25 (4), 2024, 1719-1737
Jurnal Pendidikan MIPA
e-ISSN: 2685-5488 | p-ISSN: 1411-2531
http://jurnal.fkip.unila.ac.id/index.php/jpmipa/

Optimizing Students' HOTS Skills through AI and IoT Integration in Digital Technology Learning

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Abstract: Higher-order thinking skills (HOTS) are essential for students to face increasingly complex global challenges. However, results from the Programme for International Student Assessment (PISA) indicate that these skills among Indonesian students remain low. This study aims to address this limitation by integrating Artificial Intelligence (AI) and Internet of Things (IoT) technologies into learning, specifically to enhance students' HOTS within the framework of the Kurikulum Merdeka. This research employs a quasi-experimental method with a one-group pretest-posttest design, involving three schools in East Nusa Tenggara as the sample. Data on students' HOTS were collected before and after the AI and IoT-based learning intervention and analyzed using paired sample T-tests and N-Gain to assess the significance and effectiveness of the improvement. The results show a significant increase in students' HOTS scores across all three schools, with $p < 0.001$ in paired sample T-tests and an average N-Gain score in the medium category. These findings suggest that AI and IoT-based learning can improve students' critical and analytical thinking skills. Implementing technology within the Kurikulum Merdeka offers relevant and promising benefits in preparing students to face future knowledge dynamics. This study contributes to the literature on technology-based education in Indonesia, with the hope that broader technology integration will accelerate the enhancement of national education quality.

Keywords: higher-order thinking skills, artificial intelligence, internet of things, kurikulum merdeka, technology-based learning.

▪ INTRODUCTION

In today's world, society faces increasingly complex global challenges. Students need to develop competencies, skills, and innovative abilities before engaging in society (Kurniawan et al., 2024). Ironically, the results of the 2022 Programme for International Student Assessment (PISA) reveal that Indonesia has not shown significant improvement since 2000. The PISA data also indicates that countries with better educational achievements have successfully integrated educational technologies into their learning systems (Ika Sari et al., 2024), thus significantly enhancing students' critical and analytical thinking skills. This serves as a reminder that Indonesia needs to immediately implement deeper reforms, particularly in the area of technology integration in the classroom. This conclusion is supported by the very low levels of High Order Thinking Skills (HOTS) among Indonesian students. In fact, HOTS is key to addressing increasingly complex global challenges ((Liu et al., 2024). HOTS involves cognitive activities at a higher level, aimed at improving students' thinking abilities (Anggoro et al., 2024).

In response to this, the current Minister of Education and Culture has initiated the Merdeka Belajar program as a new step to improve the quality of education in Indonesia (Christwardana et al., 2022). This program emphasizes the development of creativity, skills, and students' abilities in literacy and numeracy. The curriculum gives freedom to students and schools to develop learning methods that consider social phenomena in

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DOI: http://dx.doi.org/10.23960/jpmipa/v25i4.pp1719-1737
Received: 07 December 2024
Accepted: 09 January 2025
Published: 10 January 2025

understanding the learning process (Mufanti et al., 2024). However, despite the freedom offered by the Merdeka Curriculum, the implementation of technologies such as AI and IoT in Indonesian schools is still very limited. Existing research indicates that the integration of technology in Indonesia's education system has not been maximized, with infrastructure limitations and lack of teacher training being the main barriers (Fernandes et al., 2024).. This program focuses on developing interactive learning that takes into account contextuality, inclusivity, and responsiveness to students' needs, which aligns with the need to improve the quality of classroom learning (Agoes Salim et al., 2023).

Globally, developed countries have successfully applied technologies such as AI and IoT to support HOTS learning. For example, in Finland and South Korea, AI has been used to provide smart, personalized feedback to students, enabling them to develop critical thinking skills more quickly (Salih et al., 2024). Additionally, IoT has helped create a more contextual and relevant learning environment, allowing students to connect with the real world through interactive learning experiences (Mylonas et al., 2019). The involvement of advanced technologies like AI and IoT presents a strategic opportunity to enhance the quality of classroom learning (Lee & Kwon, 2024; Tabuenca et al., 2023). AI technology can help improve students' critical thinking by providing intelligent feedback (Aleksandra Fostikov, n.d.; Farizi et al., 2024), while IoT offers a more contextual learning experience, linking it with the real life (Dong et al., 2024; Verma et al., 2024). By leveraging these technological innovations, HOTS learning becomes not only more effective but also more relevant to the ever-changing global demands. However, to date, there has been limited research specifically examining the impact of AI and IoT integration on optimizing HOTS in the era of the Merdeka Curriculum. Most previous studies have focused on the use of technology to improve basic skills like literacy and numeracy, with few exploring its impact on higher-order thinking skills. The integration of AI and IoT in the learning process is expected to create a more adaptive, interactive learning environment that can enhance students' higher-order thinking skills.

Based on this gap, this research aims to fill the gap in the literature by investigating the direct impact of AI and IoT integration on HOTS learning in Indonesia, particularly in the context of the Merdeka Curriculum. This study aims not only to test the effectiveness of technology in enhancing students' analytical abilities but also to explore how these technologies can be practically implemented in Indonesian schools, given the existing infrastructure limitations. Based on this background, the research problem addressed in this study is: How does the integration of AI and IoT impact the optimization of students' HOTS in interactive learning in the era of the Merdeka Curriculum?

▪ METHOD

This study is part of a quasi-experimental research that evaluates the effectiveness of AI and IoT integration in enhancing students' HOTS in interactive learning within the context of the Merdeka Curriculum. Experimental research is a type of study that controls at least one variable and carefully observes the effects it produces on the dependent variable. According to Gay (1981), experimental research is the only appropriate approach to examine causal relationships between variables. This experimental study takes a quantitative form with a one-group pretest-posttest design. To strengthen internal validity, a control class without the use of AI and IoT-based learning was included. This approach was implemented to provide a clearer comparison of effectiveness between the control and experimental classes.

