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The Development of E-Content to Increase Students' Problem-Solving Accuracy on Cryptarithmetic Tasks Through Dual-Process Interaction

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ABSTRACT

E-content that delivers learning materials in a massive, inclusive, and interactive manner with flexible access is widely favored by students, including learning applications related to cryptarithmetic and its problem-solving tasks. Learning cryptarithmetic can stimulate students' problem-solving accuracy. Therefore, this study aimed to develop EKOSISTEM (Cryptarithmetic-Based Fun-Problem E-Content) to enhance students' problem-solving accuracy through dual-process interaction. The development of EKOSISTEM followed the Plomp development model. The instruments developed included the EKOSISTEM media, a rubric for dual-process interaction indicators, observation sheets, validation sheets, semi-structured interview guidelines, and an interview recording device. The results showed that the EKOSISTEM learning media was found to be valid, practical, and effective for use in the learning process. The validation results yielded an average score of 93% (very valid) from Validator 1 and 82.8% (valid) from Validator 2. The practicality test indicated positive responses, with scores of 65.42% from students and 85.71% from teachers, categorized from practical to very practical. The effectiveness test showed a significant difference in students' problem-solving accuracy before and after the use of EKOSISTEM, as indicated by the Wilcoxon test result (Sig. = .014 < .05). Furthermore, the effect size analysis yielded an r value of .48, which falls within the interval .30 ≤ r< .50. Therefore, EKOSISTEM has a medium effect on improving students' problem-solving accuracy. Accordingly, the EKOSISTEM media is considered valid, feasible, and effective in improving students' problem-solving accuracy.

KEYWORDS

E-content; Cryptarithmetic; dual-process; problem-solving.

INTRODUCTION

Ruang Guru, one of the largest tutoring institutions in Indonesia, initiated an educational game show called Class of Champions, which gained high popularity among students. The event supports Indonesian education programs by promoting problem-solving activities. One of its sections, Cryptarithm War, required participants to solve mathematical logic puzzles quickly. Cryptarithmetic-based problem-solving plays an important role in students' cognitive processes, especially in addressing higher-order problems (Doroudi, 2023; Mintzberg, 2022). This activity supports the achievement of the content and process standards of Mathematics learning in Indonesia. However, many students are still unfamiliar with cryptarithmetic and how to solve such problems.

Cryptarithmetic problem-solving requires adequate reasoning (Chen, 2025; Hynek & Medková, 2022). Reasoning involves memory and mental processes used to generate solutions. The dual-process theory refers to the mental processes in reasoning, consisting of System 1 and System 2 (Nugroho et al., 2024). System 1 is characterized by automatic, subjective-empirical, and unconscious processes (Darmawan et al., 2020), producing fast and intuitive responses. Meanwhile, System 2 is marked by conscious processes and empirical accuracy, producing slower but more analytical responses. Reasoning involves the interaction between these two systems. Systematic and structured management of students' dual-process interactions can improve accuracy in solving cryptarithmetic problems, as each interaction type has distinct reasoning characteristics.

Dual-process theory of reasoning involves the interaction between System 1 and System 2 (Nugroho et al., 2024). Problem-solving accuracy is closely related to the types of dual-process interactions, including default-interventionist interaction and the parallel-competitive interaction at each level of reasoning (Sari et al., 2020). In the default-interventionist interaction, System 1 becomes active before System 2. Meanwhile, in the parallel-competitive interaction, System 1 is active simultaneously with System 2. Other types of dual-process interactions include the "System 2 Triggers System 1" interaction and a combined interaction that integrates the three previously mentioned types (Darmawan et al., 2020; Darmawan et al., 2021; Susiswo et al., 2024).

The characteristics of dual-process interaction can benefit students if managed properly. Such management can be achieved by habituating students to solve problems so that the activation of specific types of dual-process interactions becomes relevant to the problem being addressed. Problem-solving practice that is designed in an engaging way can enhance students' motivation and interest in learning. Motivation and interest serve as the foundation for improving students' learning outcomes, particularly their problem-solving accuracy. However, various studies have shown that students continue to demonstrate inaccuracies when solving mathematical problems. The errors experienced by students consist of procedural and conceptual mistakes, one cause of which is that students provide intuitive responses without responding analytically. This indicates that improving problem-solving accuracy cannot be

achieved solely by using digital media without problem designs that facilitate the reasoning process, such as cryptarithmetic (Elizar et al., 2026). Furthermore, the stimulation of cryptarithmetic-based problem-solving skills has never been explored by experts. Therefore, it is important to create an innovative breakthrough through the development of cryptarithmetic-based fun-problem e-content to stimulate students' problem-solving accuracy.

Fun-problem e-content has been proven to increase students' interest in learning mathematics (Asenova et al., 2023; Shemy, 2022). This is because fun-problem e-content, which presents problem-solving activities interactively, can be accessed flexibly by students (Bhatnagar & Sharma, 2023; Kannusamy, 2023; Manzi & Moreeng 2024; Orazali, 2025). Meanwhile, cryptarithmetic is a topic that has attracted considerable interest from students since it was featured in the Cryptarithm War section of the viral game show Class of Champions in 2024. Cryptarithmetic-based fun-problem e-content, which presents mathematical logic puzzles interactively, can serve as a stimulus to enhance students' problem-solving accuracy.

Stimulating students' problem-solving accuracy through e-content uploaded on digital platforms such as TikTok, Instagram, YouTube, and Spotify is effective (Asenova et al. 2023; Pouw et al., 2023; Reskianissa et al., 2022). Digital platforms have the potential to reach a broad audience due to content delivery algorithms tailored to user interests and interactions (Hu & Ou, 2025). Moreover, the Cryptarithmetic-Based Fun-Problem E-Content (EKOSISTEM) developed in this study is highly relevant to students' needs. This is because digital platforms enable uploaded content to gain high popularity, thereby encouraging discussions in the comment sections among viewers. Through such discussions, EKOSISTEM can reach a wider audience of viewers who engage with the e-content uploaded on digital platforms.

Digital platforms can also facilitate students in acquiring knowledge not covered in formal school education, including cryptarithmetic and its solutions to stimulate problem-solving accuracy. However, no application on digital platforms currently provides cryptarithmetic material, fun-problem e-content related to cryptarithmetic, instructional videos on cryptarithmetic and its solutions, Spotify audio podcasts presenting mathematical logic puzzles as a supplementary material for cryptarithmetic courses, digital gamification slides that deliver information about cryptarithmetic, or interactive gamification-based assessment tools to measure students' cryptarithmetic skills. Yet, such cryptarithmetic learning applications are popular among students and are essential for stimulating problem-solving accuracy. Therefore, EKOSISTEM (Cryptarithmetic-Based Fun-Problem E-Content) is an important innovation. If EKOSISTEM is unavailable, students may rely on cryptarithmetic learning resources that are unvalidated, impractical, and inefficient, which may lower their problem-solving ability.

Based on the research focus, covering content structure, process structure, and the theoretical foundation of dual-process theory, the research and development of EKOSISTEM occupy a distinct position compared with previous studies. The main novelty of this research is the development of learning media aimed at improving students' problem-solving accuracy through dual-process theory. Table 1 provides a summary of this comparison.

Table 1.

Position of This Research

Researcher (Year)	Focus	Result
Daryanes et al. (2023)	Developing interactive learning media using Articulate Storyline 3 and analyzing students' responses to the media through a case study approach to foster students' problem-solving skills.	The Articulate Storyline-based interactive learning media developed using the case-study approach can improve students' problem-solving abilities.
Pujiastuti et al. (2020)	Development of interactive e-content for mathematics learning.	E-content supports mathematical critical thinking skills and addresses students' learning needs in mathematics.
Darmawan et al. (2020) and Susiswo et al. (2024)	Students' dual processes in solving mathematical problems.	The dominance of one system (System 1 or System 2) influences students' problem-solving accuracy.
Rofiki et al. [this current research]	Development of e-content to improve students' problem-solving accuracy in cryptarithmetic through dual-process interaction.	EKOSISTEM is valid, practical, and effective in improving students' problem-solving accuracy.

Table 1 presents a summary of previous studies related to the development of interactive learning media and students' problem-solving processes in mathematics learning. Several studies, including those by Daryanes (2023) and Pujiastuti et al. (2020), focused on the development of interactive learning media and e-content to support students' problem-solving abilities and mathematical critical thinking. Furthermore, the studies conducted by Darmawan et al. (2020) and Darmawan et al. (2024) specifically examined students' dual processes (System 1 and System 2) in solving mathematical problems and revealed that the dominance of one cognitive system significantly affects students' problem-solving accuracy. However, these studies were conducted separately, either emphasizing media development without integrating a dual-process theoretical framework or analyzing dual processes without embedding them into interactive e-content design. Moreover, none of the previous studies addressed cryptarithmetic-based problem-solving as a learning context. Therefore, this research fills this gap by developing EKOSISTEM, an interactive cryptarithmetic-based e-content explicitly designed to enhance students' problem-solving accuracy through structured dual-process interaction. The aim of this study was to develop EKOSISTEM, an interactive cryptarithmetic-based application designed as a trigger for dual-process interaction to enhance students' problem-solving accuracy. This study contributes to two aspects, namely, theoretical and practical contributions. Its theoretical contribution is to provide additional insights into

problem-solving and dual-process theory. Meanwhile, the practical contribution is that the EKOSISTEM platform can be used by teachers to develop students' problem-solving skills.

The study seeks to analyze the process and outcomes of developing EKOSISTEM (Cryptarithmetic-Based Fun-Problem E-Content) to ensure that it meets the criteria of validity, practicality, and effectiveness, characterize students' problem-solving accuracy in solving cryptarithmetic problems, and analyze students' dual-process interactions during cryptarithmetic problem-solving. Accordingly, the two research questions are as follows.

