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AI-powered e-modules for mathematics learning: Impact on elementary school students' mathematical disposition

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Abstract. Mathematical disposition is an essential affective aspect that influences students' success in understanding and enjoying mathematics, but it is often neglected in conventional learning approaches. Students' lack of motivation, confidence, and perseverance in mathematics is a fundamental problem in elementary schools. This study aims to analyze the effect of implementing an Artificial Intelligence (AI)-based E-Module on improving the mathematical disposition of elementary school students. A quantitative approach with a quasi-experimental design was used. The sample consisted of 70 fifth-grade students in Pekanbaru who were randomly divided into experimental and control groups. The instrument used was a mathematical disposition test developed based on five leading indicators validated for validity and reliability. The t-test results showed a significant difference between the post-test scores of the experimental and control groups ($p < 0.05$), with higher mathematical dispositions in the group using AI-based E-Modules. These findings indicate that AI-based learning systems are effective in cognitive aspects and capable of fostering positive attitudes and motivation toward learning among students. The novelty of this study lies in its focus on measuring affective elements within the context of adaptive technology in elementary education. The implications of these findings encourage the integration of AI-based learning that is not only oriented toward academic outcomes but also toward strengthening students' character and mental readiness to face the challenges of 21st-century education.

Introduction

Mathematics education at the elementary school level plays a key role in developing cognitive and problem-solving skills that will be useful throughout students' lives (Ouyang et al., 2023). With its abstract and systematic nature, mathematics requires practical approaches to address the challenges students often face, such as difficulty in understanding concepts, lack of confidence, and low motivation (Mazon et al., 2023). Among these challenges, mathematical disposition, a concept encompassing attitudes, self-confidence, motivation, and perseverance in solving mathematical problems, is critical in determining students' success in mathematics learning (Mozer et al., 2019). Students with good mathematical dispositions are more motivated to learn mathematics and tend to be more successful in understanding the material and facing higher academic challenges. Therefore, improving students' mathematical disposition at the elementary school level should be one of the top priorities in mathematics education.

Based on the latest PISA (Program for International Student Assessment) 2018 report, Indonesia ranks low in mathematics competency among OECD member countries, with an average score of 379, far below the global average of 489 (OECD, 2019). This indicates a significant gap in mathematics achievement in Indonesia that needs to be addressed immediately. One of the factors contributing to this low achievement is the lack of motivation and favorable disposition toward mathematics learning, which often hinders the development of students' mathematical abilities (OECD, 2019). In this context, educational technology, notably that based on artificial intelligence (AI), offers excellent opportunities to overcome these problems. One of the emerging innovations is the application of AI-based E-Modules in mathematics learning. These E-Modules can be tailored to the needs and abilities of individual students, providing a more personalized and adaptive learning experience (Chen et al., 2023; Sukendra et al., 2023). For example, using AI algorithms, E-Modules can adjust the difficulty level of math problems given to students based on their progress, allowing students to learn at a pace that suits their abilities (Rebollo et al., 2022). In addition, AI-based E-Modules can provide real-time and more interactive feedback, which can help boost students' confidence and motivate them to continue learning (Wagan et al., 2023).

Although this technology offers enormous potential, research discussing the impact of AI-based E-Modules on the mathematical dispositions of elementary school students is still limited. Mathematical dispositions refer to positive attitudes toward mathematics, confidence in solving math problems, and motivation to continue learning (Pappa et al., 2024; Widana et al., 2024). Based on data from the Ministry of Education and Culture, in the 2022-2023 academic year, around 30% of elementary school students in Indonesia reported difficulties in understanding mathematics, with most citing lack of confidence and anxiety as the main obstacles (Hardiansyah et al., 2024). Therefore, it is important to explore how AI-based E-Modules can help address this problem, provide a more engaging learning experience, and improve students' mathematical dispositions (Memon et al., 2022; Damayanthi et al., 2022). The urgency of this research is very high, given the low achievement in mathematics competency in Indonesia and the importance of improving students' mathematical dispositions to achieve better results.