Population and Sample

The population in this study consists of all 12th-grade students who have been using the Merdeka Curriculum in senior high schools in East Nusa Tenggara Province. However, due to the limited implementation of the newly adopted Merdeka Curriculum, this study takes a sample from three schools that have fully implemented the curriculum. The sample selection was done purposively to obtain a broad representation and accommodate the variation in the integration of AI and IoT technology across different educational contexts.

The distribution map of the research locations conducted in these three districts can be seen in Figure 1. The selection of these schools is also based on the use of the Merdeka Curriculum as the main curriculum in teaching, where only a small number of schools in East Nusa Tenggara Province have fully implemented this curriculum.

Figure 1. Research location distribution

The sample taken includes three schools from three different districts: SMA N 1 Maumere in Sikka District, SMA N 1 Wolowaru in Ende District, and SMA N Buyasuri in Lembata District. Each school contributed 30 students, bringing the total sample size to 90 students. This sample size is expected to provide in-depth insights into the effectiveness of AI and IoT integration in enhancing students' HOTS across different learning contexts.

Research Instruments

The instruments used in this study consist of two types: the Student Worksheet and a HOTS test instrument. The Student Worksheet serves to assess the students' learning process, including their ability to create AI and IoT-based projects, their active involvement in learning activities, and their understanding of the steps provided in the project tasks. The student worksheets is designed using the Project-Based Learning (PjBL) model, which aims to introduce 12th-grade students to the concepts and applications of Digital Technology. This Student Worksheet guides students to actively learn through real-world projects, focusing on the application of technologies AI and IoT.

The content of the Student Worksheet encompasses several key elements, including learning objectives that help students grasp digital technology concepts, ranging from basic understanding to real-life applications. It also contains learning materials that cover theories about digital technology, digital tools such as sensors and Arduino, as well as explanations of AI and IoT technologies. Additionally, the worksheet includes activity sheets designed to guide students in carrying out digital technology-based projects, starting from formulating questions, designing projects, and presenting the results.

Through this Student Worksheet, students are encouraged to develop critical thinking, problem-solving, and creativity skills in applying digital technology. The developed Student Worksheet was validated by subject matter experts and media experts to assess its quality in the learning process. To strengthen the validity of the instrument and evaluate the agreement among all validators, inter-rater reliability was calculated using the Intraclass Correlation Coefficient. The validation process employed a Likert scale model, focusing on aspects such as the relevance of the content, clarity of instructions, visual design, and ease of use for both students and teachers. The following is the instrument grid used for validation by media and subject matter experts.

Table 1. Instrument indicators for subject matter experts

No.	Assessment Indicator	Number of Statement Items
1.	Design and Layout	5
2.	Clarity of Material	5
3.	Depth of Material	5
4.	Activities and Exercises	5
	Total Items	**20**

This instrument covers several aspects, such as design and layout, which assess the alignment of the material with the curriculum, the accuracy of the concepts, and the completeness of the content. Additionally, the instrument evaluates clarity of material, including the ease of understanding the language, instructions, and the relevance of the examples provided. The depth of material is also assessed to ensure that the content is presented in detail and encourages students to think critically. Finally, the instrument measures the activities and exercises in the student worksheet, focusing on their relevance, variety, and ability to motivate students in active learning.

Table 2. Media expert instrument indicators

No.	Assesmen Indikator	Number of Statements
1.	Design and Layout	5
2.	Use of Visual Media	5
3.	Physical Quality and Printing	5
4.	User Ease and Motivation	5
	Total Statements	**20**

Table 2 above explains the instrument indicators for media experts. It covers several important aspects, such as design and layout, which assess the readability of the text, neatness of the layout, and the use of colors that support readability and create an attractive visual appearance. Additionally, the aspect of visual media usage is evaluated, including the relevance of images and graphics used in relation to the material, as well as their quality and visual appeal to students. The physical quality and printing of the student worksheet are assessed to ensure print clarity, durability, and formatting that meets students' needs. This instrument also evaluates ease of use and motivation, assessing whether the student worksheet is easy for students to use independently and whether the activities presented can motivate students to engage in learning more actively.

The second instrument is the test instrument, which is designed to measure students' HOTS abilities, covering three high-level cognitive domains: analysis (C4), evaluation (C5), and creation (C6). These questions are developed to assess students' skills in analyzing data, evaluating situations, and designing and developing creative solutions related to the use of digital technology in physics. The instrument consists of multiple-choice and essay questions that focus on aspects such as the ability to analyze, compare, assess, design, and develop solutions. Assessment is based on specific HOTS indicators integrated into each question.

Table 3. HOTS assessment indicators

No.	HOTS Category	Assesment Indikator	Description	Question Number
1.	Analysis (C4)	Analyzing	Identifying patterns, structure, or parts of information	MCQ 1. Essay 1
		Correlation	Connecting information to find relevant relationships	MCQ 2. Essay 2
		Breaking Down	Breaking information into smaller parts	MCQ 3. Essay 4
2.	Evaluation (C5)	Comparing	Evaluating similarities and differences between two concepts	MCQ 4. Essay 3
		Assesing	Drawing conclusions or providing judgments on information or solutions	MCQ 5
3.	Creation (C6)	Organizing	Designing steps to solve a problem	MCQ 6. Essay 4
		Collection	Integrating information to draw conclusions	MCQ 7
		Developing	Creating or developing new solutions based on information	MCQ 8
		Designing	Making a plan or design based on analysis and evaluation	MCQ 9. Essay 5
		Planning	Formulating strategies to solve a specific problem	MCQ 10

The table above presents the HOTS assessment indicators used in this test instrument. In the C4 domain, students are assessed based on their ability to analyze information, connect data, and break down information into smaller parts. In the C5 domain, students are expected to compare concepts and critically assess information to draw relevant conclusions. In the C6 domain, the assessment focuses on students' ability to develop new solutions, design strategies, as well as organize and plan projects related to the use of digital technology in physics learning. These indicators ensure that the questions are designed to thoroughly measure students' higher-order thinking skills.