1. How is the development process of the EKOSISTEM learning media to increase students' problem-solving accuracy on cryptarithmetic tasks through dual-process interaction?
2. To what extent does the EKOSISTEM learning media meet the criteria of validity, practicality, and effectiveness in improving students' problem-solving accuracy on cryptarithmetic tasks through dual-process interaction?

LITERATURE REVIEW

Dual-Process Theory in Mathematical Problem-Solving

When solving mathematical problems, individuals usually produce responses intuitively, with a dominance of System 1, based on pattern recognition or previous experience. These responses can then be modified, accepted, or even rejected after undergoing a more in-depth analytical and verification process conducted through the activation of System 2 dominance (Darmawan et al., 2020; Nugroho et al., 2024; Sari et al., 2020). However, students' success in solving mathematical problems is not limited to the dominance of these two systems but also depends on the ability to manage the interaction between System 1 and System 2 during the reasoning process. An effectively functioning interaction enables individuals to integrate speed and accuracy, thereby producing more precise solutions. Conversely, reasoning accompanied by an imbalanced interaction between System 1 and System 2 can result in procedural and conceptual errors (Darmawan et al., 2021; Susiswo et al., 2024).

Cryptarithmetic as a Mathematical Reasoning Task

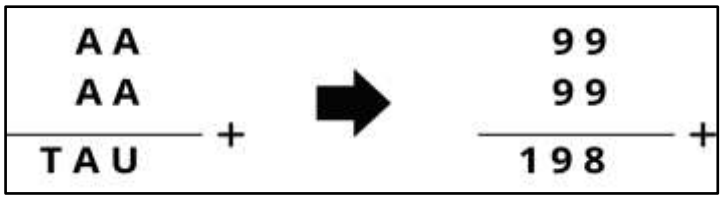
Cryptarithmetic is a problem in the form of an arithmetic puzzle involving numerical operations (Doroudi, 2023; Mintzberg, 2022). In a cryptarithmetic problem, digits in numerical operations are replaced with letters or other symbols. These letters or symbols can only represent integers from 0 to 9. There are two rules that must be observed: (1) the leading letter cannot be 0, and (2) each letter must be unique and represent a different number. To solve this problem, one must determine the value or number assigned to each letter or symbol while ensuring that the rules of numerical operations apply. An example of a cryptarithmetic problem is shown in Figure 1.

Figure 1 presents a cryptarithmetic problem, for which the formula is $AA + AA = TAU$, where the solution is that A is 9, T is 1, and U is 8, confirming that $99 + 99 = 198$. To solve this problem, logical reasoning is required to identify relationships between letters, test and

eliminate various possibilities, and verify the correct solution based on the applicable rules (Chen, 2025; Hynek & Medková, 2022).

Figure 1.

An Example of a Cryptarithmetic Problem



E-Content for Mathematical Problem-Solving

The development of digital technology has changed the way mathematics is learned by enabling the development of digital learning content (e-content) that supports interactive and student-centered learning (Darmawan et al., 2026; Lestari et al., 2024). E-content is digital learning material that combines various multimedia elements, such as text, images, audio, video, animation, simulation, and interactive activities (Bankar et al., 2023). The integration of these multimedia elements allows students to actively interact with the learning material through exploration, practice, immediate feedback, and reflection. This learning experience enhances students' engagement in exploring, reflecting, and evaluating problem-solving strategies. In addition, e-content can improve individual learning experiences and motivation to solve mathematical problems (Bhagwonparsadh & Pule, 202; Maulana et al., 2022; Warsitasari & Rofiki, 2024).

Previous studies have shown that e-content can enhance problem-solving abilities by providing interactive learning experiences, immediate feedback, or opportunities for students to reflect on their problem-solving processes (Darmawan et al., 2026; Gultom et al., 2025; Maulana et al., 2022; Warsitasari & Rofiki, 2024). The available features help students explore various strategies, identify errors, and correct them, resulting in more accurate solutions. Nevertheless, the effectiveness of e-content in enhancing problem-solving skills has not yet fully shown consistent results. Some studies indicate that e-content cannot directly improve problem-solving skills if it only functions as a tool to deliver material without encouraging cognitive engagement (Désiron, et al., 2023; Abdulrahaman et al., 2020). In such cases, e-content tends to improve students' motivation and engagement, but its contribution to higher-order reasoning skills remains limited when it is not supported by instructional designs that actively engage learners in cognitive processing. These findings indicate that the success of e-content depends not only on the use of technology but also on instructional design that can facilitate students' thinking processes. Despite these findings, most of these studies still focus on improving general mathematical problem-solving skills and have not specifically developed e-content designed to facilitate the interaction dual process.

METHOD

Research Design

This study employed a Research and Development (R&D). The study aimed to develop EKOSISTEM (Cryptarithmetic-Based Fun-Problem E-Content) and evaluate its validity, practicality, and effectiveness in improving students' problem-solving accuracy. The development of EKOSISTEM followed the Plomp development model, which consists of three phases (Plomp, 2013). The first phase was preliminary research and instrument development. During this phase, the researchers conducted a literature review and a needs analysis to identify existing problems, students' abilities, learning conditions, and learners' needs in studying cryptarithmetic. The second phase was the prototyping phase, during which Prototype I was designed and developed based on the findings of the preliminary research. Prototype I of EKOSISTEM was developed as a web-based learning platform designed to enhance students' accuracy in solving cryptarithmetic problems through dual-process interaction. The prototype comprised six integrated components: (1) Fundamental Concepts, (2) Cryptarithmetic Problem-Solving, (3) Adventure Game, (4) Interactive Assessment, (5) User Guide, and (6) General Information. During this phase, the researchers also designed the prototype architecture, developed all multimedia learning components, and conducted expert validation to obtain feedback for refining Prototype I prior to small-group trials, resulting in Prototype II. At this stage, research instruments were developed and tested to determine whether they were valid and reliable. The third phase was the assessment phase, in which Prototype II was evaluated to determine whether it met the criteria for validity, practicality, and effectiveness, thereby establishing its suitability for implementation in mathematics learning.

Participants and Research Setting

The participants were ninth-grade junior high school students from Banyuwangi Regency, East Java, Indonesia. This study involved 15 students as respondents in the validation and reliability tests of the instrument before implementation. Meanwhile, the implementation, practicality, and effectiveness tests of EKOSISTEM involved 26 students as participants. The researchers also conducted interviews with four students to gain deeper insights into improvements in their problem-solving accuracy. All students involved were from different classes within schools at the same level. Furthermore, a purposive sampling technique was used to select the sample classes based on teacher recommendations and students' learning experiences. The students selected for the study had already understood the prerequisite material, namely arithmetic. In addition, the students had studied cryptarithmetic problem-solving using EKOSISTEM and had completed both the pretest and posttest. Next, the pretest and posttest data were analyzed using a one-group pretest-posttest method. Consequently, the findings of this study cannot yet be generalized to all students. However, they may be applied to students with similar characteristics. Furthermore, this study involved not only students but also teachers and mathematics education experts. For the practicality evaluation, the researchers involved a mathematics teacher who acted as the implementer of the EKOSISTEM. For the validity

evaluation, the researchers engaged two doctoral-qualified lecturers who are experts in mathematics education to evaluate the validity of EKOSISTEM.

Need Analysis

A needs analysis was conducted through classroom observations and a literature review to identify students' problems and learning needs related to cryptarithmetic problem-solving. The findings indicated that no digital learning media had been specifically developed to facilitate cryptarithmetic learning and improve students' problem-solving accuracy. Therefore, these findings served as the basis for the development of EKOSISTEM.

Initial Design

Based on the results of the needs analysis, Prototype I of EKOSISTEM was developed as a web-based learning medium. The initial design comprised six main modules that integrated interactive multimedia based on dual-process theory to support students' cryptarithmetic problem-solving. Before conducting a small-scale trial, an alpha test was carried out from the researchers' perspective. In this study, alpha testing was conducted using black box testing. Black box testing was performed to verify that the prototype of EKOSISTEM was free of errors and bugs so that it could function optimally. The prototype was subsequently validated by experts and revised accordingly, while the research instruments underwent empirical validity and reliability testing before being administered in the preliminary study. The empirical validity of test items was conducted and analyzed using the Pearson product-moment correlation coefficient. An item was considered valid if the calculated correlation coefficient (r-test) is greater than the critical value of the Pearson correlation coefficient (r-table) at the chosen significance level ($\alpha = .05$), adjusted according to the sample size. The reliability testing of the pretest and posttest instruments was done using the Intraclass Correlation Coefficient (ICC) and Cronbach's Alpha (CA). ICC was used to assess the interrater reliability by measuring the consistency of the total scores assigned by the raters, while CA was used to evaluate the internal consistency of the test items. The criteria for the Intraclass Correlation Coefficient (ICC) test are shown in Table 2.

Table 2.

The Criteria for the Intraclass Correlation Coefficient (ICC)

Score Rank	Criteria
$x < .50$	Poor
$.50 \leq x < .75$	Moderate
$.75 \leq x < .90$	Good
$x \geq .90$	Excellent

(Source: Koo & Li, 2016)

In the reliability test, the pretest and posttest results were assessed by two evaluators who held bachelor's degrees in mathematics education and had more than two years of

teaching experience at the junior high school level. Both evaluators used the same assessment rubric based on problem-solving accuracy indicators to maintain consistency and objectivity in the assessment process. The reliability of the pretest and posttest instruments was evaluated using Cronbach's Alpha. An instrument was considered reliable if the Cronbach's Alpha value was at least .70; otherwise, it was categorized as not reliable (Groenwold, 2018). If the reliability test results indicated reliability, the pretest and posttest instruments were considered suitable for the use in the study. In addition, a validated semi-structured interview guide was used to further explore students' responses regarding problem-solving processes and the features of the EKOSISTEM media.

Validity of EKOSISTEM

The validators completed validation questionnaires containing assessment items corresponding to the aspects observed for the purpose of tabulating data scores from the EKOSISTEM assessment. The EKOSISTEM validation used a Likert scale ranging from 1 (very poor) to 5 (very good). The validators' assessment data were analyzed using the following validity formula.

$$Validity\ (V) = \frac{Total\ score}{Maximal\ score} \times 100\%$$

From the validity scores obtained, the researchers categorized the validity level of the EKOSISTEM learning media according to the validity criteria presented in Table 3.

