention; and (3) the contextualization of mathematical problems using real-life scenarios familiar to students, such as boiling water, packing apples, and assembling hydroponic systems. This study contributes a validated, practical, and effective digital simulation media that can be immediately implemented in eighth-grade mathematics classrooms and serves as a model for similar developments in other schools.

## B. METHODS

This study employed the Research and Development (R&D) approach, utilizing the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) as the primary framework for developing and testing the digital simulation media (Branch, 2009). This systematic model ensures the final product is valid, practical, and effective.

The development process followed five sequential stages of the ADDIE model: (1) Analysis, involving a needs assessment of numeracy learning and student characteristics in Grade VIII; (2) Design, which included creating storyboards, mathematical activity flows, and interface mockups for the simulation; (3) Development, where the interactive digital simulation was built using the Desmos platform (Desmos Studio PBC, n.d.), leveraging its graphing and activity builder functionalities. Using Google Sites as website portal to navigate and manage the learning process;



**Figure 1.** Activity Number One in Desmos



**Figure 2.** Homepage Built with Google Sites

(4) Implementation, where the completed media was trialed in an actual classroom setting; and (5) Evaluation, conducted formatively at each stage and summatively at the end to assess the product's quality. The primary trial (implementation) used a one-group pretest-posttest design to measure the media's effectiveness.

The study was conducted at SMP Negeri 2 Pleret, Bantul, Yogyakarta, Indonesia. The participants for the product effectiveness trial were 32 eighth-grade students (Class VIII A), selected using a convenience sampling technique. One mathematics teacher from the school was also involved in assessing the practicality of the media.

Data for this study were collected through a multi-instrument approach designed to comprehensively assess validity, practicality, and effectiveness. To evaluate the quality of the developed media, validation sheets were administered to one media expert and one content expert. These sheets employed a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), to appraise specific criteria such as design usability, software functionality, content accuracy, and pedagogical alignment. Perceptions of practicality were gauged using separate questionnaires for the participating teacher and the 32 students, which also utilized the same 5-point Likert scale to measure ease of integration, clarity of instruction, and time efficiency in a classroom setting.

To measure effectiveness, two primary researcher-developed instruments were administered in a pre-test and post-test design. First, a numeracy skills test was constructed based on core Grade VIII numeracy aspects, including number sense, data interpretation, and pattern recognition. Second, a learning interest questionnaire was developed by operationalizing key affective dimensions such as attention, relevance, and confidence in learning mathematics. Supplementary qualitative data were gathered through structured observation notes and interview guides to capture contextual insights during the implementation phase.

The collected data were analyzed according to the corresponding research objectives. Quantitative data from the validation and practicality instruments were analyzed descriptively. The average scores from the Likert-scale responses were calculated and converted into percentages, which were then interpreted using predetermined qualitative categories (e.g., 81-100%: Very Valid/Very Practical).

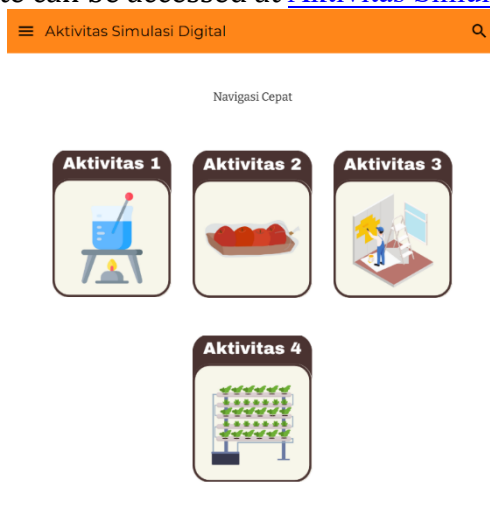
For the effectiveness data, a series of statistical tests were conducted. The pre-test and post-test scores for both numeracy and learning interest were first tested for normality using the Shapiro-Wilk test to determine the appropriate subsequent test. As the data met the assumption of normality, Paired Sample t-tests were employed to determine whether statistically significant differences existed between the pre-intervention and post-intervention scores for each variable. To quantify the magnitude of the improvement

beyond mere significance, the Normalized Gain (N-Gain) score was calculated for the group. Finally, a simple percentage was derived to determine the proportion of students who met or exceeded the school's minimum mastery criterion (KKM) after the intervention.