In addition to national data, the latest regional survey in Pekanbaru, Riau, shows a rather alarming situation regarding mathematics learning in elementary schools, particularly among fifth-grade students. According to the 2023 Education Quality Report from the Riau Provincial Education Office, around 62.5% of fifth-grade students in Pekanbaru scored below average in mathematics, and only 18.3% achieved a "good" rating. Furthermore, diagnostic assessment results involving 1,250 fifth-grade students from 25 elementary schools in Pekanbaru revealed that over 55% of students have low self-confidence in solving mathematics problems, and approximately 48% feel anxious and afraid when facing mathematics evaluations. These findings are consistent with classroom observations conducted by local education supervisors, who noted that students are passive and rarely participate actively during mathematics lessons. In addition, based on feedback obtained through structured interviews with teachers, around 70% of mathematics teachers in Pekanbaru stated that students lack perseverance and motivation in working on problem-solving tasks, and nearly 60% of teachers mentioned that students still rely heavily on memorizing formulas rather than understanding concepts. These figures underscore the urgent need for innovative learning interventions that focus on cognitive achievements and strengthen students' affective aspects, such as motivation, self-confidence, positive attitudes, and perseverance in facing mathematical challenges.

AI-based e-modules are an innovation in education designed to provide a more personalized and adaptive learning experience. Unlike traditional e-modules, AI-based e-modules use intelligent algorithms that can adjust the material, difficulty level of questions, and learning strategies according to the needs and abilities of each student. Through continuous analysis of learning data, AI can monitor student progress, provide real-time feedback, and adjust tasks better to suit the student's ability and learning style. This enables more interactive and responsive learning, increasing student engagement and motivation to continue learning. AI e-modules can also identify specific difficulties faced by students and provide personalized additional support, enabling each student to learn at their own pace and in the way that suits them best. As a result, using AI-based e-modules optimizes the learning process from a cognitive perspective. It supports students' affective development, such as increasing self-confidence, motivation, and positive attitudes toward the subjects they are studying.

Previous studies on the use of technology in mathematics education have shown varying results. For example, Yue et al. (2022) found that educational technology, such as computer-based applications, can improve students' mathematical understanding. However, this study focused more on mathematical concepts and skills without touching on students' mathematical dispositions. Similarly, a study by Ökördi & Molnár (2022) showed that E-Modules could improve mathematics learning outcomes but did not discuss their influence on students' mathematical dispositions. In addition, research by Kim & Lee (2023) examining the use of technology in mathematics education only focused on improving academic skills without considering the dimensions of students' dispositions toward mathematics. The main gap in the literature is the lack of research examining the impact of AI-based E-Modules on students' mathematical dispositions at the elementary school level. Although many studies have examined the use of technology to improve academic outcomes, few have discussed how this technology affects students' attitudes and motivation in mathematics learning. In addition, existing research tends to focus on higher levels of education or more limited contexts of mathematics learning, so there has been no in-depth study of the application of AI-based E-Modules in the context of mathematics learning in elementary schools.

The novelty of this study lies in its new focus on the use of AI-based E-Modules to improve the mathematical dispositions of elementary school students, which has not been widely discussed in the literature. This study also adopts a more personalized and adaptive approach to mathematics learning by utilizing AI's ability to adjust the level of difficulty and type of questions to students' abilities. So far, various studies related to educational technology have focused only on improving cognitive learning outcomes, such as mastery of concepts, calculation skills, or academic scores alone. In contrast, students' affective aspects—including motivation, self-confidence, positive attitudes toward mathematics, and persistence in solving problems—have not been the primary focus of intervention, even though they contribute significantly to long-term learning success.

Thus, this study makes an important contribution to the literature on mathematics education and provides practical recommendations for teachers and education policymakers in implementing AI technology in mathematics learning. As such, this study has the potential to improve the quality of mathematics learning in elementary schools and serves as a foundation for the broader application of technology in Indonesian education, particularly in the context of technology-based and adaptive learning. The implementation of AI-based E-Modules is expected to have a positive impact on students' mathematical dispositions and contribute to improved mathematics learning outcomes in the future.