Table 3.

Validity Criteria

Score	Criteria
$85\% \leq V \leq 100\%$	Very valid
$70\% \leq V < 85\%$	Valid
$50\% \leq V < 70\%$	Less valid
$1\% \leq V < 50\%$	Not valid

EKOSISTEM to enhance students' problem-solving accuracy was considered valid if the validity percentage was $\geq 70\%$.

Practicality of EKOSISTEM

For the practical test, data tabulation was collected from a teacher and 26 students through the EKOSISTEM practicality questionnaire. The scoring guidelines for the EKOSISTEM practically test used a Likert scale ranging from 1 (very poor) to 5 (very good). The data obtained from the teacher responses were analyzed using a practicality analysis technique with the following formula.

$$Practicality\ percentage\ (P) = \frac{Total\ score}{Maximal\ score} \times 100\%$$

From the average scores obtained, the researchers categorized the practicality of the EKOSISTEM teaching media according to the practicality criteria presented in Table 4. EKOSISTEM to enhance students' critical thinking was considered practical if the practicality percentage was $\geq 60\%$

Table 4.

Practicality Criteria

Score	Criteria
$80\% \leq P \leq 100\%$	Very practical
$60\% \leq P < 80\%$	Practical
$40\% \leq P < 60\%$	Quite Practical
$20\% \leq P < 40\%$	Less practical
$0\% \leq P < 20\%$	Not practical

Effectiveness of EKOSISTEM

The effectiveness of EKOSISTEM was evaluated based on students' learning outcomes after using the media. Students' learning outcomes were measured through pretest and posttest scores. The data were analyzed quantitatively using a one-group pretest–posttest design with SPSS, following these steps.

1. The researchers collected the pretest and posttest scores.
2. The data collected for the dual-process-based problem-solving aspects were entered into the software for further analysis.
3. The researchers tested the normality of the differences between the pretest and posttest scores for each aspect using the Shapiro–Wilk test. If the significance value was greater than .05, the data were considered normal. Conversely, if the significance value was less than or equal to .05, the data were considered non-normal.
4. The researchers continued the analysis based on the results of the normality test. Normally distributed data were analyzed using a paired-sample t-test, while non-normally distributed data were analyzed using a paired-sample t-test, while non-normally distributed data were analyzed using the Wilcoxon Signed-Rank Test.
5. In each test, the researchers applied a significance level of α = .05.
6. This study examined whether there were differences in the problem-solving accuracy observed in students. The following hypotheses were tested.

H_o: There was no significant difference in students' problem-solving accuracy before and after using the EKOSISTEM media ($p > .05$).

H_1: There was a significant difference in students' problem-solving accuracy before and after using the EKOSISTEM media ($p \leq .05$).

After analyzing the differences in students' problem-solving accuracy before and after using the EKOSISTEM media, the researchers conducted calculations using the Wilcoxon Effect Size Test. These calculations were conducted to determine the effect size of using EKOSISTEM on students' problem-solving accuracy. The formula for the Wilcoxon effect size is presented as follows.

$$r = \frac{|Z|}{\sqrt{n}}$$

In this formula, r is the effect size value, Z is the Wilcoxon test statistic value, and n is the number of samples or data pairs analyzed. Based on the calculated value, the researchers categorized the effect size of the EKOSISTEM learning media according to the criteria presented in Table 5.

Table 5.

Wilcoxon Effect Size Test Criteria

Range of r Values	**Effect Size**
$r < .30$	Small
$.30 \leq r < .50$	Medium
$.50 \leq r$	Large

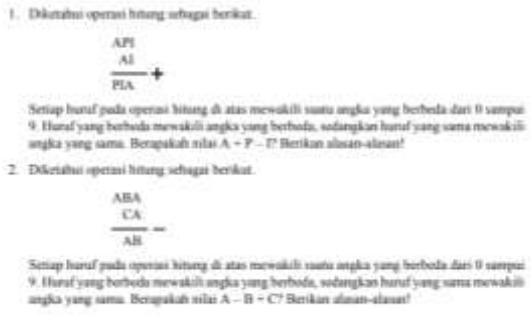
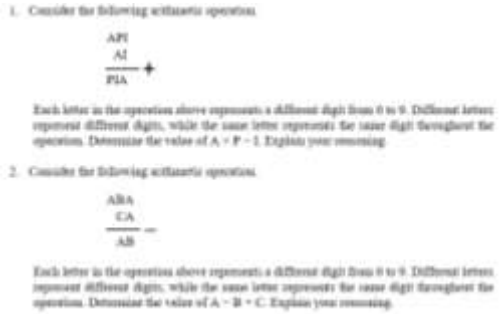
(Source: Cohen, 1992)

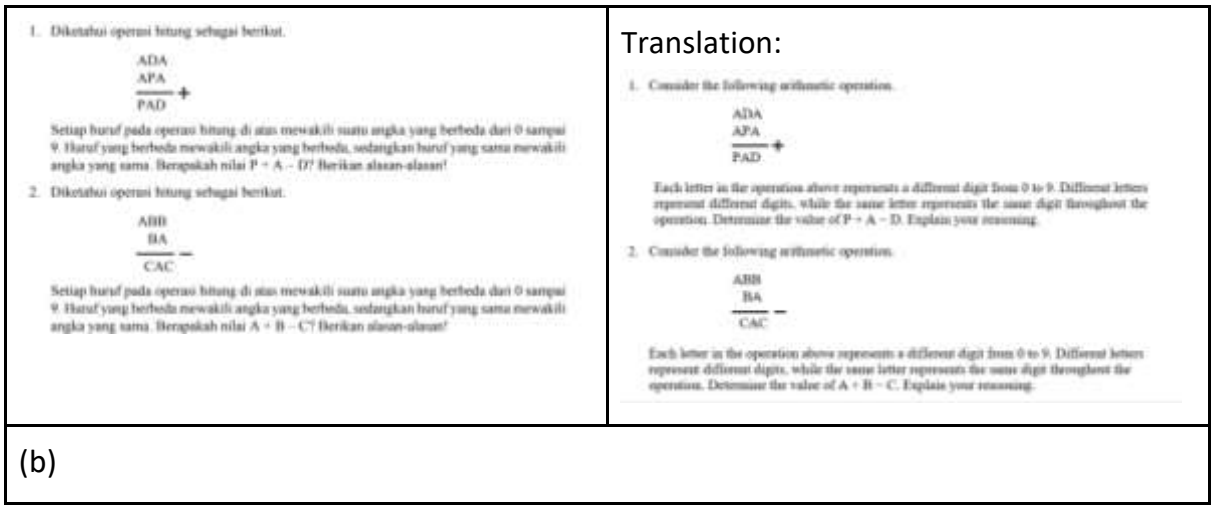
Data Collection Techniques and Research Instruments

Data collection was carried out through the development of instruments designed to evaluate the learning media. The instruments developed included the EKOSISTEM media, a rubric for dual-process interaction indicators, observation sheets, validation sheets, semi-structured interview guidelines, an interview recording device, and pretest and posttest instruments. The pretest and posttest instruments are presented in Figure 2.

Figure 2.

(a) Pretest Questions; (b) Posttest Questions

<table>
<tr>
<td>
1. Diketahui operasi hitung sebagai berikut.
API
AI
PIA +
Setiap huruf pada operasi hitung di atas mewakili suatu angka yang berbeda dari 0 sampai 9. Huruf yang berbeda mewakili angka yang berbeda, sedangkan huruf yang sama mewakili angka yang sama. Berapakah nilai A + P – I? Berikan alasan-alasan!
2. Diketahui operasi hitung sebagai berikut.
ABA
CA
AB –
Setiap huruf pada operasi hitung di atas mewakili suatu angka yang berbeda dari 0 sampai 9. Huruf yang berbeda mewakili angka yang berbeda, sedangkan huruf yang sama mewakili angka yang sama. Berapakah nilai A – B + C? Berikan alasan-alasan!</td>
<td>Translation:

1. Consider the following arithmetic operation.
API
AI
PIA +
Each letter in the operation above represents a different digit from 0 to 9. Different letters represent different digits, while the same letter represents the same digit throughout the operation. Determine the value of A + P – I. Explain your reasoning.
2. Consider the following arithmetic operation.
ABA
CA
AB –
Each letter in the operation above represents a different digit from 0 to 9. Different letters represent different digits, while the same letter represents the same digit throughout the operation. Determine the value of A – B + C. Explain your reasoning.</td>
</tr>
<tr>
<td colspan="2">(a)</td>
</tr>
</table>


1. Diketahui operasi hitung sebagai berikut.

ADA
APA
PAD +

Setiap huruf pada operasi hitung di atas mewakili suatu angka yang berbeda dari 0 sampai 9. Huruf yang berbeda mewakili angka yang berbeda, sedangkan huruf yang sama mewakili angka yang sama. Berapakah nilai P + A – D? Berikan alasan-alasan!

2. Diketahui operasi hitung sebagai berikut.

ABB
BA
CAC –

Setiap huruf pada operasi hitung di atas mewakili suatu angka yang berbeda dari 0 sampai 9. Huruf yang berbeda mewakili angka yang berbeda, sedangkan huruf yang sama mewakili angka yang sama. Berapakah nilai A + B – C? Berikan alasan-alasan!

Translation:

1. Consider the following arithmetic operation.

ADA
APA
PAD +

Each letter in the operation above represents a different digit from 0 to 9. Different letters represent different digits, while the same letter represents the same digit throughout the operation. Determine the value of P + A – D. Explain your reasoning.

2. Consider the following arithmetic operation.

ABB
BA
CAC –

Each letter in the operation above represents a different digit from 0 to 9. Different letters represent different digits, while the same letter represents the same digit throughout the operation. Determine the value of A + B – C. Explain your reasoning.