To ensure the quality of the instrument, the questions will undergo reliability and validity testing. Reliability testing aims to measure the consistency of the instrument in generating stable data, while validity testing ensures that the instrument truly measures what it is intended to measure, which is students' higher-order thinking abilities. Through these tests, the instrument will be strengthened and optimized before being used in the research, ensuring that the data obtained can be relied upon for further analysis.

Research Procedure

The research procedure follows a systematic and structured flow, starting from the pre-research phase to the post-research phase. Each step is designed to ensure that the research progresses according to plan, with valid and reliable results. The procedure includes several key steps such as the development and validation of instruments, the administration of pretests and posttests, as well as data collection and analysis. Below is an explanation of the research procedure, based on the flowchart that has been prepared, as shown in Figure 2.

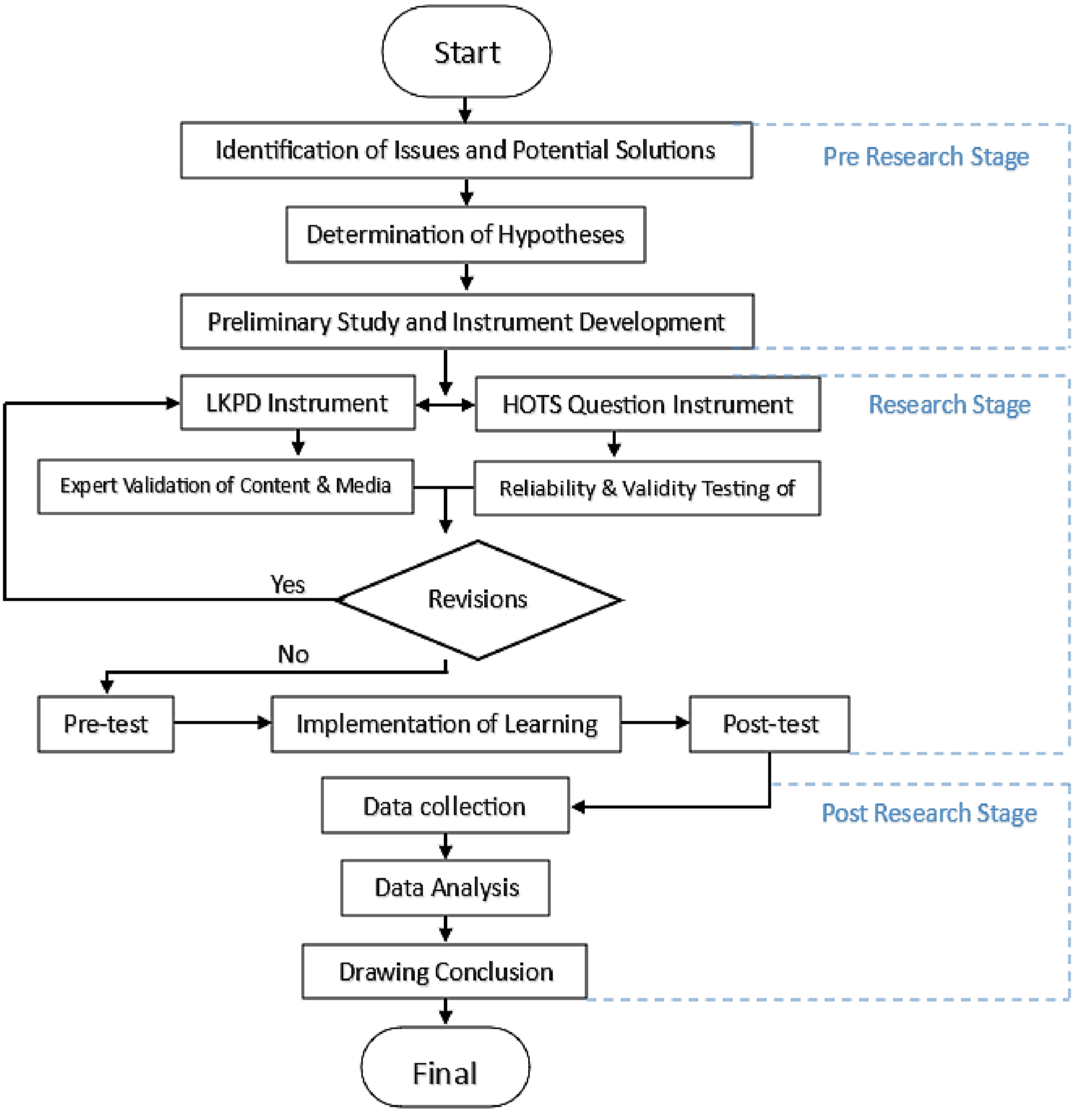

Figure 2. Research flowchart

Figure 2 illustrates that in the pre-research phase, the first step is to identify the main problem related to the low HOTS abilities of students and to formulate potential solutions through the integration of AI and IoT technology in learning. After the problem and solutions are formulated, the research hypothesis is established to test whether there is a significant effect of applying this technology on improving students' HOTS abilities. A preliminary study is then conducted to develop the research instruments, including the Student Work Sheet and HOTS test questions, which will be used to measure students' skills before and after the AI and IoT-based learning intervention.