This study aims to fill the knowledge gap regarding how implementing AI-based E-Modules can help students develop more positive mathematical dispositions and increase their motivation to learn mathematics, thereby better preparing them for future mathematics learning challenges. The research questions in this study are: (1) How can the implementation of AI-based E-Modules improve the mathematical dispositions of elementary school students? (2) How do AI-based E-Modules impact students' attitudes and motivation in mathematics learning? (3) To what extent are

AI-based E-Modules more effective than conventional learning methods in developing students' mathematical dispositions? This study aims to answer these questions clearly and contribute to developing more effective technology-based mathematics learning methods. This study aims to identify and analyze the impact of AI-based E-Modules on elementary school students' mathematical disposition. This study also aims to compare the effectiveness of AI-based E-Modules with conventional learning methods in improving students' mathematical disposition, motivation, and attitudes toward mathematics.

Method

This study uses a quantitative approach with a quasi-experimental design to explore the impact of AI-based E-Modules on the mathematical disposition of elementary school students. The quasi-experimental approach was chosen because it allows researchers to evaluate the effects of the treatment (in this case, the implementation of AI-based E-Modules) on the experimental and control groups without complete randomization in the placement of students into the experimental groups. This is relevant to the research conditions in elementary schools, where complete randomization at the individual level is difficult to achieve. However, existing groups of students can be used as research subjects (Essa et al., 2023). This design also allows researchers to compare differences in mathematical dispositions between students who use AI-based E-Modules and those who use conventional learning while considering external factors that cannot be controlled.

The population in this study was all fifth-grade students at Muhammadiyah 019 Bangkinang Elementary School, Pekanbaru, Riau. The selection of this population is based on the importance of improving mathematical dispositions in early childhood, especially at the elementary education level, which serves as the foundation for further mathematics learning. The research sample consists of 70 students selected randomly from two different classes. This random sampling technique was used to ensure that each student had an equal chance of being selected, making the sample representative. The division of students into two classes aimed to form one experimental group using AI-based E-Modules and one control group using conventional learning methods. In this way, researchers can evaluate the differences in results due to differences in treatment.

In the experimental class, the learning model used was AI-based E-Interactive Module-Based Learning. In this model, students were given access to AI-based e-modules tailored to their learning abilities and needs. These e-modules use AI algorithms to adjust the difficulty level of questions and provide real-time feedback based on students' progress. The learning process begins with an initial diagnosis, where the e-module identifies students' understanding levels through a pre-test and adapts the content based on the results. Next, students engage in problem-based learning, which presents them with challenges that must be solved gradually, starting with basic questions and progressing to more complex ones. At each stage, students receive adaptive feedback, which can be suggestions or corrections to their answers, encouraging them to think more critically and creatively. At the end of the learning process, students take a post-test to measure their improvement. Meanwhile, in the control class, the learning model used is Conventional Learning, which relies on a direct approach from the teacher, where students are given material through lectures and static exercises without adaptation to individual needs or abilities. The learning stages in the control class consist of material explanation by the teacher, group exercises, and final evaluation through tests to measure student understanding.

The AI-based e-module learning model was chosen for the experimental class because of its advantages in providing a more personalized and adaptive learning experience, which can increase students' motivation and mathematical disposition. Meanwhile, the conventional learning model in the control class was chosen as a comparison to evaluate the effectiveness of the technology-based approach in improving students' mathematical dispositions. By comparing these two models, this study aims to explore the impact of AI technology on students' attitudes, motivation, and confidence in learning mathematics.

In this study, the same teacher conducted teaching in the experimental and control classes to ensure consistency in the teaching approach and avoid bias that might arise if different teachers taught in both groups. However, exceptional training and briefing were provided to the teacher to minimize potential bias before the experiment began. This training included clear instructions on implementing different learning models between the experimental and control classes and providing fair and consistent feedback to all students. In addition, to ensure that there was no bias in teaching, structured monitoring was conducted by researchers during the learning process to ensure that teachers followed the agreed procedures without treating the two groups differently.