(b)

The instruments presented in Figure 2 were used in the effectiveness test to evaluate the EKOSISTEM media. Furthermore, the remaining research instruments were validated by two experts, namely a content expert and an educational technology media expert. The validators were required to have at least ten years of teaching experience and hold a doctoral degree in mathematics education. The validation and trial processes generated both qualitative and quantitative data. Furthermore, the developed instruments were tested for practicality by mathematics teachers and for effectiveness by analyzing students' learning outcomes and problem-solving accuracy based on dual-process theory after using EKOSISTEM. The collected data were then categorized according to the evaluated aspects, namely the validity, practicality, and effectiveness of EKOSISTEM.

FINDINGS

Preliminary Study

The first phase was the preliminary study and the formulation of research instruments. In this phase, the researchers employed observations and a qualitative approach to identify and analyze students' needs, which included cryptarithmetic material, application features preferred by students, and the required e-content products. The observation results indicated that there were no digital learning media available to support cryptarithmetic learning. Furthermore, several issues were identified, including students' lack of understanding of the precise steps required to solve cryptarithmetic problems, as well as their difficulties with mental calculation processes. The preliminary study revealed errors made by students in solving cryptarithmetic problems. The errors were primarily due to students' misunderstanding of cryptarithmetic rules. The data obtained from the needs analysis and the preliminary study were used as the basis for the development of the EKOSISTEM website in the subsequent phase, namely, the prototyping phase. Therefore, Figure 3 illustrates examples of the errors made by students when solving the cryptarithmetic problems.

Figure 3 (a) presents a cryptarithmetic-based mathematical problem to be solved by students, while Figure 3 (b) illustrates the students' errors in solving the problem. In Figure 3 (b) part (i), the student made an error by writing the result as a two-digit number, namely 48. In

fact, according to the procedure, the addition should have yielded QRR in a three-digit number. This indicates that the student did not fully understand the procedure for solving cryptarithmetic problems. Furthermore, in Figure 3 (b), part (ii), the student misinterpreted $PQ + PQ = QRR$ as $89 + 89 = 188$. The error occurred in the interpretation of QRR because the student represented it as 188. This violated the basic rule of cryptarithmetic, in which each letter must represent a unique digit. In the student's answer, both P and R were assigned the value of 8, resulting in inconsistency. Consequently, the student misunderstood the fundamental rule of cryptarithmetic regarding the one-to-one correspondence between letters and digits. In addition, in Figure 3 (b), part (iii), the student again made an error by writing a result inconsistent with cryptarithmetic rules. The student solved $PQ + PQ = QRR$ as $94 + 94 = 188$, thereby assigning two different values to Q, namely $Q = 4$ and $Q = 1$. However, in cryptarithmetic each letter can represent only a single digit. Therefore, the student experienced a misconception in applying the rules of cryptarithmetic problem-solving. These misconceptions indicate that the reasoning employed by the student in solving cryptarithmetic problems remains limited.

Figure 3.

(a) Cryptarithmetic-Based Mathematics Problem; (b) Students' Errors in Solving Cryptarithmetic Problems

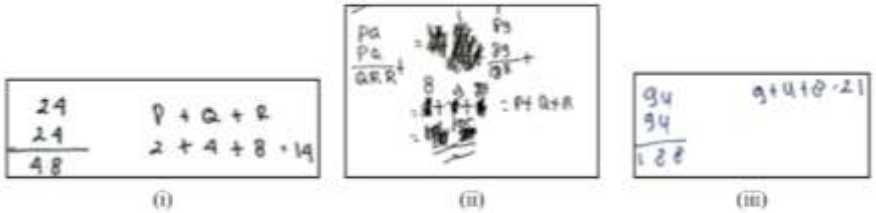
(a)

Consider the following arithmetic operation.

PQ
PQ +
QRR

Each letter in the arithmetic operation above represents a different digit from 0, 1, 2, 3, 4, 5, 6, 7, 8, or 9. Different letters represent different digits, while the same letters represent the same digit. What is the value of P + Q + R? Provide your reasoning!

(b)



(i) (ii) (iii)

Based on the preliminary study, these problems were addressed through the development of a website that provides clear problem discussions and presents an attractive and interactive interface. Therefore, EKOSISTEM was designed to serve as a solution by offering educational videos, audio podcasts, and engaging educational adventure games, accompanied by adaptive step-by-step simulation exercises. The integration of various interactive multimedia becomes the main differentiator between the EKOSISTEM media and other cryptarithmetic e-learning content, which generally present materials and exercises separately. Through the integration of learning components within a single platform, EKOSISTEM provides a more dynamic, interactive, and in-depth learning experience, making it more relevant to students'

learning needs. Accordingly, the EKOSISTEM blueprint was developed to define the product specifications, including the learning objectives, the integration of dual-process theory into the media design, the web-based platform, interactive multimedia features, and the design of six main menus: Basic Concepts of Cryptarithmetic, Cryptarithmetic Problem-Solving, Adventure Game, Assessment, User Guide, and Media Information. The blueprint is shown in Figure 4.

Figure 4.

Blueprint of EKOSISTEM



The blueprint in Figure 4 served as a reference for the development of Prototype I during the prototyping phase. The blueprint systematically outlines the features of EKOSISTEM, starting with the home page, followed by the main menu, concept learning, cryptarithmetic problem-solving, adventure games, and assessments. This demonstrates that all learning components were systematically designed prior to the development of Prototype I.

Prototyping Phase

The second phase was the prototyping stage, which focused on designing research instruments for the pretest, the posttest, and the EKOSISTEM media. The development of the pretest and posttest instruments was conducted to measure students' problem-solving accuracy before and after using the media. In addition, the prototyping phase aimed to produce a functional EKOSISTEM prototype that could be evaluated in terms of pedagogy, content, technology, visual and multimedia design, engagement and motivation, as well as accessibility and affordability aspects.

Prototyping Pretest and Posttest Instruments

In the phase of designing pretest and posttest instruments, validity and reliability tests were also conducted. Validity testing was carried out using two types: expert validation and empirical validation. Empirical validity testing was conducted using the Pearson product-moment correlation coefficient. Meanwhile, reliability testing was conducted using the ICC and Cronbach’s Alpha, which involved 15 respondents. The results of the expert validity test are shown in Table 6.

Table 6.

Results of the Expert Validity Test on the Test Instrument

Test Instrument	Aspect	Average Score of Validator 1	Average Score of Validator 2
Pretest	Material	3.50	3.25
	Language	3.00	3.25
	Question Construction	3.25	3.50
	Total Average	3.25 (81.25%)	3.33 (83.33%)
Posttest	Material	3.50	3.75
	Language	3.25	3.75
	Question Construction	3.50	3.50
	Total Average	3.42 (85.42%)	3.67 (91.67%)

Based on Table 6, the expert validation results for the pretest and posttest instruments showed positive evaluations. The pretest instrument received an average score of 3.25 (81.25%) from Validator 1 and 3.33 (83.33%) from Validator 2. Meanwhile, the posttest instrument scored an average of 3.42 (85.42%) from Validator 1 and 3.67 (91.67%) from Validator 2. Therefore, the instruments met the criteria for validity according to the experts. Next, the researchers conducted empirical validity testing on the pretest and posttest instruments. The results of the empirical validation of the pretest are presented in Table 7.

Table 7.

Results of the Pearson Product-Moment Correlation Validity Test

No	Test Instrument	r-test	Validity
1	Pretest	Question 1: $.776 > .514$	Question 1: Valid
		Question 2: $.678 > .514$	Question 2: Valid
2	Posttest	Question 1: $.659 > .514$	Question 1: Valid
		Question 2: $.855 > .514$	Question 2: Valid

Table 8 shows that the pretest and posttest questions were considered valid because all the r-test values for each question item were greater than the r-table value (.514). Thus, all question items met the criteria for empirical validity and were suitable to be used as research instruments. Furthermore, to ensure that the instrument provided consistent measurement results, a reliability test was conducted.

The reliability testing of the pretest and posttest instruments was conducted using the Intraclass Correlation Coefficient (ICC) and Cronbach's Alpha (CA). ICC was used to assess the interrater reliability by measuring the consistency of the total scores assigned by the raters, while CA was used to evaluate the internal consistency of the test items. The ICC test results for

the pretest and posttest instruments based on the total scores assigned by the two raters are presented in Table 8.

Table 8.

Results of the Intraclass Correlation Coefficient (ICC) Analysis

Instrument type	ICC score	Reliability
Pretest	.85	Good
Posttest	.86	Good

Table 8 shows the results of the Intraclass Correlation Coefficient (ICC) analysis for the pretest and posttest scores. The ICC scores for the pretest and posttest fell into the good category. These results indicate a good level of consistency and agreement among the raters. This demonstrated that the pretest and posttest instruments were reliable and produced consistent measurements among different raters. Therefore, these pretest and posttest instruments were considered suitable for use in the research. In addition, the reliability of the instrument's internal consistency was examined using Cronbach's Alpha, and the results are presented in Table 9.

Table 9.

Result of the Cronbach's Alpha

Instrument Type	Cronbach's Alpha	Reliability
Pretest	.97	Reliable
Posttest	.76	Reliable

Table 10 shows that the pretest and posttest instruments met the reliability criteria as indicated by Cronbach's Alpha values greater than .70. This indicated that each instrument had a high level of consistency in measuring students' problem-solving accuracy. Therefore, the pretest and posttest instruments were considered reliable and suitable for use as data collection tools in this study.