Next, in the research phase, the developed instruments are validated by subject matter and media experts to ensure that the student worksheet and HOTS test questions align with the learning objectives and are suitable for use in the educational context. After validation, reliability and validity testing of the questions is conducted to ensure that the test instruments consistently and accurately measure students' abilities. If feedback from the experts suggests revisions, the instruments are modified until they meet the necessary standards. Once the instruments are deemed valid and reliable, a pretest is administered to measure students' initial abilities before the intervention. The Project-Based Learning (PjBL) process, integrating AI and IoT, is then implemented, and after the learning process, a posttest is given to measure changes and improvements in students' HOTS abilities.

In the post-research phase, data from the pretest and posttest are collected and analyzed. Before hypothesis testing, normality tests are conducted to ensure the data follows a normal distribution, and homogeneity tests are performed to assess variance similarities among the data groups. After the data are confirmed to be normal and homogeneous, a T-test is conducted to test the hypothesis, i.e., whether there is a significant effect of AI and IoT application on the improvement of students' HOTS abilities. The results of this data analysis are then used to draw conclusions about the effectiveness of the applied technology, and recommendations are made based on the findings.

Data Collection and Analysis Techniques

Data collection in this research is carried out through the results of the pretest and posttest administered to students before and after the implementation of AI and IoT-based learning. The pretest is conducted to measure students' initial HOTS abilities, while the posttest is given after the learning process to measure improvements in those abilities. The instruments used for data collection are HOTS test questions that cover indicators of analysis, evaluation, and creation abilities. The test consists of multiple-choice and essay questions designed to assess students' higher-order thinking skills. The pretest and posttest data are then recorded and organized in tables for statistical analysis, aimed at testing the hypothesis regarding the significant effect of applying AI and IoT on improving students' HOTS abilities.

The data analysis technique in this research is conducted in stages, starting with normality and homogeneity tests to ensure that the data meet the assumptions of normal distribution and equal variances across groups. After that, N-gain calculations are performed to measure the level of improvement in students' HOTS abilities before and after AI and IoT-based learning. The analysis continues with paired sample T-tests, which aim to compare the pretest and posttest results within each school separately. This test is used to determine whether there are significant differences between the pretest and posttest within a group of students at each school. It is important to note that the data from the three schools are not intended to be compared with each other, but rather to reinforce the research findings, with the hope that similar improvement patterns can be observed across all schools. The results of this analysis will be used to draw conclusions about the effectiveness of applying AI and IoT in improving students' HOTS abilities, taking into account the statistical significance values obtained from the T-tests at each school.

▪ RESULT AND DISSCUSSION

Expert Validation Results

Subject Matter Expert Validation

The table below presents the results of the subject matter expert validation conducted by three validators concerning the student worksheet instrument used in this study. This validation covers several aspects of assessment, including design and layout, clarity of the material, depth of the material, and activities and exercises. Each validator provided assessments based on a Likert scale, and the average score from the three validators was calculated for each indicator, which was then converted into a percentage to determine the validity level of the instrument.

Table 4. Expert validation of content

No.	Indicator	Average Validator Score			Average Precentage	Criteria
		V1	V2	V3		
1.	Design and Layout	3.6	3.4	3.4	86.7	Highly Valid
2.	Clarity of Material	3.6	3.8	3.4	90.0	Highly Valid
3.	Depth of Material	3.2	3	2.8	75.0	Valid
4.	Activities and Exercises	3.6	3	3.2	81.7	Valid
Average Precentage					**83.3**	**Valid**

The table above shows the assessment results from three validators for four main indicators in the validation of the student worksheet. The first indicator, design and layout, received an average percentage of 86,7%, which is categorized as valid. The second indicator, clarity of material, achieved the highest average score with a percentage of 90%, also deemed valid. The indicator for depth of material showed a percentage of 75%, which is also categorized as valid, although its value is lower compared to the other indicators. Lastly, the indicator for activities and exercises received a percentage of 81,7% and was declared valid. Overall, the average percentage of all indicators is 83,3%, meaning the instrument is generally considered valid for use in this study.

Media Expert

Next are the results of the media expert validation. The following table presents the validation results from three validators for the student worksheet instrument used in this study. This validation covers several indicators, including design and layout, use of visual media, physical and printing quality, as well as ease of use and motivation. Each validator provided assessments that were converted into percentages to determine the validity level of each indicator.

Table 5. Media expert validation

No.	Indicator	Average Validator Score			Average Precentage	Criteria
		V1	V2	V3		
1.	Design and Layout	3.6	3.8	3.4	90	Highly Valid
2.	Use of Visual Media	2.6	2.8	3	70.0	Valid
3.	Physical Printing Quality	3	3.2	3.2	78.3	Valid
4.	Ease of Use and Motivation	2.6	3	3	71.7	Valid
Average Precentage					**77.5**	**Valid**

From the table above, it can be seen that the first indicator, "Design and Layout," received the highest score with a percentage of 90%, which is categorized as "Highly Valid." This indicates that the design of the student worksheet was highly rated by the validators. The second indicator, "Use of Visual Media," scored 70%, which is categorized as "Valid." This suggests that the visual aspects of the student worksheet are considered adequate, but there is still room for improvement. The third indicator, "Physical and Printing Quality," received a percentage of 78.3%, also categorized as "Valid," indicating that the physical and printing quality of the student worksheet is quite good. Lastly, "Ease of Use and Motivation" was rated with a percentage of 71.7%, which is also categorized as "Valid." Overall, the average percentage for media expert validation is 77.5%, indicating that the student worksheet is valid and suitable for use in the study.

To support the validation results, an Intraclass Correlation Coefficient (ICC) test was also conducted to measure the level of agreement or consistency among multiple evaluators (validators) on the same object. The ICC test is used to assess the reliability of data in research, particularly in the validation of instruments or media used. The data from the ICC test are presented in the following Table 6.