The instrument used in this study is a mathematical disposition test consisting of 25 questions designed to measure students' mathematical disposition, such as motivation, positive attitudes toward mathematics, self-confidence, and perseverance in facing mathematical problems. The test was developed by considering indicators of mathematical disposition relevant to the research topic. The following table shows the indicators of the test instrument used:

Table 1. Test Instrument Indicator

Indicator	Description
Motivation	Measures the extent to which students are motivated to learn mathematics actively.
Self-confidence	Measures the level of students' self-confidence in solving mathematical problems.
Perseverance	Assesses the perseverance of students in solving complex mathematical problems.
Positive Attitude toward Mathematics	Measures students' positive or negative attitudes toward learning mathematics.
Creativity in Problem-Solving	Measures how creatively students can think in solving mathematical problems.

Each question in this test is designed to measure one or more of the above indicators, using various question types such as multiple choice, short answer, and short essay questions that allow students to demonstrate their understanding and attitudes toward mathematics. Before being used in research, this test will undergo a validity testing stage using content and construct validity. Content validity measures whether the questions in the test are consistent with the predetermined indicators of mathematical disposition. Construct validity tests whether the test accurately measures mathematical disposition as a whole. This validity test will involve mathematics education experts to assess the questions' relevance to the research objectives. Next, reliability testing will be conducted using Cronbach's Alpha reliability coefficient, which is used to measure the instrument's internal consistency. This reliability test ensures that the test instrument provides consistent results when repeated on the same sample.

The data obtained from the mathematical disposition test will be analyzed using several statistical tests to ensure the validity of the research results. The following are the stages of data analysis used in this study: a normality test is conducted to check whether the data distribution follows a normal distribution. This test is essential because the statistical test type depends on the assumption of data normality. The normality test will be performed using the Shapiro-Wilk test on the test results before and after treatment. A homogeneity test ensures that the variance between the experimental and control groups is homogeneous. This test is essential to ensure that comparisons between groups can be valid. The homogeneity test will use the Levene test or the F test. Hypothesis Testing After normality and homogeneity tests are conducted, the next step is hypothesis testing to test the differences between the experimental and control groups. Suppose the data is usually distributed and the variances between groups are homogeneous. In that case, the t-test for two independent samples will be used to test whether there is a significant difference between the mathematical dispositions of students using AI-based E-Modules and students using conventional learning methods. Conversely, suppose the data are not normally distributed, and the variances between groups are not homogeneous. In that case, a non-parametric test such as the Mann-Whitney test will be used, which is more appropriate for testing differences between two independent groups with data that do not meet the assumptions of normality. Logically, the selection of statistical test methods is based on the characteristics of the data obtained and the research objectives, which aim to measure differences in mathematical dispositions between the experimental and control groups. The t-test is used because the expected data follows a normal and homogeneous distribution, providing the basis for parametric tests. Meanwhile, non-parametric tests are chosen as an alternative when the data do not meet the assumptions required for parametric tests. By using a series of validity, reliability, normality, homogeneity, and hypothesis tests, the researcher will be able to ensure that the results of this study are valid and reliable and provide a clear picture of the impact of AI-based E-Modules on the mathematical dispositions of elementary school students.

Results and Discussion

This study aims to examine the effect of implementing AI-based E-Modules in mathematics learning on the mathematical dispositions of elementary school students. Mathematical dispositions encompass important non-cognitive aspects such as motivation, self-confidence, perseverance, positive attitudes toward mathematics, and problem-solving creativity. These factors are crucial in supporting long-term success in mathematics learning, especially at the elementary education level, as a foundation. To obtain accurate and statistically reliable results, a series of prerequisite tests was conducted before hypothesis testing, including validity and reliability tests of the instruments and the data's normality and homogeneity tests.

It should be emphasized that all data calculations in this study were performed manually, without using computer-based statistical applications such as SPSS or other analysis software. The calculations include validity tests, reliability tests, normality tests, homogeneity tests, and hypothesis testing (t-tests), all performed using conventional mathematical calculation methods with relevant statistical formulas. This manual approach was chosen to ensure that every step of the calculation process is fully understood and to avoid reliance on software that may hide details of the analysis process. As a result, researchers can conduct detailed verification of each step in the data analysis process, thereby enhancing the accuracy and transparency of the results obtained. This also adds value to the research by demonstrating advanced analytical skills and statistical proficiency, which are crucial for educational research at the foundational level.