Prototyping EKOSISTEM

In the initial prototype, EKOSISTEM was arranged into six main menus: (1) Basic Concepts of Cryptarithmetic, which included explanations of concepts, basic rules, tips and tricks, common problem-solving errors, puzzles, and relationship between problem-solving and dual-process theory. This section was designed to activate System 2 so that knowledge internalization could occur, (2) Cryptarithmetic Problem-Solving, which provided problems with gradually increasing levels of difficulty along with alternative solution strategies. In this section, the learning activities were systematically designed to foster students' dual-process reasoning abilities. The sequence of activities progressively increased in complexity and corresponded to the specific features of each level of dual-process reasoning, (3) Adventure Game, which combined practice

activities with interactive game elements. This section focused on fostering students' logical intuition. Through interactive games, students could promptly recognize their strengths and weaknesses in generating solutions. This process helped form cognitive chunks that were stored in memory and could be efficiently retrieved when addressing future problem-solving tasks, (4) Interactive assessments, which consisted of quizzes equipped with automatic scoring and feedback, (5) User Guide, which explained the navigation flow of the media, and (6) Media Information, which provided a description of EKOSISTEM. The initial display and the main menu of the EKOSISTEM media are shown in Figure 5.

Figure 5.

(a) Initial Display of EKOSISTEM; (b) Main Menu of EKOSISTEM



(a)



(b)

The Basic Concepts and Problem-Solving menus in Figure 5 (b) were developed with easily accessible e-content. The e-content in EKOSISTEM consists of interactive learning videos, fun-problem e-content, Spotify audio podcasts, and digital slides. Each type of e-content was designed based on dual-process reasoning indicators to improve students' problem-solving accuracy. The cryptarithmetic-based learning e-content of EKOSISTEM is presented in Figure 6.

Figure 6.

(a) E-Content Submenu of Basic Concepts of Cryptarithmetic; (b) Interactive Learning Video; (c) Spotify Audio Podcast; (d) Digital Gamification Slides



(a)



(b)



(c)



(d)

The e-content shown in Figure 6 was subsequently subjected to self-evaluation and expert review to identify the feasibility of implementing EKOSISTEM for students. The evaluation at this stage was conducted to improve the initial design before proceeding to the expert scoring stage of media validation. Based on the evaluation, two major improvements were required: (1) adding a four-level adventure game to enhance interactivity, and (2) refining the problem discussion by incorporating strategies that emphasize System 1 and System 2 dominant reasoning. The revised display of the adventure game and assessment tools in Prototype II is presented in Figure 7.

Figure 7.

(a) Interactive Adventure Game; (b) Cryptarithmetic Assessment



(a)



(b)

EKOSISTEM was further refined through several minor revisions beyond those presented in Figure 7. The evaluation at this stage aims to refine the initial design before entering the alpha testing phase. The results of this research's alpha testing are presented in Table 10 (see appendix).

The minor revisions implemented in EKOSISTEM included the addition of a title to the main menu, refinement of user instructions, improvement of navigation, incorporation of animations to create a more dynamic interface, adjustment of wording, revisions to the answer example layout, and modifications to the assessment section to prevent repeated answers. After these refinements, Prototype II proceeded to the assessment phase to test its validity. The feedback obtained from this stage served as the basis for improving both the content quality

and the technical features of EKOSISTEM. Furthermore, the assessment phase also ensured that the developed media aligned with the intended learning objectives.

Assessment Phase

The third phase was the assessment stage, where the researchers evaluated whether the validated prototype met the criteria of validity, practicality, and effectiveness, and determined its feasibility for use. The EKOSISTEM media was validated by two expert validators, namely doctoral-level mathematics education lecturers. The validation results from Validator 1 and Validator 2 are presented in Table 11.

Table 11.

EKOSISTEM Validation Results by Validator 1 and Validator 2

Aspect	Average Score of	
	Validator 1	**Validator 2**
Pedagogical Aspect	4.75	4.25
Content Aspect	4.50	4.00
Technological Aspect	4.75	4.50
Visual Design and Multimedia Aspect	4.50	3.75
Engagement and Motivation Aspect	4.67	4.33
Accessibility and Affordability Aspect	4.75	4.00
Total Average	4.65 (93%)	4.14 (82.8%)

Table 11 shows that the validation results of EKOSISTEM by Validator 1 yielded an overall average score of 4.65 out of 5.00, equivalent to 93%. Thus, EKOSISTEM was categorized as very valid. Furthermore, the validation results of EKOSISTEM from Validator 2 obtained an overall average score of 4.14 out of 5.00, equivalent to 82.8%, which was categorized as valid. Based on the validation results from both validators, the EKOSISTEM media was considered feasible for use and was subsequently tested in the learning process.

Practicality Test of EKOSISTEM

The practicality assessment of the media was carried out by Grade IX-A students and their teachers. The practicality instrument used was a user response questionnaire for both students and teachers with a $1-5$ Likert scale. The response questionnaire consisted of seven statements: (1) ease of use, (2) features that facilitated student learning, (3) EKOSISTEM enhances students' problem-solving accuracy in cryptarithmetic tasks, (4) attractiveness of the design and interactivity, (5) smooth operation of the website, including the presence of bugs and errors in use, (6) relevance or appropriateness of the material, and (7) users' recommendation of the website to others. EKOSISTEM was considered practical if the

percentage reached ≥ 60%. Meanwhile, the results of the recapitulation of practicality based on the user response scores are presented in Table 12.

Table 12.

Recapitulation of Student and Teacher Response Questionnaire Scores

Aspect Statement	Average Score of	
	Student Responses	**Teacher Responses**
Easy to use	2.79	5.00
Features facilitate student learning	3.14	4.00
EKOSISTEM enhances students' problem-solving accuracy in cryptarithmetic tasks	3.17	4.00
Attractiveness of the design and interactivity	3.83	4.00
Smooth operation of the website	3.21	5.00
Relevance or appropriateness of the material	3.62	5.00
Users recommend the website to others	3.14	3.00
Mean	3.27	4.29
Percentage	65.42%	85.71%
Category	Practical	Very practical

Table 12 illustrates that the percentage of the practicality score of the EKOSISTEM media obtained through the student and teacher response questionnaires reached 65.42% and 85.71%. This percentage indicates that EKOSISTEM was classified as practical and very practical. This demonstrates that the EKOSISTEM media developed has fulfilled the feasibility criteria in terms of practicality. Furthermore, a more in-depth analysis revealed that the aspects receiving the highest scores from student response were the attractiveness of the design and interactivity, with an average score of 3.83, followed by the relevance or appropriateness of the material, with an average of 3.62. These findings suggest that the EKOSISTEM media was perceived as attractive, interactive, and aligned with the intended learning materials. However, one aspect received a relatively low score, namely ease of use, with an average of 2.79. This indicates that although the media was considered usable in learning, improvements to accessibility and the stability of the EKOSISTEM system still require further optimization.

The Impact of EKOSISTEM on Students' Problem-Solving Accuracy

The purpose of creating the EKOSISTEM media was to enhance students' problem-solving accuracy. The researchers administered a pretest before students used the EKOSISTEM media,

and a posttest after using the media to measure the achievement of students' problem-solving accuracy based on the indicators in Table 13 (see appendix).

Furthermore, the pretest and posttest scoring based on the accuracy levels or scores presented in Table 13 was determined according to several underlying reasons. The scoring rubric is presented in Table 14.

Table 14.

Scoring Rubric

Average Score for Question 1 and 2	Scoring Criteria
.00	No answer or incorrect answer There are both conceptual and procedural errors
.50	The answer to the cryptarithmetic operation in Question 1 is accurate, but there is a procedural error, not answering the problem of the arithmetic operation $A + P - I$. Meanwhile, for Question 2 the student does not find a solution to either the cryptarithmetic operation or the arithmetic operation $A - B + C$.
1.00	The answers to the cryptarithmetic operations are accurate, but the subject does not solve the $A + P - I$ and $A - B + C$ questions.
2.00	The answer to the cryptarithmetic problem in Question 1 is accurate. However, for Question 2, the student identifies two combinations that satisfy the equation $ABA - CA = AB$ (one of which is incorrect), resulting in a non-unique solution.
2.50	The answer to Question 1 is correct, the solution steps are complete, and the final result is correct. Meanwhile, for Question 2, the solution steps are complete, but in the operation $A - B + C$ the student produces the wrong answer $1 - 0 + 9 = 9$, which should be 10.
3.00	The answer is correct, and there are no conceptual or procedural errors.

The effectiveness evaluation of the EKOSISTEM media in enhancing students' problem-solving accuracy based on the scoring reason presented in Table 14 began with descriptive statistical analysis to identify the score distribution and evaluate students' performance before and after the intervention. Table 15 presents the descriptive statistics of students' pretest and posttest scores.

Table 15 presents descriptive statistics for students' pretest and posttest scores, showing a significant improvement in overall performance following the implementation of the EKOSISTEM. The mean score increased from 2.06 on the pretest to 2.62 on the posttest. These findings indicate an improvement in students' problem-solving accuracy. The standard deviation decreased slightly from 1.19 to .62, indicating reduced score variability and a more consistent level of achievement among participants following the use of EKOSISTEM. A one-group pretest-posttest design was used. First, a normality test was conducted on students' pretest and posttest responses, as presented in Table 16.

Table 15.

Descriptive Statistics of Pretest and Posttest Scores

Types of Tests		Statistic	Std. Error
Pretest	Mean	2.06	.23
	Std. Deviation	1.19	
	Minimum	.00	
	Maximum	3.00	
Posttest	Mean	2.62	.12
	Std. Deviation	.62	
	Minimum	.00	
	Maximum	3.00	

Table 16.

Test of Normality

	Shapiro-Wilk		
Type of Test	**Statistic**	**df**	**Sig.**
Pretest	.728	26	.000
Posttest	.592	26	.000

Table 16 shows that the results of the normality test using the Shapiro–Wilk test yielded a significance value Sig. < .001 for both the pretest and posttest. Both significance values were less than the threshold of α = .05 (Sig. < .05), indicating that the data in both groups were not normally distributed. Because the data were not normally distributed, a nonparametric test, specifically, the Wilcoxon test, was conducted. The results of the Wilcoxon test are presented in Table 17.

Table 17.