Tabel 6. Intraclass correlation coefficient

Validator Type	ICC Type	ICC Value	Confidence Interval (95%)	Reliability Category	p-value
Media Expert	Average Measures	0.592	0.141 – 0.826	Moderate	0.009
Content Expert	Average Measures	0.767	0.509 – 0.900	High	0.000

In the validation by the media expert, the Average Measures ICC value obtained was 0.592, with a 95% confidence interval ranging from 0.141 to 0.826. This value falls into the moderate reliability category, indicating a reasonably good level of consistency among the validators. The p-value of 0.009 shows that this result is statistically significant at the 95% confidence level. On the other hand, validation by the content expert yielded an Average Measures ICC value of 0.767, with a 95% confidence interval between 0.509 and 0.900. This value falls into the high reliability category, indicating an excellent level of agreement among the validators. The p-value of 0.000 indicates that the result is highly statistically significant. These results show that the instrument assessed by the media expert has a moderate level of consistency, while the instrument assessed by the content expert demonstrates high consistency. This provides an overview that both media and content validation received significant reliability support from the validators.

Results of Validity and Reliability Testing

Table 7. presents the results of the validity and reliability tests for the multiple-choice and essay test items used to measure students' HOTS (Higher-Order Thinking Skills). The validity test was conducted using the point-biserial correlation coefficient for each test item, by comparing the correlation results with the critical value r table at a significance level of 5%, which is 0.388. This test aims to determine whether each test item has sufficient validity to measure the intended aspect.

Table 7. Test of question validity

Question Type	Question Number	Point-Biserial Correlation Coefficient	R table (5% Significance Level)	Interpretation
Multiple Choice	1	0.669	0.388	valid
	2	0.411		valid
	3	0.527		valid
	4	0.497		valid
	5	0.583		valid
	6	0.605		valid
	7	0.725		valid
	8	0.456		valid
	9	0.425		valid
	10	0.481		valid
Essay	1	0.625		Valid
	2	0.698		Valid
	3	0.556		Valid
	4	0.864		Valid
	5	0.784		Valid

Based on the table above, it can be seen that all items, both multiple-choice and essay, have a correlation coefficient higher than the critical value of r table (0.388), meaning all items are declared valid. For the multiple-choice questions, the correlation coefficients range from 0.411 to 0.725, indicating that each item has an adequate correlation with the total score, thus categorizing them as valid. Similarly, the essay questions have correlation values between 0.556 and 0.864, demonstrating a high level of validity.

After conducting the validity test to ensure that each item measures the intended aspects, a reliability test was also performed to assess the internal consistency of this instrument. The reliability test used Cronbach's Alpha for both the multiple-choice and essay questions, with the goal of ensuring that the instrument provides consistent and reliable results in measuring students' HOTS skills. The results of the reliability test are presented in the table below.

Table 8. Reliability test of questions

Test	Question type	Scor	Interpretation
Cronbach alpha	Multiple choice	0.704	Reliable
	Essai	0.7392	

From the table above, it can be seen that the Cronbach's Alpha value for the multiple-choice questions is 0.704, and for the essay questions, it is 0.7392. Both of these values exceed the commonly accepted minimum reliability threshold of 0.7, meaning both are categorized as reliable. This indicates that both the multiple-choice and essay question instruments have good internal consistency, meaning they can provide stable and consistent results when used to measure students' HOTS (Higher Order Thinking Skills) in the context of AI and IoT-based learning.

Result of Normality and Homogeneity Test

The table below presents the results of the normality test for the pretest and posttest data from three schools involved in this study: SMA N Buyasuri Lembata, SMA N 1 Maumere, and SMA N 1 Wolowaru. The normality test was conducted to ensure that the data is normally distributed, which is a prerequisite for conducting further parametric statistical analysis. The significance (Sig.) values are used for this test, with the criterion of p-value > 0.05 indicating that the data is normally distributed.

Table 9. Normality test

Tes	School Name	df	Sig.	Criteria
Pre-Tes	SMA N Buyasuri Lembata	35	0.193	Normal
	SMA N 1 Maumere		0.542	Normal
	SMA N 1 Wolowaru		0.633	Normal
Post-Test	SMA N Buyasuri Lembata		0.602	Normal
	SMA N 1 Maumere		0.479	Normal
	SMA N 1 Wolowaru		0.168	Normal

From the results of the normality test shown in Table 9, it can be seen that all pretest and posttest data from the three schools have a significance (Sig.) value greater than 0.05. The significance value for the pretest at SMA N Buyasuri Lembata is 0.193, at SMA N 1 Maumere is 0.542, and at SMA N 1 Wolowaru is 0.633. Meanwhile, for the posttest, the significance values at SMA N Buyasuri Lembata is 0.602, at SMA N 1 Maumere is 0.479, and at SMA N 1 Wolowaru is 0.168. Based on these results, all pretest and posttest data from the three schools meet the normality assumption, allowing further analysis using parametric statistical tests. This indicates that the instruments and data collected can be considered valid in terms of normal distribution and are ready for further analysis.

After ensuring that the pretest and posttest data from the three schools meet the normality assumption, as shown in the table above, the next step is to conduct a homogeneity of variance test. This homogeneity test aims to determine whether the variances between the pretest and posttest data at each school are similar or homogeneous. The homogeneity test is conducted using Levene’s Test for Equality of Variances, as this test is effective in assessing the equality of variances between two data groups. Assuming homogeneous variances, further analysis can be performed using parametric tests.