Before the instrument was used in the main data collection, a validity test was conducted to ensure that each item in the mathematical disposition test instrument was truly capable of measuring the intended construct. The validity test was conducted on 35 test respondents from a population with characteristics similar to the research sample. Item validity was calculated by correlating each item's score with the total score using Pearson's product-moment correlation formula. The calculated correlation coefficient (r) was then compared with the table value (r) at a 5% significance level to determine whether an item was valid. The results of the validity test for the instrument on each mathematical disposition indicator are presented below:

Table 2. Results of Mathematical Disposition Test Validity per Indicator

Indicator	r-count	r-table (N=35; α=0.05)
Motivation	0.484 – 0.602	0.334
Self-confidence	0.486 – 0.565	0.334
Perseverance	0.472 – 0.592	0.334
Positive Attitude toward Mathematics	0.468 – 0.537	0.334
Creativity in Problem-Solving	0.479 – 0.532	0.334

Based on Table 2, all items in the mathematical disposition test instrument showed r-calculated values greater than r-table values, namely 0.334 (at a significance level of 5% and N = 35). This indicates that each item correlates significantly with the total instrument score, meaning the items are statistically valid for measuring mathematical disposition constructs. This high validity suggests that the items represent the measured indicators: motivation, self-confidence, perseverance, positive attitude toward mathematics, and creativity in problem-solving. This validation process is crucial in quantitative research because it ensures that the obtained data reflects the measured variables. Therefore, all items are valid and suitable for the main data collection.

After the validity test, the next stage was to test the instrument's reliability to ensure consistent and reliable results when used in repeated measurements. The reliability test was conducted on the items declared valid in the previous test, using Cronbach's Alpha internal consistency reliability coefficient. The selection of the Cronbach's Alpha formula is based on the instrument's nature, consisting of several items that measure one construct simultaneously, thus requiring a measure that can describe the consistency between items. The reliability calculation results for each mathematical disposition indicator are presented in Table 3 below:

Table 3. Results of the Test Instrument Reliability Based on Mathematical Disposition Indicators

Indicator	Cronbach's Alpha
Motivation	0.823
Self-confidence	0.807
Perseverance	0.841
Positive Attitude toward Mathematics	0.816
Creativity in Problem-Solving	0.835

Based on Table 3, all mathematical disposition indicators showed a Cronbach's Alpha value above 0.80, which was tested on 35 respondents, meaning that each indicator had a high to very high level of reliability. A high alpha value indicates that each item on the instrument has a strong relationship with the others in measuring the same construct, namely, students' mathematical disposition. Additionally, the high-reliability coefficients strengthen the confidence that the instrument's measurement results can be trusted to represent mathematical disposition comprehensively and thoroughly, encompassing the five main aspects: motivation, self-confidence, perseverance, positive attitude toward mathematics, and creativity in problem-solving. Therefore, this instrument is deemed suitable and reliable for this study's primary data collection phase.

After the validity test, the next stage was to test the instrument's reliability to ensure consistent and reliable results when used in repeated measurements. The reliability test was conducted on the items declared valid in the previous test, using Cronbach's Alpha internal consistency reliability coefficient. The selection of the Cronbach's Alpha formula is based on the instrument's nature,

consisting of several items that measure one construct simultaneously, thus requiring a measure that can describe the consistency between items. The reliability calculation results for each mathematical disposition indicator are presented in Table 4 below:

Table 4. Normality Test Results (Shapiro-Wilk Test)

Group	Test Type	N	Sig. (p-value)	Distribution
Experimental	Pre-Test	35	0.188	Normal
Experimental	Post-Test	35	0.094	Normal
Control	Pre-Test	35	0.146	Normal
Control	Post-Test	35	0.200	Normal

Based on the results of the Shapiro-Wilk test in Table 4, all significance values (p-values) from each group (both pre-test and post-test for the experimental and control groups) show values above 0.05, ranging from 0.094 to 0.200. This indicates that all data groups are normally distributed, as no group shows a significance value below the critical threshold. This normality test is a prerequisite for parametric tests such as the independent sample t-test. Normality ensures that the data distribution follows a typical distribution pattern, a key assumption in most parametric statistical analyses. Therefore, it can be concluded that both groups' pre-test and post-test data meet the assumption of normal distribution and are suitable for further analysis using parametric statistical procedures such as the t-test. The validity of the normality test results also supports the accuracy of data interpretation and enhances confidence in the conclusions drawn from the hypothesis testing.