### C. RESULT AND DISCUSSION

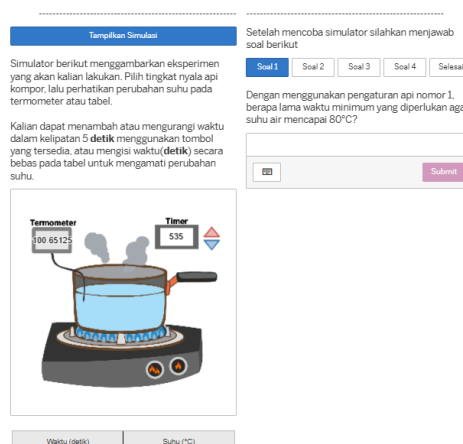
#### 1. Finding

The research resulted in the development of a digital simulation-based learning media designed to enhance numeracy skills and learning interest among junior high school students. The product was developed using the ADDIE model, which encompasses five stages: Analysis, Design, Development, Implementation, and Evaluation. The final product, named "Aktivitas Simulasi Digital" (Digital Simulation Activities), is a website-based learning media integrating Google Sites, Desmos, Disqus, and Google Forms. Website can be accessed at [Aktivitas Simulasi Digital](#).



**Figure 3.** Shortcut of Desmos Activity at Homepage

There is four activity such as boiling water, packing apples, painting walls, and assembling hydroponic systems. Every activity have automatic validation to check student's answers. The preview of this activity can be seen in Figure 4, Figure 5, Figure 6, and Figure 7.



**Figure 4.** Boiling Water Simulation with Problem Question

Seorang karyawan sedang mengemas buah apel. Dia sudah memasukkan dua buah apel dengan berat 150 gram dan 100 gram. Bantulah karyawan tersebut memasukkan sisa enam buah apel ke dalam kemasan supaya hasil akhirnya diperoleh rata-rata berat apel 120 gram.

**Tampilkan Simulasi**

Untuk membantu karyawan tersebut, lakukan langkah berikut:

- kalian bisa geser gambar buah apel ke atas atau bawah untuk berat yang kalian inginkan.
- garis mendatar warna merah menunjukkan rata-rata buah apel yang kalian masukkan
- aturlah berat enam buah apel sampai garis mendatar warna merah menunjukkan berat rata-rata 120 gram.

Soal 1 Soal 2 Soal 3 Selesai

Tuliskan berat keenam apel yang kamu dapat dari kegiatan simulasi

Apel 1	Apel 2	Apel 3	Apel 4	Apel 5	Apel 6
150	100				

Silahkan isi tabel terlebih dahulu

**Cek Jawaban**

Figure 5. Packing Apples Simulation with Problem Question

Kalkulator Cat

**Tampilkan Simulasi**

Kamu ingin mengecat seluruh permukaan dinding kamar tidur dengan ukuran panjang 3 meter, lebar 3 meter, dan tinggi 4 meter. Kamar tersebut memiliki satu pintu berukuran 70 cm x 170 cm dan satu jendela berukuran 50 cm x 100 cm. Gunakan simulasi kalkulator cat untuk menghitung luas total permukaan dinding yang harus dicat. Berapa luas total yang perlu dicat? (dalam  $m^2$ )

46.31

[ Jawaban kamu 46.31 adalah benar ✓. ]

Panjang (cm)	Lebar (cm)	Tinggi (cm)	Jumlah Lapisan	Luas Tembok
300 cm	300 cm	400 cm	1 Lapis	480000 cm <sup>2</sup>

Lebar (cm)	Tinggi (cm)	Jumlah	Luas
70 cm	170 cm	1	11900 cm <sup>2</sup>

Lebar (cm)	Tinggi (cm)	Jumlah	Luas
50 cm	100 cm	1	5000 cm <sup>2</sup>

Luas tembok yang terkena cat = 463100  $cm^2$   
 Jumlah cat yang dibutuhkan = 9.262 Liter

Figure 6. Painting Walls Simulation with Problem Question

bawah ini untuk merancang sistem pipa hidroponikmu sendiri.