Table 10. Homogeneity test

School Name	Tes	F	Sig.	Criteria
SMA N Buyasuri Lembata	Pre-Test	0.278	0.600	Homogen
	Post-Test			
SMA N 1 Maumere	Pre-Test	1.298	0.259	Homogen
	Post-Test			
SMA N 1 Wolowaru	Pre-Test	1.878	0.175	Homogen
	Post-Test			

Table 10 above presents the results of the homogeneity of variance test for the pretest and posttest data from three schools: SMA N Buyasuri Lembata, SMA N 1 Maumere, and SMA N 1 Wolowaru. The results show that SMA N Buyasuri Lembata has an F value of 0.278 with a p-value (Sig.) of 0.600, SMA N 1 Maumere has an F value of 1.298 with a p-value (Sig.) of 0.259, and SMA N 1 Wolowaru has an F value of 1.878 with a p-value (Sig.) of 0.175. In all cases, the p-values (Sig.) are greater than 0.05, indicating that the variances between the pretest and posttest data are homogeneous. This result confirms that the homogeneity of variance assumption is met, allowing the paired sample T-test to be conducted on the pretest and posttest data at each school.

Analysis of HOTS Scores of Students

The analysis of students' High Order Thinking Skills (HOTS) scores from each school is presented in the diagram below. The data displayed includes the average score (mean), standard deviation (std), maximum score (max), and minimum score (min) for each assessment stage. This information provides an overview of students' skill development after a particular learning process or intervention, as measured through changes in pre-test and post-test scores.

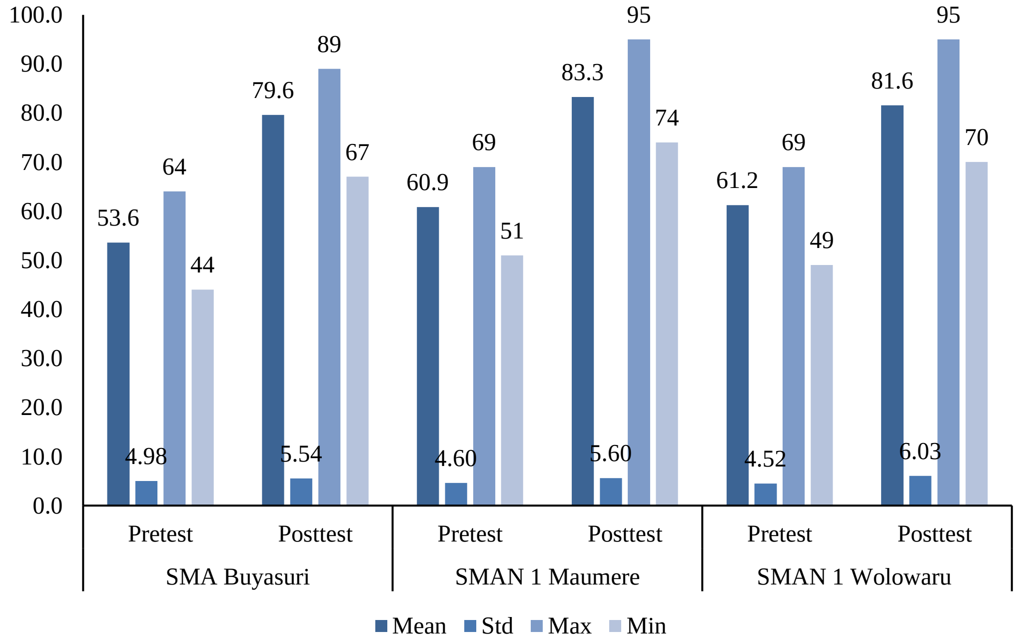

Figure 2. Diagram of students' HOTS results analysis

Based on the HOTS assessment results from three schools—SMA Buyasuri, SMAN 1 Maumere, and SMAN 1 Wolowaru—there was a significant increase in post-test scores compared to pre-test scores in all schools. At SMA Buyasuri, the average score increased from 53.6 in the pre-test to 79.6 in the post-test, with the maximum score increasing from 64 to 89 and the minimum score from 44 to 67. The standard deviation also rose from 4.98 to 5.54, indicating a slight increase in the spread of post-test scores. Furthermore, at SMAN 1 Maumere, the average pre-test score was 60.9, while the average post-test score increased to 83.3. The maximum score rose from 69 to 95, while the minimum score increased from 51 to 74. The standard deviation also rose from 4.60 in the pre-test to 5.60 in the post-test, indicating greater score variation in the post-test results. At SMAN 1 Wolowaru, the average pre-test score was 61.2, which increased to 81.6 in the post-test. The maximum score rose from 69 to 95, while the minimum score increased from 49 to 70. The standard deviation also rose from 4.52 in the pre-test to 6.03 in the post-test, indicating a broader distribution of post-test scores.

Overall, all three schools showed a similar trend of improvement in terms of average scores, maximum scores, and minimum scores. This reflects the development of students' abilities to solve HOTS questions after certain learning processes or interventions, as evidenced by better post-test results compared to pre-test results. The slightly increased standard deviation in each school suggests a broader variation in post-test results, possibly due to the improved performance of students with varying skill levels.

N-Gain Calculation Results

The table below presents the results of the N-Gain calculation for each school involved in this study. N-Gain is used to measure the effectiveness of the improvement in students' abilities from the pretest to the posttest after the implementation of AI and IoT-based learning. The N-Gain scores provide an overview of the level of improvement that occurred, which is then categorized as low, moderate, or high.

