**EDUMATSAINS**
JURNAL PENDIDIKAN MATEMATIKA DAN SAINS
E-ISSN:2527-7235
Volume 11 Issue. 2, October 2026, pp 374-386
http://ejournal.uki.ac.id/index.php/edumatsains

# AI-Based Smart E-Module: Transformation of Dakonan Games into RME Learning Trajectory for Junior High School Students' Numeracy Literacy Escalation

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**Article Info**

Article history:
Received: July 20th, 2026
Revised: October 27th, 2026
Accepted: October 28th, 2026
Available online: October 31st, 2026

https://doi.org/10.33541/edumatsains.v11i2.8575

**Abstract**

The low level of middle school students' numeracy literacy based on the National Assessment is a crucial challenge stemming from abstract mathematics learning detached from cultural contexts. This study aims to develop and test the effectiveness of an AI-Exploration-based Smart E-Module that transforms the traditional Dakonan game into a Realistic Mathematics Education (RME)-based Learning Trajectory. The research method used is Design Research of the Validation Studies type, consisting of three phases: Preparing for the Experiment, The Design Experiment, and Retrospective Analysis. The subjects involved eighth-grade students from a partner junior high school in Malang Regency (with a small pilot group of 6 students in Cycle 1 and an intact class of 32 students in Cycle 2 teaching experiment). Furthermore, qualitative interaction logs indicate that AI chatbot scaffolding assisted students in overcoming individual learning hurdles and sustained student engagement. Quantitative analysis revealed an increase in the mean numeracy score from 52.40 to 78.50 with an N-Gain value of 0.55 (moderate category) and significance $p < 0.05$. This study contributes to the formulation of local instructional theory based on ethnomathematics and adaptive technology.

**Keywords:** AI-Exploration, Dakonan, Learning Trajectory, Numeracy Literacy, Realistic Mathematics Education

## 1. Introduction

The low level of numeracy literacy among junior high school (*Sekolah Menengah Pertama* / SMP) students in Indonesia remains a critical educational challenge requiring strategic intervention. Findings from national assessments and international comparative studies (e.g., OECD, 2023)

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consistently indicate that a majority of students operate primarily at the level of mechanical computing without deep conceptual understanding. True numeracy literacy extends beyond basic arithmetic fluency; it demands the capacity of individuals to formulate, use, and interpret mathematics across diverse, authentic contexts (OECD, 2023; Stacey, 2015). A primary catalyst for this deficit is traditional classroom instruction that is excessively rigid, anchored in formal symbolic formulas, and isolated from students lived cultural experiences (Bishop, 1988; Rosa & Orey, 2021). This decontextualized pedagogical environment frequently induces high levels of mathematical anxiety, which severely constrains students' logical reasoning, working memory, and independent problem-solving capacities (Ashcraft, 2002; Maloney & Beilock, 2012).

An effective bridge facilitating the cognitive transition from concrete, situational experiences to abstract mathematical formalization is the integration of local wisdom through an ethnomathematical approach (D'Ambrosio, 2006; Eglash et al., 2006). In the Malang Regency of East Java, traditional cultural artifacts such as the *Dakonan* game possess profound mathematical potential. Mechanically, the sequential distribution and capturing of seeds in *Dakonan* embody complex logical structures closely linked to modular arithmetic, algebraic patterns, division algorithms, and foundational computational thinking (Setiawan, 2025). Grounding mathematics in such cultural activities aligns directly with the tenets of Realistic Mathematics Education (RME) initiated by Freudenthal (2002), which posits that mathematics is fundamentally a human activity that must originate from and return to meaningful real-world situations (*realizable* contexts). Through RME design principles, students are guided through horizontal mathematization (translating a contextual problem into mathematical language) and vertical mathematization (moving from mathematical models to formal abstractions) via meticulously structured Learning Trajectories (Gravemeijer, 1994; Bakker & van Eerde, 2015).