**Petunjuk:**

- Rancang sistem pipa sehingga terdapat jalur masuk dan jalur keluar air.
- Pastikan arah aliran air mengalir dari atas ke bawah.
- Dari konverter pipa ke sambungan bercabang (seperti sambungan "T", "+", atau siku), wajib menggunakan pipa kecil sebagai penyambung.
- Dari satu sambungan ke sambungan lainnya (misalnya dari siku ke sambungan "T"), juga harus disambungkan dengan pipa kecil.

Susunlah pipa-pipa ini seperti menyusun rak, dan cobalah temukan pola tertentu agar sistemmu efisien, modular, dan mudah diperluas.

menampung 10 netpot

Aan ingin membuat rangkaian hidroponik baru. Bantulah Aan untuk menyusun rangkaian hidroponik yang mampu menampung 15 netpot. Berapa jumlah tiap komponen yang dibutuhkan untuk menyusun rangkaian hidroponik tersebut?

Komponen	Jumlah
Pipa besar	0
Sambungan berbentuk plus (+)	0
Sambungan berbentuk "T" (T)	0
Sambungan siku (L)	0
Konverter pipa	0
Pipa kecil	0

**Cek Jawaban**

Isi tabel terlebih dahulu, kemudian klik Cek Jawaban

Figure 7. Assembling Hydroponic Systems Simulation with Problem Question

## 2. Product Validity

The learning media and its accompanying instruments were validated by two expert validators, a media expert and a content expert from the Master of Mathematics Education Program at Yogyakarta State University. The validation results are summarized as in Table 1:

**Table 1.** Summary of Learning Media Validation

Media Expert Assessment	Score	Content Expert Assessment	Score
Ease of Navigation	15	Cognitive Content	10
Information Presentation	4	Information Presentation	9
Media Integration	10	Media Integration	10
Artistic and Aesthetic	18	Artistic and Aesthetic	13
Overall Function	5	Overall Function	5
Total	52	Total	47
Category	Highly Valid	Category	Highly Valid

The numeracy test instrument consisting of 10 items received a total score of 48 from the validator, placing it in the "Highly Valid" category. The learning interest questionnaire, comprising 30 items across three indicators (curiosity, engagement, and enjoyment), received a total score of 149, also categorized as "Highly Valid." The practicality instrument for teacher and student responses achieved a score of 50, indicating "Highly Valid."

## 3. Product Practicality

The practicality of the learning media was assessed through teacher and student response questionnaires after implementation. The teacher's assessment covered four aspects: ease of use, visual appeal, content clarity, and technical performance. The results are presented in Table 2.

**Table 2.** Teacher's Practicality Assessment

Aspect	Score	Category
Ease of Use	25	
Visual Appeal	14	
Content and Instructions Clarity	9	
Technical Performance	10	
Total	58	Highly Practical

The student practicality assessment involved 32 eighth-grade students from SMP Negeri 2 Pleret, Bantul, Yogyakarta. The results are presented in Table 3.

**Table 3.** Students's Practicality Assessment

Number of Respondents	Total Score	Mean Score	Category
32	1587	49.6	Practical

## 4. Product Effectiveness

The effectiveness of the digital simulation media was evaluated by analyzing the improvement in students' numeracy skills and learning interest through pre-test and post-test measurements.

### Numeracy Skills Improvement

The numeracy test was administered to 32 students before and after the intervention using the digital simulation media. The results are presented in Table 4.