Results of the Wilcoxon Test

	Posttest-Pretest
Z	-2.461
Asymp. Sig. (2-tailed)	.014

Table 17 shows that the Wilcoxon test yielded a significance value (Sig.) of .014. This result indicates that there was a significant difference in students' problem-solving accuracy. Furthermore, an effect size test was conducted to determine the extent to which the use of EKOSISTEM improved the achievement of the students' problem-solving accuracy. The effect size test revealed that $r = \frac{|Z|}{\sqrt{n}} = \frac{|-2.461|}{\sqrt{26}} = .48$. The effect size value of $r = .48$ fell within the interval $.30 \leq r < .50$. Therefore, the use of EKOSISTEM had a medium effect on improving students' problem-solving accuracy.

The development of students' problem-solving accuracy was further demonstrated through a comparison of pretest and posttest answer sheets and interview results. Therefore, this section presents the subjects' responses containing this information for each category. As shown in Table 13, there are four problem-solving categories, namely, (1) inaccurate, (2) local accuracy, (3) global accuracy, and (4) overall accuracy. First, the students classified as inaccurate are indicated by S1's responses, as shown in Figure 8.

Figure 8.

(a) S1's Inaccurate Pretest Answers and Their Reasons; (b) S1's Inaccurate Posttest Answers and Their Reasons

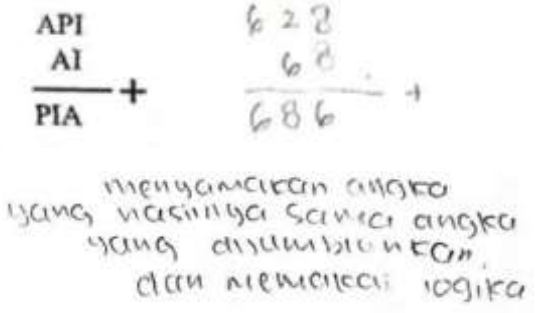
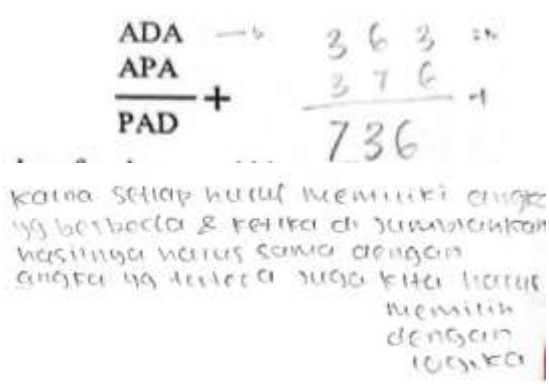
<table>
<tr><td></td><td>Translation:
$\begin{array}{r} API \\ AI \\ \hline PIA \end{array} + \quad \begin{array}{r} 628 \\ 68 \\ \hline 686 \end{array} +$
Reason:
Equalizing the numbers whose result is the same as the numbers being added and using logic.</td></tr>
<tr><td colspan="2">(a)</td></tr>
<tr><td></td><td>Translation:
$\begin{array}{r} ADA \\ APA \\ \hline PAD \end{array} + \quad \begin{array}{r} 363 \\ 376 \\ \hline 736 \end{array} +$
Reason:
Because each letter has a different number and when added the result must be the same as the number shown, we also have to choose using logic.</td></tr>
<tr><td colspan="2">(b)</td></tr>
</table>

Figure 8 shows that the solutions formulated by S1 were still dominated by conceptual and procedural inaccuracies in both the pretest and the posttest. Figure 8 (a) shows S1's inconsistency in determining the number represented by the letter F in the pretest answers. At the top, S1 assigned the number 2 to F, but in the results section of the operation, F changed to 6, which was the same as the number represented by the letter A. Furthermore, S1 made errors in performing the arithmetic operation $628 + 68 \neq 686$, whereas the correct result of the operation should be 696. The posttest answer in Figure 8 (b) also shows that S1 consistently

repeated the same mistakes. S1 was inconsistent in determining the number represented by A, which initially was 3 and then became 6. In addition, there was an error in the arithmetic operation $363 + 376 \neq 736$, whereas the correct operation should have been $363 + 373 = 736$. Furthermore, S1 did not pay attention to the answer requested by the question. For the pretest the requested final result was $A + P - I$, whereas for the posttest, it was $P + A - D$. In both responses, S1 demonstrated an understanding that the final result must match the number represented by the letters previously assigned and that logic had to be applied. The posttest also showed an increased understanding that each letter must have a different number. This is also supported by S1's statement in Interview 1.

Interview 1

R : "Is there a difference in how you approached the pretest and posttest questions?"

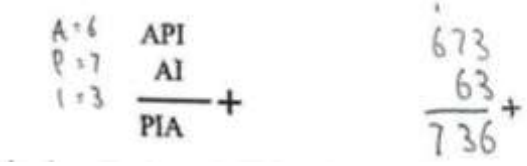
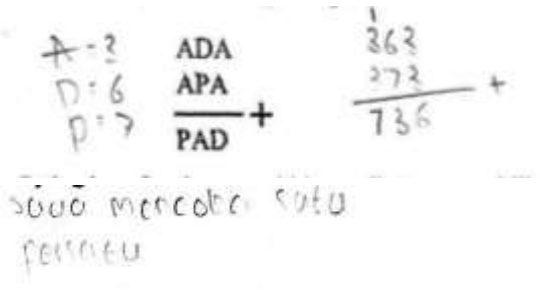
S1 : "The approach is the same. I tried different combinations using logic. I replaced the letters with numbers from 0 to 9, and matched the numbers that add up to the same total. The difference in this answer (posttest) is that the letters must be different."

R : "What else should you keep in mind? Do you think your answer is correct? How do you determine that the answer is correct?"

S1 : "That's it. My answer is correct because it matches the question."

Figure 9.

(a) S2's Pretest Answers; (b) S2's Posttest Answers and Their Reasoning

<table>
<tr><td>
</td><td>Translation:
A P I
A I
P I A
+
6 7 3
6 3
7 3 6
+</td></tr>
<tr><td>(a)</td><td></td></tr>
<tr><td>
</td><td>Translation:
A D A
A P A
P A D
+
3 6 3
3 7 3
7 3 6
+
Reason:
I tried them one by one.</td></tr>
<tr><td>(b)</td><td></td></tr>
</table>

Based on Interview 1, S1 was not yet able to fully state the rules for solving cryptarithmetic problems. S1 had not realized that, when determining the number represented by a letter, consistency must be maintained. Furthermore, S1 immediately assumed that the obtained answer was correct and accurate without first rechecking it. This finding indicates that

S1 required further learning that focuses on the concept of rules for solving cryptarithmetic problems, examples of problem-solving, and analysis of mistakes in those examples. Next, students classified as having local accuracy are indicated by the S2 responses, as shown in Figure 9.

Figure 9 shows that S2 did not experience any conceptual errors in determining the numbers representing the given letters. In the pretest, S2 successfully determined the numerical values corresponding to the final calculation, where $A = 6$, $B = 7$, and $I = 3$, as shown in Figure 9(a). The same occurred the posttest, where S2 determined $A = 3$, $D = 6$, and $P = 7$, as shown in Figure 9(b). However, S2 still experienced procedural errors, particularly in responding to the information requested in the problem. In both the pretest and posttest, S2's work stopped at determining the corresponding numbers without addressing the final question, namely the result of the operation $A + P - I$ for the pretest and $P + A - D$ for the posttest. S2's work showed improvement in the posttest, marked by the awareness of the question requesting the student to explain the reasoning behind the written result. However, S2's mistake in determining the expected final result was consistent with the results of the conducted interview. This finding is also supported by S2's statement in Interview 2.

Interview 2

R : "Can you explain how you solved these two problems? Is there a difference between them?"

S2 : "Actually, it's the same, it's just a matter of trial and error. The difference is that I only realized later that the question asked me to write down my reasoning. At first, I chose numbers between 1 and 9; each letter had to be different, and 0 wasn't allowed at first; the sum of the numbers below had to be the same."

R : "Do you think your answer is correct? How do you determine that the answer is correct?"

S2 : "It should be correct. I'm sure it is."

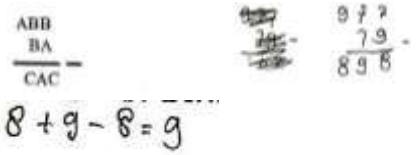
In the Interview 2, S2 was able to explain the problem-solving rules completely and could determine step by step how to identify the numbers represented by the presented letters. Nevertheless, S2 remained convinced that the final answer written was correct and accurate without considering rechecking it. Next, students classified as global accuracy are indicated by S3, as shown in Figure 10.

Figure 10 shows that S3 did not experience conceptual errors in determining the numbers representing the given letters. However, S3 made mistakes in writing the procedure both in the pretest and posttest. Nevertheless, S3's accuracy improved in the posttest, which was previously from the local accuracy level to the global accuracy. As shown in Figure 10 (a), S3's pretest steps stopped at determining the numbers without answering the information expected in the problem. Meanwhile, Figure 10 (b) shows that S3 had performed the expected calculation steps in the posttest, namely, $A + B - C$ by writing $8 + 9 - 8 = 9$. However, S3 made a mistake in substituting the numbers representing A and B in the operation. S3 should

have substituted 9 for A, 7 for B, and 8 for C, so that the operation and final result would be $9 + 7 - 8 = 8$. This shows that S3 completed most of the problem-solving steps on the posttest. But, there was still one error that affected the accuracy of the final result. Furthermore, although S3 did not write down the reasoning behind the result on the answer sheet, S3 was able to explain the entire problem-solving process during the interview. This is also supported by S3's statement in Interview 3.

Figure 10.

(a) S3's Pretest Answers; (b) S3's Posttest Answers

<table>
<tr><td></td><td>Translation:
ABA
CA
AB
101
91
10</td></tr>
<tr><td colspan="2">(a)</td></tr>
<tr><td></td><td>Translation:
ABB
BA
CAC
977
79
898
8+9-8=9</td></tr>
<tr><td colspan="2">(b)</td></tr>
</table>

Interview 3

R : "Can you describe the steps you used to solve these two problems? Is there a difference between them?"