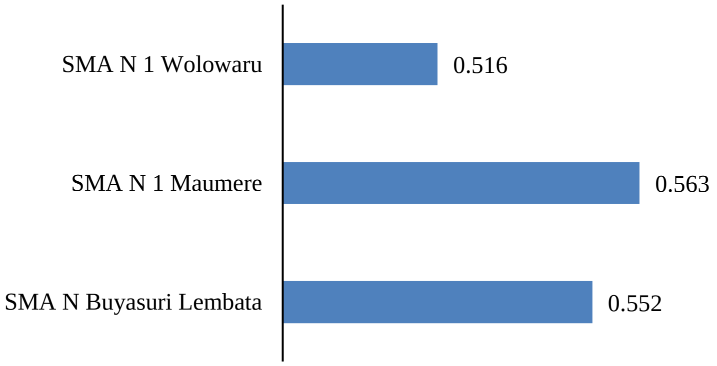

Figure 2. Scor N-Gain

Figure 2 above shows the N-Gain scores for each school, with SMA N Buyasuri Lembata scoring 0.552, SMA N 1 Maumere scoring 0.563, and SMA N 1 Wolowaru scoring 0.516, all of which fall into the moderate category. These results indicate that the improvement in students' higher-order thinking skills (HOTS) across the three schools is at a moderate level. This suggests that the AI and IoT-based learning implemented in this study has had a significant and consistent effect in enhancing students' HOTS abilities. The consistent N-Gain scores in the moderate category across all schools further demonstrate the stable effectiveness of this teaching method in different educational contexts.

Results of Paired Sample T-Test

The final stage of this research is the paired sample T-test, conducted to analyze the difference between pretest and posttest scores from three schools: SMA N Buyasuri Lembata, SMA N 1 Maumere, and SMA N 1 Wolowaru. This test aims to determine whether there is a significant improvement in students' HOTS abilities after the implementation of AI and IoT-based learning. The values presented in this table include the Mean Difference (the average difference between pretest and posttest), Std. Deviation, Std. Error Mean, t-value, df (degrees of freedom), and Sig. (p-value) indicating the significance of the difference.

Table 11. Result of paires sample t-test

School Name	Mean Difference	Std. Deviation	Std. Error Mean	t	df	Sig.
SMA N Buyasuri Lembata	-26	8.128	1.374	-18.925	34	< 0.001
SMA N 1 Maumere	-22.4	8.088	1.367	-16.384	34	< 0.001
SMA N 1 Wolowaru	-20.3	7.915	1.338	-15.206	34	< 0.001

The table above presents the complete results of the paired sample T-test that was conducted. At SMA N Buyasuri Lembata, the average difference in scores between the pretest and posttest was -26, with a standard deviation of 8.128 and a standard error of 1.374. The t-test value for this school was -18.925 with 34 degrees of freedom (df), and the p-value was < 0.001. This indicates a significant improvement in students' abilities after the treatment.

At SMA N 1 Maumere, the average score difference was -22.4, with a standard deviation of 8.088 and a standard error of 1.367. The t-test value at this school was -16.384 with 34 df, and p < 0.001, also indicating a significant improvement. SMA N 1 Wolowaru showed an average score difference of -20.3 with a standard deviation of 7.915 and a standard error of 1.338. The t-test value for this school was -15.206 with 34 df and p < 0.001, indicating a significant improvement between the pretest and posttest.

Overall, the results of the paired sample T-test in all three schools show that the p-value is < 0.001, meaning that the posttest scores significantly improved compared to the pretest scores. This result indicates that AI and IoT-based learning has a strong positive effect on students' HOTS abilities in all the schools studied, strengthening the evidence that this learning method is effective in improving students' critical and analytical thinking skills.

Discussion on HOTS Improvement

In this study, the effectiveness of AI and IoT-based learning in improving students' HOTS abilities was tested through a paired sample T-test to compare pretest and posttest scores. Before conducting the T-test, the pretest and posttest data from each school were examined for normality using the Shapiro-Wilk test. This step is crucial to ensure that the paired sample T-test is appropriate and valid for assessing the impact of the learning intervention on the same group, thereby controlling individual variability and providing a clearer measure of the effectiveness of this technology-based learning method.

The results of the paired sample T-test showed a significant improvement between the pretest and posttest scores for students' HOTS abilities in all three schools, namely SMA N Buyasuri Lembata, SMA N 1 Maumere, and SMA N 1 Wolowaru. Based on the T-test results, the mean differences in scores were -26 for SMA N Buyasuri Lembata, -22.4 for SMA N 1 Maumere, and -20.3 for SMA N 1 Wolowaru. These values indicate that after the AI and IoT-based learning was implemented, there was an average increase of 26 points, 22.4 points, and 20.3 points, respectively, in each school.

Furthermore, the T-test results showed a p-value (Sig. 2-tailed) < 0.001 for all three schools, which means this improvement is statistically significant. A p-value smaller than 0.001 indicates that the difference between the pretest and posttest scores is highly unlikely to have occurred by chance and is very likely due to the intervention, which in this case is the implementation of AI and IoT-based learning. Therefore, these results support the conclusion that the intervention applied in this study successfully enhanced students' HOTS abilities in each of the schools involved.

The success in improving HOTS abilities aligns with the primary objective of the study, which aimed to observe the positive impact of integrating technology in learning, specifically AI and IoT, on enhancing students' higher-order thinking skills. However, several factors can explain the variation in the level of improvement across schools, such as facilities, location, and additional support provided. SMA N Buyasuri recorded lower pretest and posttest averages compared to the other two schools. Based on an initial survey conducted, this is likely due to the limited technological facilities at SMA N Buyasuri, such as inadequate computer and physics laboratories, compared to SMAN 1 Maumere and SMAN 1 Wolowaru, which have better-equipped facilities. Additionally, the location of the school also plays a role; SMA N Buyasuri is situated in Kabupaten Lembata, which is classified as a 3T region (Remote, Frontier, and Underdeveloped), while SMAN 1 Maumere is located in the center of Maumere City, and SMAN 1 Wolowaru is situated in the center of Wolowaru District, which has better access to educational resources.

The significant improvement in posttest scores across the three schools is also attributed to the optimal support provided by the research team, such as the provision of laptops, internet access, premium ChatGPT accounts, and IoT devices like Arduino sensors and others. This support ensured that all students could actively participate in project-based learning, complete group tasks, and apply technology directly in their learning activities. This indicates the success of the intervention in enhancing students' HOTS abilities.