**Table 4.** Pre-test and Post-test Numeracy Results

Description	Pre-test	Post-test
Mean Score	38.75	76.56
Median	40.00	75.00
Minimum Score	0	50
Maximum Score	80	100
Standard Deviation	18.50	14.28
Completion Rate	13% (4 students)	75% (24 students)

The normality test on the gain scores (post-test minus pre-test) using Shapiro-Wilk yielded a significance value of 0.26 ( $p > 0.01$ ), indicating that the data were normally distributed. Subsequently, a paired sample t-test was conducted. The results are presented in Table 5.

**Table 5.** Paired Sample T-Test Results for Numeracy

	Mean	Std. Deviation	t	df	Sig. (2-tailed)
Post - Pre	37.81	17.18	12.46	31	0.00

The t-test show a significant difference between pre-test and post-test scores ( $t = 12.46, p < 0.001$ ). The N-Gain analysis revealed a mean score of 0.62, which falls into the "medium" category, indicating a moderate improvement in students' numeracy skills after using the digital simulation media.

### Learning Interest Improvement

Students' learning interest was measured using a 5-point Likert scale questionnaire administered before and after the intervention. The results are summarized in Table 6.

**Table 6.** Pre-test and Post-test Learning Interest Results

Description	Pre-test	Post-test
Mean Score	3.76	4.19
Minimum Score	2.60	3.57
Maximum Score	4.87	4.93
Standard Deviation	0.59	0.34

The normality test on the gain scores showed a significance value of 0.039 ( $p > 0.01$ ) using Shapiro-Wilk, confirming normal distribution. The paired sample t-test results are presented in Table 7.

**Table 7.** Paired Sample T-Test Results for Learning Interest

	Mean	Std. Deviation	t	df	Sig. (2-tailed)
Post - Pre	0.43	0.32	7.4	31	0.00

The analysis revealed a significant difference between pre-test and post-test scores ( $t = 7.4, p < 0.001$ ). The N-Gain analysis produced a mean score of 0.31, categorized as "medium," indicating a moderate improvement in students' learning interest following the use of the digital simulation media.

## 5. Discussion

### The Digital Simulation Media as a Facilitator of Numeracy and Learning Interest

The digital simulation media developed in this study, "Aktivitas Simulasi Digital," integrates Google Sites as a content management system with Desmos for interactive simulations, Disqus for discussion forums, and Google Forms for assessment. This integration created a web-based learning environment that addressed both cognitive and affective learning dimensions. In practice, students could manipulate variable sliders in Desmos and immediately observe corresponding changes in graphs and data

tables. This hands-on experimentation directly supports what Chechan et al. (2026) identified as the "integrated method" of digital tool use, where students flexibly combine algebraic reasoning with simulation verification depending on the problem context.

The media's design incorporated real-life contexts familiar to students in Bantul Regency, including boiling water, packing apples, painting walls, and assembling hydroponic systems. These contextual problems embedded mathematical concepts in meaningful situations, which is essential for developing numeracy skills as it helps students recognize the relevance of mathematics in their daily lives (OECD, 2023). The interactive simulation features allowed students to manipulate variables and observe real-time outcomes, transforming abstract mathematical concepts into tangible, explorable phenomena.

The inclusion of discussion forums addressed the social dimension of learning. Observations during implementation revealed that students voluntarily posted questions, shared solution strategies, and responded to peers' inquiries. This feature supported the development of mathematical communication skills and created a learning community that extended beyond classroom hours. As Salinas et al. (2016) noted, dynamic digital technology can foster a "dialogic ecosystem" where teachers, students, and software cohabit in an environment where dialogue becomes an essential component for acquiring mathematical knowledge.