After determining that the data is normally distributed, the analysis continues with a variance homogeneity test to ensure that the variance of the data from the experimental and control classes is the same or homogeneous. The homogeneity test is essential because it is one of the basic assumptions when using t-tests for two independent samples. This study used Levene's test because it is relatively more robust against deviations from data normality. The statistical formula for Levene's test is generally written as follows: The results of the homogeneity test for pre-test and post-test data in the experimental and control classes are shown in Table 5 below:

Table 5. Homogeneity of Variance Test Results (Levene's Test)

Test Type	Group	F	Sig. (p-value)	Conclusion
Pre-Test	Experimental vs Control	1.124	0.294	Homogeneous
Post-Test	Experimental vs Control	0.894	0.348	Homogeneous

Based on Table 5, the significance value (p-value) in the Levene test for the pre-test was 0.294, and for the post-test, it was 0.348. Both values are greater than the significance threshold $\alpha = 0.05$, so it can be concluded that there is no significant difference in variance between the experimental group and the control group, both before and after treatment. This homogeneity test was conducted to ensure that the data from both groups had uniform variance, which is one of the main prerequisites for using parametric statistical tests such as the independent sample t-test. When the variances between groups are homogeneous, comparing means between two groups can be evaluated more objectively and validly. The results of this test strengthen the basis for continuing the comparison of results between the experimental and control groups using parametric tests, as the basic assumption of equality of variances has been met. Thus, using the t-test to test the difference in the effect of treatment on mathematical disposition between groups is statistically justified.

Table 6. Distribution of Pre-Test and Post-Test Scores for Experimental and Control Groups

Group	N	Mean (Pre-Test)	SD (Pre-Test)	Mean (Post-Test)	SD (Post-Test)
Experimental	35	67.20	5.89	78.47	6.45
Control	35	66.43	6.12	69.14	5.78

Table 6 shows that the pre-test average scores between the experimental class (67.20) and the control class (66.43) were relatively balanced with an insignificant difference, indicating that both groups had almost equal mathematical disposition abilities before the treatment was given. After the treatment was administered, there was a significant increase in the average post-test score in the experimental class, reaching 78.47, compared to the control class, which only reached 69.14. In addition, the standard deviation in both groups showed a consistent data distribution, with minimal variation, reinforcing the interpretation that outliers or extreme data did not cause an increase in scores in the experimental group.

The increase in post-test scores in the experimental group was +11.27 points compared to the initial score, which was much higher than the increase of +2.71 points in the control group. This shows that using AI-based E-Modules in mathematics learning significantly improves students' mathematical dispositions. These results provide initial evidence that adaptive learning technology interventions can create more meaningful learning experiences, encourage student engagement, and shape stronger mathematical dispositions compared to conventional approaches. These findings will be confirmed inferentially through hypothesis testing in the next section.

Table 7. T-test Results of Post-Test between Experimental and Control Groups

Compared Groups	t	df	Sig. (2-tailed)	Conclusion
Experimental vs Control (Post-Test)	6.412	68	0.000	A significant difference exists

Based on Table 7, the independent samples t-test results show a t-value of 6.412 with a degree of freedom (df) = 68 and a significance value (p-value) of 0.000, which is much smaller than the significance threshold of 0.05. Thus, there is a statistically significant difference between the experimental and control classes' post-test results. These results indicate that the treatment in the form of AI-based E-Modules in mathematics learning significantly improves students' mathematical dispositions compared to conventional learning. The high t-value reflects the magnitude of the intervention effect on the experimental group and the low probability that this difference occurred by chance. Substantially, these findings strengthen the research hypothesis that an adaptive technology-based learning approach, personalized by artificial intelligence, is more effective than traditional methods in building students' motivation, confidence, and positive attitudes toward mathematics. Thus, these results provide a strong empirical basis for recommending AI-based E-Modules as an innovative strategy in mathematics education at the elementary school level.