Despite the theoretical strength of combining ethnomathematics and RME, practical implementation in large Indonesian classrooms often encounters severe logistical bottlenecks. Teachers struggle to monitor individual student progress and deliver timely, personalized guidance (*scaffolding*) when cognitive impasses occur (Drijvers et al., 2010). To address these limitations, contemporary educational research highlights the efficacy of AI-supported learning environments and intelligent scaffolding (Molenaar, 2022; Hwang et al., 2023). Unlike static digital materials, AI-driven adaptive platforms can analyze students' intermediate problem-solving steps in real time. Specifically, AI chatbots or virtual pedagogical agents configured for heuristic prompting can deliver customized hints and probing questions without disclosing direct answers, thereby preserving and stimulating students' independent critical reasoning (Hwang & Tu, 2021; Luckin et al., 2016). Furthermore, while digital game-based learning has demonstrated substantial success in fostering proportional reasoning and numeracy development (Plass et al., 2020; Sailer & Homner, 2020), existing digital mathematics modules remain predominantly static. Most current digital learning media function merely as digitized PDF worksheets or automated drill-and-practice applications (Setiawan & Rifa'i, 2024). They lack real-time cognitive mapping capabilities to track individual mental models during problem-solving, and they fail to integrate culturally responsive

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ethnomathematical contexts within a systematic RME learning trajectory. Similarly, generic AI tutoring tools lack domain-specific pedagogical grounding in RME and ethnomathematics, often resulting in superficial feedback or direct answer-giving that short-circuits conceptual learning.

To address this critical gap, this study proposes a novel synthesis by developing an AI-Exploration-based Smart E-Module anchored in the traditional *Dakonan* game within an RME learning trajectory. This research delivers a dual original contribution: first, an instructional design contribution by establishing a reproducible, scalable framework that bridges indigenous ethnomathematics with RME learning trajectories through AI-driven heuristic scaffolding; and second, an empirical evidence contribution by providing empirical evaluation of the module's pedagogical efficacy in facilitating students' cognitive transition from situational to formal levels while enhancing numeracy literacy in Malang Regency. To guide this investigation, this study addresses three explicit research questions: (1) How is the RME-based learning trajectory, integrating traditional *Dakonan* game contexts and AI-Exploration, structurally designed to facilitate junior high school students' horizontal and vertical mathematization? (2) In what ways does the AI-supported intelligent scaffolding within the Smart E-Module differ from traditional static e-modules in diagnosing student learning bottlenecks and mitigating math anxiety? (3) To what extent does the implementation of the *Dakonan*-based AI-Exploration Smart E-Module significantly improve the numeracy literacy skills of junior high school students in Malang Regency?

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what extent does the implementation of the *Dakonan*-based AI-Exploration Smart E-Module significantly improve the numeracy literacy skills of junior high school students in Malang Regency?

## 2. Methods

This study employs a design research methodology of the validation studies type, integrating both qualitative and quantitative strands within a mixed-methods explanatory framework (Bakker, 2018). Specifically, quantitative data (pre-test and post-test scores) were utilized to measure overall changes in students' numeracy literacy performance, while qualitative data (classroom observations, chat logs, and clinical interviews) served to deeply examine and explain the students' cognitive transitions and interactions with the AI scaffolding throughout the learning trajectory. This design was chosen to systematically develop, test, and evaluate an instructional intervention comprising an AI-Exploration-based Smart E-Module that transforms traditional *Dakonan* mechanics into an RME-based learning trajectory.

The research was conducted during the odd semester of the 2025/2026 academic year at a partner junior high school in Malang Regency (specifically located in Wagir district). Participants were selected using purposive sampling based on specific criteria: the class had completed baseline algebraic foundation units, possessed basic digital literacy for tablet/web navigation, and had prior familiarity with traditional *Dakonan* game rules. The study involved a small pilot group of 6 students in Cycle 1 and an intact class of 32 eighth-grade students (comprising both male and female students with diverse academic abilities) in Cycle 2.