#### **Validity of the Developed Product**

The validation process involved two expert validators from the Master of Mathematics Education Program at Yogyakarta State University. The media expert's assessment (total score 52) and content expert's assessment (total score 47) both fell into the "Highly Valid" category. These results are comparable to those reported by (Setiyani et al., 2022), who developed an e-module using the Kvisoft Flipbook application for junior high school mathematics and reported high validity scores from material experts (86.47%) and media experts (88.3%) using the ADDIE model. The high validity scores in both studies demonstrate that systematically developed digital learning media consistently achieve expert approval when designed with structured development frameworks.

The numeracy test instrument (10 items) received a total score of 48 out of 50, placing it in the "Highly Valid" category. The learning interest questionnaire (30 items across three indicators: curiosity, engagement, and enjoyment) received a total score of 149 out of 150. These high validity scores demonstrate that the instruments were well-aligned with their intended constructs. The numeracy test items were designed to reflect the content, context, and cognitive levels specified in international mathematics assessments, ensuring they appropriately measured students' numeracy abilities (OECD, 2023).

#### **Practicality of the Digital Simulation Media**

The practicality assessment revealed that the digital simulation media was well-received by both teachers and students. The teacher's evaluation (total score 58, "Highly Practical") indicates that from an instructional perspective, the media was easy to use, visually appealing, clear in its instructions, and technically stable. This positive response is significant because teacher acceptance is crucial for successful technology integration in classroom instruction. Abas et al. (2019) found that perceived ease of use and perceived usefulness are the strongest predictors of teachers' behavioral intention to integrate digital technology in their classrooms.

The students' assessment (mean score 49.6, "Practical") suggests that the media was accessible and user-friendly for the target audience. Observations during implementation revealed that students quickly adapted to using the simulations, exploring manipulable variables and engaging with problem-solving tasks. The flexibility of access through smartphones, tablets, or computers was particularly appreciated, as it allowed students to learn at their own pace and convenience.

Technical challenges encountered during implementation included display issues on small screens and unstable internet connections. While the media was optimized for smartphone access, larger screens provided a more optimal experience. This suggests that implementation in computer laboratories when possible, or with tablet devices, would enhance the learning experience. These practical considerations align with findings from Chen et al. (2022), who emphasized the importance of responsive design in digital learning media development.

### **Effectiveness in Improving Numeracy Skills**

The significant improvement in students' numeracy skills from pre-test (mean = 38.75) to post-test (mean = 76.56) provides strong evidence of the media's effectiveness. The paired sample t-test results ( $t = 12.46$ ,  $p < 0.001$ ) confirm that this improvement was statistically significant. The N-Gain score of 0.62, falling into the "medium" category, indicates a substantial and meaningful improvement in numeracy abilities.

Several specific factors from our implementation contributed to this improvement. First, in the first activity (boiling water), students could adjust time and flame settings while observing temperature changes in real-time. This direct manipulation helped students develop intuitive understanding of relationships between variables, which is a fundamental aspect of numeracy. Second, the immediate feedback mechanism enabled students to check their answers, receive corrective information, and attempt problems again. This iterative process supports mastery learning. Third, the contextual problems connected mathematical concepts to situations students encounter in daily life, making learning more meaningful and memorable.

The increase in completion rates from 13% (4 students) to 75% (24 students) is particularly noteworthy. Rittle-Johnson et al. (2015) found that structured practice with immediate feedback in digital learning environments significantly improved procedural and conceptual knowledge in mathematics. Similarly, Kulik & Fletcher (2016) conducted a meta-analysis of computer-based instruction and found that interactive digital media produced average effect sizes of 0.35 to 0.50 for cognitive outcomes, which is consistent with our N-Gain of 0.62.

The results align with previous research on simulation-based learning media. Chechan et al. (2026) studied 28 Year 11 students using Desmos for quadratic functions and identified four student approaches: solving algebraically and verifying with Desmos, solving with Desmos and verifying algebraically, integrated method, and using Desmos as an aide after failed algebraic attempts. Our study extends these findings by demonstrating the effectiveness of a more comprehensive learning environment that integrates Desmos simulations with supporting features such as discussion forums and structured learning pathways in an Indonesian junior high school context.