The study results indicate a significant increase in students' mathematical dispositions in the experimental group who used AI-based E-Modules, compared to the control group who used conventional learning approaches. The average post-test scores of the experimental group were significantly higher than those of the control group, with a p-value < 0.05 in the t-test. These findings confirm that integrating AI-based adaptive technology in the learning process has a tangible impact on the development of students' affective aspects, particularly mathematical disposition, which includes motivation, self-confidence, perseverance, positive attitudes, and problem-solving creativity.

In the context of the mathematical disposition theory proposed by (Casal-Otero et al., 2023; Sperling et al., 2022), these results indicate that AI-based interventions can activate the affective dimension of learning through personalized and dynamic feedback. AI-based e-modules allow for the personalization of question difficulty levels, learning pace, and the presentation of material tailored to students' cognitive and emotional profiles. This capability encourages students to be more confident and motivated in tackling mathematical challenges while strengthening their perseverance in facing learning difficulties (Sayed et al., 2023). These results are also in line with several previous studies. For example, a study by Zafari et al. (2022) showed that interactive e-modules can increase elementary school students' engagement and understanding of mathematical concepts. Research by Jang et al. (2022) & Schroeder et al. (2022) also concluded that using AI-based learning systems positively impacts student engagement in the learning process, including increased learning affectivity.

However, the contribution of this study goes beyond mere confirmation, as it focuses on mathematical disposition as a psychological construct that has not been widely discussed in the context of AI learning technology for elementary school students. Thus, the results of this study are strong evidence that technology-based learning approaches, especially those involving artificial intelligence, are relevant in the context of academic mastery and have great potential in supporting dispositional aspects essential for long-term success in mathematics learning.

Theoretically, this study expands our understanding of the effectiveness of learning approaches that integrate AI in supporting modern constructivism and personalized learning. AI is not merely an instructional aid but functions as a pedagogical partner capable of responding to the unique needs of each student in real time (García-Martínez et al., 2023; Pardamean et al., 2022). These findings support the theoretical framework proposed by Hwang (2022) regarding the Zone of Proximal Development, where AI technology can act as adaptive scaffolding to help students bridge the gap between their actual and potential abilities in understanding mathematics.

From an educational practice perspective, these results significantly affect teachers, schools, and policymakers. Teachers must recognize that mathematical dispositions do not develop independently but must be cultivated through deliberate instructional strategies designed to activate students' affective dimensions (Martín-Núñez et al., 2023; Yeh et al., 2019; Purnadewi & Widana, 2023). Using AI-based E-Modules enables teachers to deliver engaging, challenging, and adaptive learning experiences. For schools, integrating this technology can be an effective strategy for facing learning challenges in the digital era, especially in facilitating the diversity of students' learning needs (Ouyang et al., 2023). Meanwhile, for policymakers, these findings reinforce the urgency of developing a curriculum and teacher training focusing on AI technology in disposition-based learning (Mozer et al., 2019).

The uniqueness and originality of this research lies in its contribution to enriching studies on mathematics learning in elementary schools through an artificial intelligence (AI)-based technology approach, which specifically focuses on strengthening students' mathematical dispositions. Unlike previous studies that generally only evaluate the impact of technology on cognitive outcomes or academic achievement, this study comprehensively measures and analyzes students' affective dimensions, such as motivation, self-confidence, perseverance, positive attitudes, and problem-solving creativity. The emphasis on mathematical dispositions as the primary indicator of learning innovation demonstrates an original contribution that has not been extensively explored at the elementary school level, particularly in Indonesia.

Additionally, the implementation of AI-based E-Modules in the local context of Muhammadiyah 019 Bangkinang Elementary School in Pekanbaru, Riau, offers a new, contextual, and relevant perspective aligned with real-world challenges, where mathematics learning challenges primarily revolve around low self-confidence and lack of interest among students. The research findings, which show a significant improvement in mathematical disposition scores among the experimental group, strengthen the argument that adaptive technology interventions enhance cognitive aspects and facilitate the transformation of students' attitudes and mental readiness. This reaffirms the originality of the findings that AI can serve as an effective pedagogical partner in building a practical foundation that supports long-term learning.