S3 : "I tried to figure out which one was correct and matched the instructions. For the top question, since the three-letter word was reduced to two letters, it must have started with a 1, and then I just needed to find the rest. The difference is that for this one (the pretest), I didn't do the calculation $A - B + C$, so my answer was wrong. I should have calculated it like this (the posttest), by calculating $A + B - C$ that is $8 + 9 - 8 = 9$"

R : "Do you think your answer is correct? How do you determine that the answer is correct?"

S3 : "My answer is correct because I've already done the calculations $A + B - C$."

Based on Interview 3, S3 was able to explain the trial-and-error steps taken to determine the numbers representing each letter. S3 was also able to point out the incorrect step in the pretest and its correction in the posttest after using EKOSISTEM. However, S3 did not realize there was still an error in the final posttest answer. Next, students classified as overall accuracy are indicated by the S4's responses, as shown in Figure 11.

Figure 11.

(a) S4's Pretest Answers and Their Reasons; (b) S4's Posttest Answers and Their Reasons

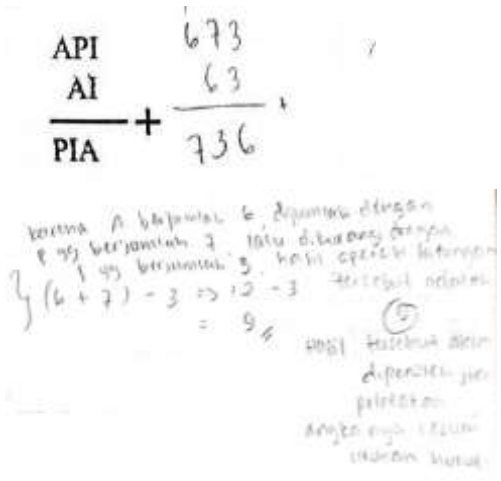
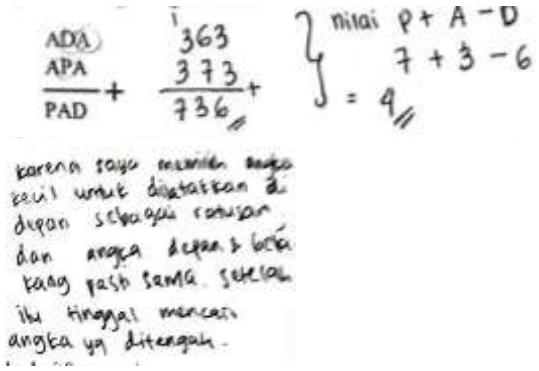
<table>
<tr>
<td></td>
<td>Translation:
$\begin{array}{r} API \\ AI \\ \hline PIA \end{array} + \begin{array}{r} 673 \\ 63 \\ \hline 736 \end{array} +$
Reason:
Because A equals 6, P equals 7, and I equals 3, adding A and P and then substracting I gives 9.
$(6+7)-3 \rightarrow 12-3$
$= 9$
This result is obtained if the numbers are placed according to the letter order.</td>
</tr>
<tr>
<td colspan="2">(a)</td>
</tr>
<tr>
<td></td>
<td>Translation:
$\begin{array}{r} ADA \\ APA \\ \hline PAD \end{array} + \begin{array}{r} 363 \\ 373 \\ \hline 736 \end{array} +$
Value $P - A - D$
$7 + 3 - 6$
$= 4$
Reason:
Because I chose a small number to put first as the hundreds digit, and the first and last digits must be the same. After that, I just needed to find the middle number.</td>
</tr>
<tr>
<td colspan="2">(b)</td>
</tr>
</table>

Figure 11 presents the problem-solving results of S4, which do not show any conceptual errors in determining the numbers represented by letters in the cryptarithmetic problem. However, S4 still made a calculation error of $6 + 7 - 3 = 9$ in the pretest work, as shown in Figure 11(a). The error occurred in the addition of 6 and 7, which should be 13, but S4 mistakenly wrote it as 12. Nevertheless, S4 was able to identify and correct this error during the interview. This is also supported by S4's statement in Interview 4.

Interview 4

R : “Can you explain how you solved these two problems? Did you solve them in the same way or differently?”

S4 : “For the first question (pretest), I kept trying until I got it right. As for the second one (posttest) I chose a small number to put in front as the hundreds digit, and the first and last digits had to be the same. After that, I just needed to find the middle number.”

R : “Do you think your answer is correct? How do you determine that the answer is correct?”

S4 : “Oh, for this first question, the answer shouldn't be 9, but 10 because $6 + 7 = 13$, not 12.”

Based on Interview 4, S4 was also able to explain the problem-solving rules and the steps of the solution in a sequential and accurate manner. This indicates that S4's accuracy level improved from the global accuracy to the overall accuracy level, as reflected in the posttest work shown in Figure 11(b). This improvement is also demonstrated through the reasons provided, which reflect problem-solving strategies that are not merely trial and error but also accompanied by the elimination of possibilities based on logical reasoning.

All four participants showed an increase in accuracy from the pretest to the posttest. Some participants showed a gradual increase within the same accuracy level, marked by a growing understanding of problem-solving rules and problem information. In addition, other participants showed improvement across different accuracy levels, as demonstrated by the increasing completeness of their problem-solving procedures and their ability to evaluate their answers independently.

DISCUSSION

The product of this research is a learning medium called EKOSISTEM (cryptarithmetic-based fun-problem e-content). EKOSISTEM was developed to stimulate the improvement of students’ problem-solving accuracy. The development process began with a literature review, an observation of existing competitor media, and student interviews to ensure users’ needs. The development of EKOSISTEM has been validated by two experts with average scores of 4.14 and 4.65, respectively, categorized as valid and highly valid. These results indicate that EKOSISTEM was designed with content and media appropriate to students’ needs and met quality standards in terms of both content relevance and media feasibility.

The e-content designed in EKOSISTEM triggers dual-process interaction that can support the improvement of students’ problem-solving accuracy and reasoning. EKOSISTEM consists of six main menus: (1) Basic Concepts of Cryptarithmetic, which includes explanations of concepts, basic rules, tips and tricks, common problem-solving errors, and the relationship between problem-solving with dual-process theory, (2) Cryptarithmetic Problem-Solving, which provides problems with gradual levels of difficulty along with alternative solution strategies, (3) Adventure Game, which combines practice activities with interactive game elements, (4)

Interactive assessments in the form of quizzes equipped with automatic scoring and feedback, (5) User Guide, which explains the navigation flow of the media, and (6) General Information, which presents a description of EKOSISTEM. The main menus developed play a role in integrating learning experiences that trigger dual-process interaction, namely the intuitive process (System 1) and the analytical process (System 2). This is in line with dual-process theory, which emphasizes the importance of transitioning from heuristic reasoning to analytical verification in solving complex problems (Nugroho et al., 2024; Susiswo et al., 2025).

The Basic Concepts and Problem-Solving menus were developed with e-content consisting of interactive learning videos, fun-problem e-content, Spotify audio podcasts, and digital slides. Each type of e-content was designed to stimulate dual-process interaction in an effort to improve students' problem-solving accuracy and level of reasoning. Interactive video features, podcasts, and digital slides facilitate the building of conceptual understanding through exposure to rules, explanations of problem-solving strategies, and analyses of common mistakes. Through these explanations, students whose problem-solving process is still dominated by System 1 are stimulated to activate System 2, thereby reducing conceptual and procedural inaccuracies. Furthermore, the adventure games and interactive quizzes are intended to stimulate students to provide initial intuitive responses followed by verification. This verification process is facilitated through the provision of challenges accompanied by real-time feedback on correct or incorrect answers. As a result, students gradually transition toward System 2 activation, parallel competitive thinking, and System 1-triggered parallel processing. Furthermore, through repeated learning and practice using EKOSISTEM e-content, it is expected that students' reasoning will develop into System 2 triggers of parallelism and logical intuition, which enables them to become accustomed to solving problems accurately and precisely. The integration of these features has been proven to foster motivation, reduce cognitive load, and strengthen the connection between intuitive guessing and analytical verification. These findings support the research results of Widodo et al. (2019), which demonstrated the effectiveness of cryptarithmetic-based games on problem-solving skills, as well as those of Alqahtani & Li (2025), which showed that interactive videos can improve mathematics learning outcomes. Furthermore, the use of e-content is in line with the perspectives regarding the effectiveness of multimedia-based learning in enriching problem-solving strategies (Daryanes et al., 2023).

The practicality test showed that the EKOSISTEM obtained a score of 65.42% from students and 85.71% from teachers. This finding indicates that the developed media falls into the practical category for use in learning. These results are in line with previous studies, which stated that learning media can be considered practical when their usability exceeds the minimum threshold of 61% and can be effectively applied (Lee et al., 2021). Furthermore, the high scores in the aspects of design attractiveness and interactivity (3.83), as well as material relevance (3.62) demonstrate that EKOSISTEM effectively meets students' needs in terms of attractive and interactive displays, as well as material suitability with learning objectives. This is consistent with previous studies indicating that attractive, interactive, and relevant media

design positively influences students' motivation and engagement in learning (Domagk et al., 2010).

However, the ease-of-use aspect only obtained an average score of 2.79. This finding indicates that although the media is feasible for use, challenges related to accessibility and system stability remain. Therefore, further development should focus on optimizing navigation and system stability to ensure that it is easily accessible by students. This is supported by Jannah et al. (2020), who identified the ease-of-use factor is one of the key indicators in measuring the practicality of digital media. The effectiveness test showed a significant difference in students' problem-solving accuracy before and after using EKOSISTEM, as indicated by the Wilcoxon test result (Sig. = .014 < .05). Furthermore, the effect size analysis yielded an *r* value of .48, which falls within the interval $.30 \leq r < .50$. Therefore, EKOSISTEM has a medium effect on improving students' problem-solving accuracy.