### **Effectiveness in Improving Learning Interest**

The significant improvement in learning interest from pre-test (mean = 3.76) to post-test (mean = 4.19) demonstrates that the digital simulation media positively affected students' affective engagement with mathematics. The paired sample t-test

results ( $t = 7.4$ ,  $p < 0.001$ ) confirm the statistical significance of this improvement, while the N-Gain score of 0.31 ("medium" category) indicates a meaningful increase in interest levels.

The improvement in learning interest can be attributed to four specific design features observed during implementation. First, the visual appeal with vibrant colors, engaging illustrations, and interactive elements created an inviting learning environment that captured students' attention. Second, the hands-on nature of the simulations fostered curiosity as students explored "what if" scenarios by manipulating variables. This exploratory aspect taps into students' natural curiosity and makes learning feel more like play than work. Third, the immediate feedback and validation features provided a sense of accomplishment when students solved problems correctly, reinforcing their engagement and encouraging persistence. Fourth, the discussion forum allowed students to share ideas, ask questions, and receive support from peers, creating a collaborative learning community.

Hidi & Renninger (2006) theorized that well-designed learning environments can trigger situational interest, which can develop into longer-term individual interest when supported by meaningful tasks, feedback, and social interaction. Our findings support this theoretical model. The significant increase in learning interest within a relatively short intervention period (five sessions) suggests that the digital simulation media successfully triggered situational interest in mathematics. Ainley & Ainley (2011) found that students who reported higher interest in mathematics were more likely to engage in deeper cognitive processing and pursue further mathematics education, highlighting the importance of affective outcomes alongside cognitive gains.

The consistency between our findings and previous research suggests that interactive, visualization-based digital media reliably produces positive affective outcomes across different technological platforms and mathematical content areas. Meta-analyses of digital game-based learning in mathematics have found significant positive effects on both cognitive achievement and affective motivation, with effect sizes comparable to our N-Gain values of 0.62 (cognitive) and 0.31 (affective). Cetintav & Yilmaz (2023) investigated the effects of augmented reality applications in geometry teaching on secondary school students and found that AR applications were fun and interesting for students, positively affecting academic achievement and active participation in the lesson. Similarly, H. K. Lee & Choi (2020) found that a tablet-based math game intervention substantially improved early numeracy skills, with statistically significant effects identified in quantity discrimination, addition, and subtraction tasks.

### **Implications and Novel Contributions**

This study makes several contributions to the field of mathematics education and educational technology. First, it demonstrates that a well-designed digital simulation environment can independently address both cognitive and affective learning outcomes. While previous research has often focused on either skill development or motivational outcomes, this study shows that thoughtfully designed media can achieve both goals. The finding that the same intervention significantly improved numeracy skills and learning interest suggests that these outcomes are not mutually exclusive but can be pursued together through integrated design.

Second, the study provides empirical evidence for the effectiveness of Desmos-based learning media in the Indonesian educational context. The student strategies documented by Chechan et al. (2023) in Swedish high schools were also observable in our Indonesian setting, suggesting that the "integrated method" of digital tool use may

be transferable across educational contexts. While Desmos has been widely studied in Western educational settings, research in the Indonesian context with its unique curriculum (Kurikulum Merdeka), cultural contexts, and technological infrastructure is still limited. This study contributes to filling this gap and provides a model for developing similar media in other Indonesian schools.

Third, the study identifies a novel finding regarding the impact of simulation-based media on learning interest. While previous research has established the cognitive benefits of simulation-based learning, the affective benefits particularly in terms of increased interest have received less attention. The finding that digital simulations can significantly enhance learning interest opens new avenues for research and practice, suggesting that well-designed digital tools may help address the affective barriers that often impede mathematics learning.