In accordance with the Design Research framework developed by Gravemeijer and Cobb (2006), this research stage is carried out through three iterative phases:

### 2.1. Preparing for the Experiment

In this initial phase, the researcher conducted an in-depth analysis of the Independent Curriculum, especially the elements of junior high school numeracy literacy, ethnomathematical deconstruction on *Dakonan* game mechanics, and mapping students' learning hurdles in algebra materials and number patterns. These insights informed the formulation of a **Hypothetical Learning Trajectory (HLT)** comprising: (1) learning objectives for numeracy, (2) *Dakonan*-based instructional activities, and (3) conjectured student learning processes paired with explicit didactical anticipations.

To ensure transparency and evaluability, the HLT operationalized specific learning hurdles and pedagogical responses as follows:

- **Hurdle 1 (Horizontal Mathematization - Modulo Bottleneck):** When students transition from physical stone distribution to abstract counting of seed distribution across houses (*lumbung*), they frequently encounter a bottleneck at the 7th or 8th seed iteration due to cyclic wrapping limits. *Conjectured student response:* Students restart manual counting from the beginning or lose track of grouping multiples. *Didactical anticipation:* The AI scaffolding is programmed to

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detect repeated errors within a 3-step sequence and deploy a prompt directing attention to grouping patterns (mod 7 or mod 8 cyclical remainder) rather than restarting manual counts.

- **Hurdle 2 (Vertical Mathematization - Algebraic Generalization):** When formalizing the total seed accumulation after n rounds, students often rely on additive recursion ($x_n = x_{n-1} + k$) rather than an explicit functional equation. *Conjectured student response:* Students struggle to construct a generalized formula for sequence patterns involving board storage holes. *Didactical anticipation:* The Smart E-Module presents visual partitioning in the digital simulator, and the AI chatbot issues heuristic scaffolding questions (e.g., *"How many seeds are added per full board cycle? Can you express total seeds without counting every single house?"*) without disclosing the algebraic formula.

Concurrently, the **Smart E-Module technical architecture** was developed on Google Sites as the host interface, embedding a custom HTML5/JavaScript interactive *Dakonan* simulator that logs student move coordinates and step durations in real time. The AI scaffolding was implemented using a secure LLM backend accessed via an embedded API widget, governed by strict *system-level prompt engineering* rules. The system prompt explicitly restricted the AI from giving direct mathematical answers, enforcing instead a Socratic pedagogical protocol: detecting learning difficulties via trigger conditions (such as inactivity exceeding 45 seconds or consecutive incorrect input attempts) and dynamically generating heuristic hints, probing questions, or visual redirection clues.

### 2.2. The Design Experiment

This phase evaluated the HLT in authentic classroom settings across two sequential cycles:
**Cycle 1 (Pilot Experiment):** Conducted with a small group of 6 students representing diverse academic abilities (high, medium, low). The primary aims were to test module usability, verify smooth AI chatbot interactions, and observe initial HLT alignment. Feedback from Cycle 1 guided refinements regarding button navigation responsiveness and prompt clarity prior to broader deployment.

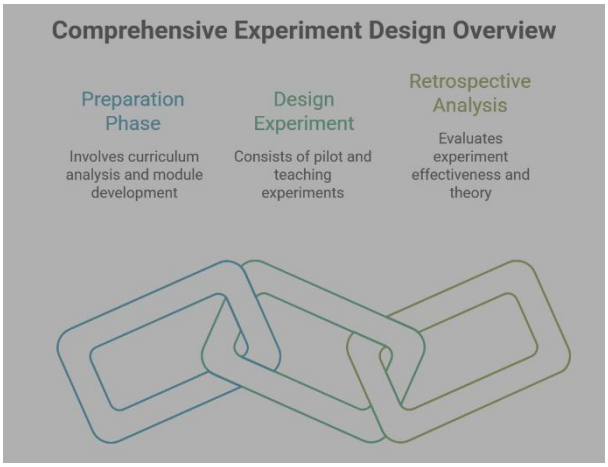
**Cycle 2 (Teaching Experiment):** Implemented in an intact classroom comprising 32 eighth-grade students at the partner junior high school. The primary researcher observed classroom dynamics and recorded field notes, while instruction was facilitated by a collaborating mathematics teacher who had been thoroughly briefed on the AI-RME pedagogical scenario.