This study contributes new insights into the problem-solving accuracy based on dual-process interactions, which encompass four categories: inaccurate, local accuracy, global accuracy, and overall accuracy. These categories represent distinct patterns of interaction between System 1 and System 2 (Gronchi & Perini, 2024). The inaccurate category is characterized by the dominance of System 1, resulting in responses that are rapid and intuitive but lack sufficient analytical verification (Da Silva, 2023; De Nays, 2021). The local accuracy category indicates the activation of System 2, accompanied by parallel-competitive interaction and parallelism triggers System 1 interaction, suggesting that analytical processing has emerged but is not yet consistently sustained throughout the problem-solving process (De Nays, 2023). The global accuracy category is characterized by System 1 triggers parallelism and parallelism triggers System 2 interaction, enabling initial intuitive responses to be regulated through analytical processing, thereby minimizing errors (De Nays, 2023; De Nays, 2025). Finally, the overall accuracy category represents the highest level of problem-solving accuracy, characterized by System 2 triggers parallelism and the emergence of logical intuition, allowing students to generate solutions that are both rapid and accurate through the optimal coordination of System 1 and System 2 (De Nays, 2023; Raoelison et al., 2021).

Inaccurate: System 1

The lowest level of problem-solving accuracy is inaccurate, characterized by students' cognitive processes being predominantly governed by System 1, a mode of thinking that is fast, intuitive, and heuristic, yet insufficiently regulated by analytical control. As a result, students are more likely to rely on guessing strategies, indicating a weak grasp of underlying conceptual knowledge (Pherson et al., 2024; Susiswo et al., 2024). Consequently, students at the inaccurate level exhibit pervasive conceptual errors. This condition can be improved through the Basic Concepts features of EKOSISTEM, which include explanations of cryptarithmetic rules and simulations of problem-solving steps delivered via interactive videos and digital slides. This e-content was designed because it has the potential to gradually stimulate the activation of System 2.

Local Accuracy: System 2, Parallel-Competitive, and Parallelism Triggers System 1

The local accuracy category reflects students' ability to perform certain components of correct reasoning. However, the accuracy achieved is limited, resulting in problem-solving outcomes that are not fully accurate. Within this category, students are engaged in the activation of System 2, as indicated by the use of analytical reasoning in solving cryptarithmetic problems. Nevertheless, students still exhibit conceptual or procedural errors, which subsequently affect the correctness of the final solution. In addition, at the local accuracy level, students demonstrate a parallel-competitive interaction, in which intuitive responses from System 1 compete with analytical responses from System 2 (Hochman, 2024). This interaction leads students to produce solutions that appear plausible without undergoing comprehensive verification. Furthermore, the local accuracy category is also characterized by parallelism triggers System 1 interaction. This interaction is marked by analytical processing that is initiated at the early stages of problem solving but is not sustained in subsequent steps (Da Silva, 2023; Zucchelli et al., 2025). As a result, the solutions generated by students ultimately rely only on intuitive responses (System 1). In this context, EKOSISTEM features, including videos explaining basic concepts, videos illustrating common errors, and assessments accompanied by immediate feedback serve as stimuli to optimize the activation of System 2 and support students in regulating emerging intuitive responses. Overall, within the local accuracy category, students do not rely exclusively on intuition when solving problems. However, they have not yet been able to manage the interaction between System 1 and System 2 effectively to produce fully accurate solutions.

Global Accuracy: Interaction of System 1 Triggers Parallelism and Interaction of -Parallelism Triggers System 2

At the global accuracy level, students demonstrate that most problem-solving steps are performed correctly, with only minor errors that do not significantly affect the final outcome. The thinking pattern at this level is characterized by System 1 triggers interaction that induce parallelism and parallel interactions that subsequently activate System 2. This pattern indicates that the role of initial intuition in problem solving no longer operates independently, but is instead regulated through analytical processing and verification mechanisms (Pherson et al., 2024). Through the use of EKOSISTEM, students are facilitated to practice problem solving through a combination of rapid pattern recognition complemented by step-by-step evaluation via feedback and discussions of alternative solution strategies embedded in the Adventure Game menu. These features enable students to correct minor errors and maintain consistency in applying cryptarithmetic rules. Consequently, EKOSISTEM plays a crucial role in supporting a more stable form of global accuracy and in promoting students' progression toward a higher level of accuracy, namely overall accuracy.

Overall Accuracy: System 2 Triggers Parallelism and Logical Intuition

In the overall accuracy category, students are able to produce fully correct solutions without exhibiting significant conceptual or procedural errors. Within this category, a System 2 triggers

parallelism interaction is observed, in which students' problem-solving processes are initiated by the activation of System 2, operating in an analytical and controlled manner (Gronchi et al., 2024; Orona & Trautwein, 2024). This interaction subsequently triggers the selective use of intuition to accelerate problem solving without compromising the accuracy of the resulting solutions. Such interactions are stimulated through EKOSISTEM e-content, particularly through features that provide practice tasks accompanied by immediate alternative solution explanations. These features encourage students to engage in verification processes before accepting intuitively generated solutions. Furthermore, the overall accuracy category is also characterized by logical intuition. Logical intuition is marked by intuitive activation (Zhu et al., 2025). This intuitive activation may develop from students' conceptual understanding acquired through EKOSISTEM concept exploration activities, including instructional videos, audio podcasts, and digital slides. As a result, System 1 and System 2 are able to operate in a coordinated and complementary manner. Consequently, students can solve cryptarithmetic problems accurately by adhering to the given rules and problem structures, thereby producing solutions that are both rapid and accurate through the optimal management of dual-process interactions.

CONCLUSIONS AND RECOMMENDATIONS

To conclude, the EKOSISTEM learning media was found to be valid, practical, and effective for use in the learning process. The validation results from Validator 1 obtained an average score of 4.65 out of 5.00 (equivalent to 93%) categorized as very valid, while Validator 2 obtained an average score of 4.14 out of 5.00 (equivalent to 82.8%) categorized as valid. The practicality test showed response scores of 65.42% from students and 85.71% from teachers, placing the media in the practical and very practical categories. Furthermore, the effectiveness test revealed a significant difference in students' problem-solving accuracy, with the Wilcoxon test result of $Sig. = .014 < .05$ and the effect size analysis yielded an *r* value of .48, which falls within the interval $.30 \leq r < .50$. Therefore, EKOSISTEM has a medium effect on improving students' problem-solving accuracy. Accordingly, the EKOSISTEM media is considered valid, feasible, and effective for enhancing students' problem-solving accuracy.

Although students' problem-solving accuracy improved after using EKOSISTEM, this study has a limitation. Specifically, the study did not confirm whether the improvement was solely due to the use of EKOSISTEM because the control group was not included in the research design. Future research should examine the effectiveness of digital-based learning media in enhancing students' problem-solving accuracy and consistency through quasi-experimental designs and the inclusion of more diverse samples. In addition, further exploration of the integration of learning media with adaptive technology approaches is necessary to strengthen the development of higher-order thinking skills within technology-based learning contexts.

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APPENDIX

Table 10.

Results of Alpha Testing

Test Details	Expected Result	Actual Result	Test Result
Home and Login Page	The home page displays the media title, and the user successfully login after entering their full name, class, and school of origin.	The user successfully accessed the home page displaying the media title, full name information, class, and school of origin; the user was successfully detected and recorded on the following pages.	Success
Basic Concepts of Cryptarithmetic Menu	Users can access learning components (learning objectives and outcomes), materials (educational videos, audio podcasts, and digital slides). Furthermore, the terms used in this menu are easy to understand and free from typographical errors.	The user successfully accessed the available learning components and materials. The user found the term 'reveal' difficult to understand, so it was replaced by 'explore'.	Success
Cryptarithmetic Problem-Solving Menu	Users can access learning components (learning objectives and outcomes), and problem discussions (e-content fun problems and audio podcasts).	Users can access components and problem discussions.	Success

Test Details	Expected Result	Actual Result	Test Result
Adventure Game Menu	Users can access each level of the game one by one after completing the previous level.	Users can access the next level after answering correctly.	Success
Assessment Menu	The system detects the user's answers and displays the score and explanation for each question.	Users can enter their answers, receive feedback on whether their answers are correct or incorrect, view their scores, and access explanations for each question.	Success
User Guide Menu	Users can access the user guide, which provides a complete explanation of the menu functions and media navigation.	The user guide has been successfully accessed, allowing users to understand how to use EKOSISTEM.	Success
Media Information Menu	The Media Information menu displays comprehensive information about EKOSISTEM, including a description of the media, development objectives, usage instructions, and developer information, all presented in a clear and easy-to-understand layout.	Media information is now displayed in full, the user guide has been improved, and all information is easily accessible to users.	Success

Table 13.

Problem-Solving Accuracy and Dual-Process Categories

Category	Description	Accuracy Level/Score	Dual-Process Level
Overall Accuracy	• All solution steps are accurate. • No conceptual errors are present. • Procedural errors, if any, are only limited to technical/minor (e.g., a miswritten number that is immediately corrected). • The final result is correct.	3	System 2 triggers parallelism and logical intuition
Global Accuracy	• The majority of solution steps are accurate.	2	System 1 triggers parallelism and parallelism

Category	Description	Accuracy Level/Score	Dual-Process Level
	• Procedural or conceptual errors occur in certain steps, but they have little or no minimal impact on the overall problem-solving process. • The final result is correct or nearly correct.		triggers System 2
Local Accuracy	• Some solution steps are accurate. • Procedural or conceptual errors occur in certain steps, which affect the problem-solving process. • The final result is incorrect or does not match the expected outcome. • Nevertheless, evidence of conceptual understanding is still apparent in certain parts.	1	System 2, parallel-competitive, and parallelism triggers System 1
Innacurate	• All solution steps are incorrect. • Conceptual errors are dominant, and the final result is wrong. • No appropriate problem-solving process is demonstrated.	0	Dominated by System 1