In addition to the paired sample T-test, the N-Gain calculation was performed to clarify the effectiveness level of AI and IoT-based learning in improving HOTS abilities in the three schools. N-Gain is used to measure the extent of the improvement and categorize it into low, medium, or high levels. Based on the calculations, the average N-

Gain scores across the three schools were in the "medium" category: 0.552 at SMA N Buyasuri Lembata, 0.563 at SMA N 1 Maumere, and 0.516 at SMA N 1 Wolowaru.

The consistent medium-category N-Gain results further reinforce the findings from the previous T-test, which showed significant improvements in students' HOTS abilities after the implementation of technology-based learning. The medium-level improvement indicates that this method has had a significant impact, although it has not yet reached a high level of improvement. This could be attributed to several factors, such as the limited time for implementation, student adaptation to the new learning methods, and technical challenges in the application of AI and IoT in the classroom.

Thus, the results of this N-Gain analysis provide an indication that AI and IoT-based learning can enhance students' higher-order thinking skills (HOTS) at a fairly effective level across different school conditions in three different districts. These findings also support the results from the comparison of the magnitude of the improvement (Mean Difference) obtained from the paired sample T-test, where all three schools, despite having slight variations in average improvements, showed consistent results in the effectiveness of technology-based learning methods.

These findings align with various previous studies that have shown that the application of technology in education, particularly AI and Internet of Things-based technology, can significantly contribute to improving higher-order thinking skills (HOTS) in students (Groothuijsen et al., 2024). Research by (Bayaga, 2024; Farizi et al., 2024) indicated that AI technology can assist students in solving complex problems and developing critical thinking skills through more adaptive and responsive interactions. Additionally, IoT applied in learning allows students to be more connected to abstract concepts directly and contextually, thus improving deeper and more analytical understanding (Ali et al., 2017; Rosli et al., 2020)

These findings also support studies by several researchers who emphasize the importance of integrating technology into the classroom to improve students' analytical skills, problem-solving, and creativity. In this context, the significant T-test results and the consistent "medium" category N-Gain scores show that the application of AI and IoT-based learning has had a positive and significant impact on students' HOTS, as expected in modern educational theories that encourage the use of technology as a learning tool.

Furthermore, (Rashid & Asghar, 2016) stated that technology-based learning processes allow students to experience more independent and reflective learning. This was demonstrated in this study through results showing significant improvement in students' HOTS after the implementation of AI and IoT-based methods. With technology, students can actively participate in the learning process, with more opportunities to set the pace and depth of the material they study according to their needs.

Overall, these findings strengthen the argument that AI and IoT technology in education are not only relevant but also highly necessary to prepare students to face increasingly complex global challenges (Rashid & Asghar, 2016). This research confirms the view that the integration of technology in learning, when implemented correctly, can enhance the quality of education by facilitating students to think more critically, analytically, and creatively. Therefore, the implementation of AI and IoT in the classroom can be seen as a strategic step that supports the improvement of education quality, in line with educational theories that are adaptive to technological developments.

The findings of this study have important implications for the field of education, particularly in the context of improving higher-order thinking skills (HOTS) in students. The results showing significant improvement after the implementation of AI and IoT-based learning emphasize that the integration of technology in the classroom is not just an option, but a necessity to prepare students for the challenges of the modern world. In an era where digital literacy has become an essential part of 21st-century skills, the ability to think critically, analytically, and creatively is crucial for students to become adaptive and competitive individuals.

The implementation of AI and IoT in learning opens opportunities for the development of a more interactive, dynamic, and contextual learning environment. In the context of the Merdeka Curriculum, which encourages creativity and student freedom in the learning process, the use of AI and IoT technology can be a highly effective learning tool. Students do not only learn passively but can also actively interact with learning materials through connected devices and smart technologies, enabling more meaningful learning that is relevant to real-life situations.

Another implication is that AI and IoT technology can help overcome resource limitations in some schools, especially in areas that may have limited access to conventional learning materials. With technology, students can learn with broader access to information and receive faster and more personalized feedback, both from devices and AI-based systems. This is essential in supporting diverse learning styles and allowing students to learn according to their individual needs.

However, to maximize these benefits, support in terms of infrastructure and teacher training is necessary for technology to be applied optimally. Schools and educational institutions need to ensure that technological facilities are available and that teachers are trained in using technology in teaching. With the proper implementation, AI and IoT-based learning has the potential to become a powerful tool in achieving higher educational goals, helping students not only understand subject matter but also develop critical life skills that are relevant for the future.

▪ CONCLUSION

This study successfully demonstrates that the integration of AI and IoT technology in learning can significantly enhance students' HOTS, particularly in the context of the Merdeka Curriculum. Based on the paired sample T-test results, it was found that there was a significant improvement in students' HOTS scores in the three schools that were part of the research sample, with $p < 0.001$. Additionally, the N-Gain analysis results show improvement in the "medium" category across all schools, indicating the effectiveness of this learning method in strengthening students' critical and analytical thinking skills.

These findings support the relevance of the Merdeka Curriculum in improving the quality of learning in Indonesia through a technology-based approach. AI and IoT-based learning not only have a significant positive impact on enhancing students' HOTS but also demonstrate strong potential as an adaptive and sustainable educational strategy. However, the implementation of this technology requires adequate infrastructure support and teacher training to ensure the sustainability of its positive impact.

Overall, this study contributes to the literature on technology-based education in Indonesia and suggests that broader integration of technology in schools could help accelerate the improvement of the national education quality. It is hoped that these findings can serve as a foundation for the development of curricula and education policies that are more adaptive to future challenges.

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