Fourth, the study's documentation of implementation challenges and contextual factors provides valuable insights for practitioners. The need to adapt to online learning, address technical issues, and accommodate students with varying levels of home support highlights the importance of flexible, resilient instructional designs. These insights can inform the development of implementation guidelines that help teachers maximize the benefits of digital learning media while mitigating potential challenges.

### **Limitations**

Several limitations of this study should be acknowledged. First, the research was conducted in a single school with 32 students, which limits the generalizability of the findings. Replication studies in different schools and with larger samples would strengthen the evidence base for the media's effectiveness. Second, the implementation was affected by unexpected school events that necessitated a shift to online learning for some sessions. While the media's flexibility accommodated this change, the inconsistency in learning modes may have influenced the outcomes. Third, the study's duration of five sessions (approximately two weeks) was relatively short. Longitudinal studies would be needed to assess whether the observed improvements in numeracy skills and learning interest are sustained over time. Fourth, the study did not include a control group, which limits the strength of causal claims about the media's effectiveness. Future research using experimental or quasi-experimental designs with control groups would provide stronger evidence of causality.

Despite these limitations, the study provides robust evidence that the digital simulation media developed through this research is valid, practical, and effective in improving both numeracy skills and learning interest among junior high school students. The findings support the continued development and implementation of such media in mathematics instruction and suggest that thoughtful integration of technology can contribute to meaningful improvements in both cognitive and affective learning outcomes.

## **D. CONCLUSION AND SUGGESTIONS**

This research successfully developed "Aktivitas Simulasi Digital," a digital simulation-based learning media using the ADDIE model to enhance numeracy skills and learning interest among junior high school students. The media integrates Google Sites, Desmos, Disqus, and Google Forms into a cohesive web-based learning environment. Expert validation categorized the product and all instruments as "highly valid." Teacher assessments rated the media as "highly practical," while student responses fell into the "practical" category. Regarding effectiveness, the media significantly improved students'

numeracy skills (mean pre-test 38.75 to post-test 76.56; N-Gain 0.62, medium category;  $t = 12.46$ ,  $p < 0.001$ ) and learning interest (mean pre-test 3.76 to post-test 4.19; N-Gain 0.31, medium category;  $t = 7.4$ ,  $p < 0.001$ ). These findings demonstrate that well-designed digital simulation media can effectively address both cognitive and affective learning outcomes independently.

Based on the research findings, mathematics teachers are encouraged to integrate digital simulation media like "Aktivitas Simulasi Digital" into their instruction, particularly for topics that benefit from visualization and variable manipulation. Teachers should utilize the dashboard feature to monitor student progress in real-time and foster collaborative learning through classroom discussions and the integrated discussion forum. Schools need to ensure adequate technological infrastructure, including reliable internet connectivity and access to devices, and should schedule simulation-based learning in computer laboratories when possible to provide students with optimal screen experiences. Professional development opportunities for teachers in technology-enhanced instruction are also recommended to maximize the benefits of such media.

Future researchers should address the limitations of this study through the following efforts:

1. Replication studies with larger and more diverse samples across multiple schools and different regions of Indonesia to strengthen the generalizability of findings.
2. Experimental designs employing control groups (randomized controlled trials or quasi-experimental designs) to provide stronger evidence of causality, as the one-group pretest-posttest design used in this study cannot rule out alternative explanations for the observed improvements.
3. Longitudinal studies investigating whether the observed improvements in numeracy skills and learning interest are sustained over time, including follow-up measurements three to six months after the intervention.
4. Comparative studies examining the effectiveness of different digital platforms (e.g., Desmos vs. GeoGebra vs. PhET simulations) for specific numeracy topics to identify which tools are most effective for which learning objectives.
5. Technical improvements addressing the challenges identified in this study, including:
  - a) Display optimization for various screen sizes, particularly small smartphones
  - b) Offline access capabilities for schools with unstable internet connections
  - c) Integration of adaptive learning pathways that adjust problem difficulty based on student performance
  - d) Addition of gamification elements (badges, points, leaderboards) to further enhance engagement.

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