Although the results of this study show significant findings, several limitations must be considered. First, the scope of the study was limited to one elementary school in Pekanbaru with a limited number of respondents (N = 70) and a uniform age range (fifth grade), so the generalizability of the results to a broader population is still limited. Contextual variables such as socioeconomic background, access to technology, and family learning culture may influence the results if the study is conducted in other locations. Second, the duration of the treatment was relatively short, namely one learning unit or several weeks. However, the influence of technology on students' dispositions, which are effective and develop gradually, may require a more extended period to be observed comprehensively and accurately. Therefore, interpreting the results should focus on short-term effects without negating the long-term potential that this study has not measured. Third, mathematical disposition was measured using a self-report instrument in the form of a written test, which, although proven to be valid and reliable, still has the potential for student perception bias. External factors such as mood, perceptions of teacher assessment, or limitations in understanding the meaning of questions can affect the consistency of students' responses to dispositional items.

Based on these limitations, there are several directions for future research. First, expanding the study to various regions, grade levels, and school types (public, private, inclusive, and remote areas) will enrich the external validation of this study's results and enable the identification of contextual factors that mediate the effectiveness of AI-based learning. Second, a medium- to long-term longitudinal design is needed to continuously observe the dynamics of students' mathematical disposition development after technology integration. This is important to assess the consistency of AI's impact on dispositions and to see how students' attitudes and motivations evolve. Third, further research could consider integrating measurements of affective aspects (dispositions) and cognitive aspects (mathematical learning outcomes) to obtain a holistic picture of learning effectiveness. Collaboration between self-report instruments and direct observation of student behavior in the classroom could also enhance data validity.

This study's findings have not only academic implications but also touch on social and ethical aspects of the use of digital technology in primary education. Socially, adopting AI in learning has great potential to reduce educational quality gaps, especially in areas with teacher shortages or uneven learning facilities. With proper design and adequate infrastructure, AI-based E-Modules can deliver quality learning even in 3T areas (frontier, remote, and disadvantaged).

However, there are ethical considerations that cannot be ignored. First, using AI in primary education requires protecting students' data, especially considering that the users are still children. AI-based learning systems must be designed with strong encryption and transparent privacy policies to prevent the misuse of student data. Second, although AI offers many conveniences, it cannot replace the humanistic role of teachers. Teachers play an important role in shaping students' character, values, and empathy dimensions that technology cannot yet fully replicate. Therefore, AI should be seen as a pedagogical partner, not a replacement for humans. Third, access to digital devices and internet connections remains a barrier for many students in Indonesia. Implementing AI-based learning technology must consider inclusivity to avoid creating a digital divide that widens educational inequality. Therefore, policy interventions from the government and stakeholders are essential to provide equitable infrastructure support.

Conclusion

Based on the research and discussion results, the application of AI-based E-Modules in mathematics learning significantly improves the mathematical disposition of elementary school students compared to conventional learning approaches. Mathematical disposition refers to motivation, self-confidence, perseverance, a positive attitude toward mathematics, and problem-solving creativity. These findings are supported by statistical tests that show significant differences between the post-test scores of the experimental and control groups. The effectiveness of AI-based E-Modules in shaping mathematical dispositions lies not only in the digital content presented but also in the adaptive characteristics of the system, which can adjust learning styles and difficulty levels to individual students' abilities. This confirms that AI can be a transformative pedagogical tool in cognitive aspects and building students' affective readiness for continuous mathematics learning. Theoretically, this study reinforces the adaptive technology-based learning model and supports the constructivist approach that places students at the center of the learning process. Practically, these findings have strategic implications for educators, educational technology developers, and policymakers to integrate AI-based learning systems that are child-friendly, inclusive, and ethical. Comprehensive policy support is needed to encourage the adoption of AI-based technology in primary education, including providing digital infrastructure, teacher training, and funding for developing modules tailored to local needs. The government must also ensure that the integration of AI in education does not widen the digital divide but rather serves as a tool for equitable access to and quality of education across all regions of Indonesia.

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