### 2.3. Retrospective Analysis

In the final phase, all qualitative and quantitative data collected are comprehensively analyzed. Researchers critically compared the initial Hypothetical Learning Trajectory (HLT) with the Actual

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Learning Trajectory (ALT) observed in the classroom. By analyzing the discrepancies between student conjectures and actual behaviors across cycles, this analysis formulated preliminary principles for a Local Instructional Theory regarding how ethnomathematical contexts can be effectively digitized using adaptive AI scaffolding.




### 2.4. Data Collection and Analysis Techniques

Data were gathered through methodological triangulation (Miles et al., 2014):
Qualitative Data: Collected via classroom observation sheets tracking student engagement, student-AI chat history logs capturing real-time problem-solving paths, and unstructured clinical interviews administered when students encountered learning bottlenecks. Qualitative data underwent reduction, data display, and conclusion drawing.
Quantitative Data: Collected via pre-test and post-test numeracy instruments modeled after Minimum Competency Assessment (AKM) standards. Data normality was verified using the Kolmogorov-Smirnov test, followed by a paired-samples t-test and Normalized Gain (N-Gain) calculation to evaluate score changes (Hake, 1998).

## 3. Result and Discussion

### 3.1. Results of the Development of Smart E-Module "Dakon-Numeracy"

This research has successfully developed an AI-Exploration-based Smart E-Module media called the "Dakon-Numerasi" platform. This module is hosted on Google Sites and integrates the interactive visual simulator of the game *Dakonan* with an AI chatbot system based on prompt engineering.
Operationally, the chatbot detects student *learning hurdles* through a hybrid tracking mechanism combining frontend behavioral event listeners and backend trigger logic embedded in the interactive simulator. Specifically, the system continuously monitors two main interaction

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parameters: (1) **repeated erroneous inputs**, defined as three consecutive incorrect distribution moves or calculation entries within the same game state node, and (2) **prolonged idle time**, flagged when a student exhibits inactivity exceeding 45 seconds at a specific cognitive transition point (such as during modular grouping or algebraic generalization). Upon breaching these thresholds, the interface automatically transmits a telemetry event containing the current board state coordinates and student input history to the AI module, which then deploys contextual diagnostic prompting.

To ensure strict mathematical accuracy and safety, the AI's responses are governed by a multi-layered validation architecture:

1. **System-Level Prompt Constraints:** The underlying large language model is constrained by strict prompt rules prohibiting it from performing direct calculations or supplying final answers. Instead, it is programmed using a Socratic heuristic protocol that responds exclusively with guiding questions, analogical hints, or visual redirection clues.
2. **Deterministic Backend Guardrails:** Prior to rendering output to the user interface, automated regex and computational validation filters cross-check any numerical values mentioned in the AI's prompt against pre-computed mathematical matrices of the *Dakonan* board states. If an unverified or aberrant calculation is detected in the generated text, the system intercepts the response and falls back to a verified template-based pedagogical hint, ensuring the AI functions strictly as an ethical pedagogical guide rather than an unconstrained calculation engine.

### 3.2. Emergence of Student Thinking Levels in RME Framework Learning

Based on the results of the teaching experiment in Cycle 2, empirical data derived from classroom observations, video recordings, student work artifacts, and chatbot logs revealed a gradual cognitive transition of students through four distinct levels of Realistic Mathematics Education (RME) thinking, framed within the emergent modeling perspective (Gravemeijer, 1994; 2004):

1. **Situational Level:** At this initial stage, students operated directly within the context of the traditional *Dakonan* game using the digital simulator on Google Sites. Students explored the physical-virtual movement of seeds across houses (*lumbung*) and observed the empirical pattern of filled holes without conscious mathematical abstraction.
   - *Classification Evidence:* Students' actions were bound to game rules, characterized by trial-and-error movements and physical counting without recording intermediate states.
   - *Empirical Illustration:* Student S12 manipulated the simulator by manually clicking and dragging seeds one by one across 7 holes, remarking orally, *"If I start here, it stops at the small storehouse on the seventh house."*

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2. **Model-of Level**: Students transformed the concrete play activity into diagrammatic representations (such as sequential box charts and tally marks) to record and organize the distribution of *dakon* seeds. The model remained tied to the specific situation of the game.
   - *Classification Evidence:* Student artifacts showed descriptive drawings and tabular logs mapping out individual seed placement steps corresponding directly to physical board layouts.
   - *Empirical Illustration:* Student S05 sketched a series of connected boxes representing board holes, writing explicit tallies (e.g., 4, 4, 4, 4) to track how seeds were distributed per turn.

3. **Model-for Level** (Transition from Referential to General Strategy): Operating in accordance with the emergent modeling transition where informal representations shift into generalized mathematical tools, students discovered the repetition patterns of seed distribution. They utilized these diagrams no longer merely to describe the game, but as strategic mathematical tools to predict outcomes without manually shifting seeds one by one, thereby applying foundational principles of modular arithmetic (modulo n).
   - *Classification Evidence:* Classification at this level required students to substitute repetitive manual counting with numerical pattern rules in their written logs or chatbot interactions.
   - *Empirical Illustration (Chatbot Dialogue Excerpt):* Student S19: *"I keep counting one by one up to 32 seeds and I get confused about where it lands."* AI Scaffolding Bot: *"Look at your box chart from the previous round. How many houses does the board cycle through before repeating? Can you group the seeds by that number instead of counting each one?"* Student S19: *"Oh! Every 7 houses it repeats! So, 32 divided by 7 leaves a remainder of 4. It will land on house number 4!"*

4. **Formal Level**: Students successfully formulated formal algebraic expressions and modulo operation concepts to solve complex, non-routine numeracy literacy problems of the Minimum Competency Assessment (AKM) type.
   - *Classification Evidence:* Demonstrated by abstract mathematical expressions, accurate use of modulo notation, and successful transfer of the strategy to unfamiliar word problems.
   - *Empirical Illustration (Transition to Generalized Model):* Moving from informal representations, student S22 transitioned by observing that total seed accumulation (x_n) after n cycles followed a linear recursive pattern. During clinical interviews, S22 explained: *"At first, I just drew the board holes. Then I noticed the remainder is always the same cycle. So instead of drawing, I wrote the formula S_n = (k * n) mod 7 + R to calculate the final position for any large number of seeds."*

5. **Documenting Unexpected Pathways and Learning Hurdles**: Not all students progressed smoothly to the formal level. In Cycle 2, approximately 4 out of 32 students exhibited an *unexpected pathway* or stagnation at the Model-of level. For instance, student S08 experienced a cognitive bottleneck when attempting to generalize modular wrapping for non-uniform board configurations. Rather than applying division remainders, S08 reverted to additive recursion

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($x_n = x_{n-1} + 4$) and struggled to bridge the gap toward abstract algebraic notation. Analysis of the chatbot logs for these specific cases revealed that prolonged idle times (exceeding 60 seconds) and incorrect mental models of cyclic remainders required secondary, human-facilitated pedagogical intervention alongside the AI scaffolding.

### 3.3. The Effectiveness of Numeracy Literacy Escalation

To evaluate the score changes following the utilization of the Smart E-Module, an analysis was conducted on students' pre-test and post-test numeracy literacy results. A summary of the hypothesis test and N-Gain calculation is presented in Table 1.

**Table 1**
Results of Paired T-Test Analysis and Normalized Gain (N-Gain) of Students' Numeracy Literacy

| Measurement | Mean | Standard Deviation (SD) | t-count | df | p-value | Cohen's d |
|---|---|---|---|---|---|---|
| Pre-test | 52,40 | 8,12 | -14,25 | 31 | < .001 | 2.52 |
| Post-test | 78,50 | 6,45 | | | | |

Note. N = 32; Significance Levels= 0,05. the statistical results indicate a significant difference between students' numeracy literacy scores before and after the intervention. The mean score increases from 52.40 to 78.50 yielded an N-Gain value of 0.55, placing it in the medium category.

### 3.4. Analysis of AI Scaffolding and Anxiety Reduction Interactions

Qualitative analysis of the log history of students' interactions with AI chatbots revealed that this digital scaffolding successfully acted as an emotional and cognitive tutor. When a student experiences a learning hurdle (such as the confusion of determining the pattern of the 15th seed cycle), the AI chatbot provides a tiered response:
**Student:** "I'm confused, there are too many seeds to have to be counted manually."
**Chatbot AI**: "It's okay, let's see the pattern together! Notice that, after passing through 7 small holes, what happens to the next seed? How many seeds are left in your hands?" While a single dialogue excerpt cannot substantiate broad psychological claims regarding anxiety reduction—especially given the absence of formal anxiety instruments—these interaction logs qualitatively demonstrate that empathetic, structured prompting helped students overcome immediate hesitation and encouraged independent reasoning.

### 3.5. Discussion (Pembahasan)

The findings of this study strengthen the theory of realistic mathematics learning from Freudenthal (2002) which emphasizes that mathematics must be studied as an activity of reconstructing ideas by students themselves (guided reinvention). The Dakonan ethnomathematical context provides a

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concrete foundation that is rich in intuitiveness, so that students are not immediately crammed into abstract formal formulas. The integration of AI-Exploration in this e-module closes the main gap in traditional RME implementation, namely the limited time teachers have to provide individual feedback (Molenaar, 2022). The presence of artificial intelligence as intelligent scaffolding facilitates the Zone of Proximal Development (ZPD) of each student personally (Hwang & Tu, 2021). Combining local wisdom with adaptive technology contributed to substantial score improvements (N-Gain = 0.55) and fostered an engaging learning environment, while acknowledging that causal claims remain bounded by the single-group design.

## 4. Conclusion

The transformation of the traditional Dakonan game into an RME-based learning trajectory integrated within an AI-Exploration Smart E-Module demonstrates strong potential for enhancing junior high school students' numeracy literacy skills. Although formal product validation metrics were not extensively detailed, preliminary implementation indicates that the designed learning trajectory successfully facilitated systematic cognitive transitions from situational, referential (model-of), phenomenological (model-for), to formal levels.

The prompt-engineered AI scaffolding chatbot served a vital role as an adaptive digital guide in detecting and managing individual learning hurdles. Rather than claiming a reduction in math anxiety, qualitative logs confirm that the scaffolding successfully fostered student engagement and critical reasoning independence. Quantitatively, the effectiveness of this intervention was shown by an increase in the average score of numeracy literacy from 52.40 (pre-test) to 78.50 (post-test) with an N-Gain of 0.55 (medium category) and a statistically significant difference ($p = 0.000 < 0.05$). These findings offer initial empirical insights toward the refinement of Local Instructional Theory merging ethnomathematics with adaptive digital environments, laying the groundwork for future controlled experimental validations.

## 5. Acknowledgments

The author expresses his deepest appreciation and gratitude to the Institute for Research and Community Service (LPPM) Tribhuwana Tunggadewi University for funding support through the 2026 Fundamental Research Internal Grant. Gratitude was also expressed to the leadership of the Dean of FIP UNITRI, the Principal, the mathematics teacher, and the students of Mitra Junior High School in Malang Regency who have participated actively and cooperatively during the implementation of this research experiment.

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