Evaluation of Augmented Reality in Developing Students' Higher Order Thinking Skills

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***Abstract*—This study evaluates the effect of Augmented Reality (AR) on enhancing students' Higher-Order Thinking Skills (HOTS) in education. The research aims to tackle the decline in students' HOTS using the Design-Based Research (DBR) method. The methodology involved problem identification, solution design, iterative testing, and reflection to develop and refine AR learning materials. The study involved 96 students. It demonstrated significant improvements in higher-order thinking skills, with a 56.82% enhancement in the analysis aspect and a substantial 52.77% improvement in the inference aspect. These findings emphasized AR's effectiveness in enhancing students' HOTS and offered insights for addressing this decline through AR learning materials.**

***Keywords*—Augmented Reality (AR), Higher-Order Thinking Skills (HOTS), learning**

I. Introduction

In today's era of globalization, students are required to have more advanced high-level thinking skills to face the increasing complexity of life [1–3]. However, observations of several junior high school students in the Surakarta City area, Central Java Province, Indonesia, found that students' High-Order Thinking Skills (HOTS) Were still very low, especially in the aspects of analysis and inference.

This finding is a major problem that must be addressed to find a solution. Following results of the study [4–6], the weaknesses of HOTS can be overcome with one of the options, namely providing suitable learning tools.

Previous researchers have made strides in developing learning tools to enhance students' higher-order thinking skills. Some of these tools include the Science, Technology, Engineering, Arts, Mathematics (STEAM) model approach [7], Professional Learning Community (PLC) with Project-Based Learning (PBL) [8], and Scientific Creativity and Critical Worksheets (SCCW) with Project-Based Learning (PjBL) [9]. However, despite implementing several relatively recent learning models and media, there is no conclusive evidence of their effectiveness in improving students' higher-order thinking abilities.

This has led to the importance of developing other learning devices with different media that aim to improve HOTS. One alternative is to use the Augmented Reality (AR) application. Therefore, the research problem is formulated as follows: 1) How can learning media be developed using AR? 2) How effective is AR media in developing students' HOTS?

In this study, the learning media was created as a tool in the learning process for junior high school students in the introduction to Microsoft (MS) Word material. AR is integrated with a web application as an integrated learning media. AR takes part in the section that displays the tab icon material visually in Three Dimensions (3D). In addition to learning materials, the media is also equipped with a quiz menu containing a collection of questions with the concept of developing analytical and inferential thinking. The development of analytical and inferential thinking is known to be relevant to the empowerment and improvement of HOTS [10].

II. Literature Review

The advancement of information technology has motivated instructional media designers to create more advanced and sophisticated media and learning environments [11–13]. AR is a technology that can enhance human perception and has bridged the gap between real and virtual space [14–16]. Combining digital information into real-world environments through AR is invaluable for enabling students to apply knowledge and skills [17, 18]. AR also facilitates the application of real-world scenarios through interactive activities and provides an engaging learning environment [19, 20].

In addition, AR can enhance collaborative learning experiences [21, 22] and student abilities by integrating innovative and interactive teaching methods in the presentation of 3D information [23, 24]. AR also has the potential to positively influence students' motivation and cognitive learning [25, 26] and develop their spatial and psychomotor-cognitive skills [27]. Visual, auditory, or sensory feedback is presented in AR to enhance student experience through the integration of objects in a hybrid space, allowing for smooth user movement [22, 28]. Furthermore, studies using meta-analysis methods have shown that AR has a positive impact on academic achievement [29, 30]. However, they found that the effectiveness of AR in learning is still known to have limitations, especially in the development of HOTS.

AR provides economic value by meeting the needs of high-cost learning [31, 32]. Huang *et al.* [33], Santos *et al.* [34], and Manuri and Sanna [35] demonstrates that AR applications have a significant impact on students' academic achievement by simulating the real world in three dimensions.

The implementation of AR associated with HOTS is still little done. This article examines the implementation of AR to introduce the MS Word tab icon. The learning process,

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with the material presented visually in 3D, assisted by AR, is equipped with a set of quiz questions with the concept of developing analytical and inference thinking patterns, which is investigated in improving HOTS. This study includes the steps of design analysis, validation, and media feasibility testing in small-scale tests. In addition, this study also reports the results of the effectiveness in improving the analysis and inference aspects which are part of the HOTS aspects.

III. MATERIALS AND METHODS

The research method employed in this study is Design-Based Research (DBR), which consists of four stages: problem identification and analysis, solution design, repeated cycle testing, and product design refinement, followed by reflection to establish design principles and implementation [19]. In the initial stage, problem identification and analysis, researchers must first identify and analyze the issues to be studied. This involves understanding the factors that contribute to the problem and determining potential solutions.

The second stage is solution design, where the proposed solution is developed based on the background of the identified problem to achieve the research objectives. The third stage involves repeated cycles of testing to refine the design and ultimately produce the best final version. The final stage is reflection, which leads to the formulation of design principles specific to this study. This reflection process often includes discussions with experts in fields related to the problem.

DBR is a systematic educational and instructional design process that encompasses analysis, design, evaluation, and revision activities to achieve satisfactory results. This method is particularly suitable for this study as the outcome is a learning medium. One of the advantages of DBR is its capacity to address individual issues or those affecting multiple individuals [36].

There are five key characteristics of DBR: it is interventionist, iterative, process-oriented, utility-oriented, and theory-oriented. These characteristics reinforce the use of the DBR method in this study, which involves repeated experiments utilizing Augmented Reality (AR), culminating in a summary of learning media at the study's conclusion.

The initial data collection techniques include literature reviews from various sources, such as books and journals, as well as field observations and surveys. This step aims to analyze user needs and system specifications for designing AR-based applications that enhance students' HOTS.

At the solution design stage, a standard language for visualization, design, and documentation of the system is employed. This is known as the Unified Modeling Language (UML), which includes Use Case Diagrams for creating designs of the AR-assisted learning media application. The application features two levels of access: user access and admin access. User access includes the KI-KD menu section, learning materials, AR objects, quizzes, and guides, while admin access allows for editing, deleting, updating, and evaluating content.

Core competencies (Kompetensi Inti, KI) refer to the abilities that students must possess to meet graduate competency standards at each grade level. In contrast, basic competencies (Kompetensi Dasar, KD) are the specific skills that enable students to achieve core competencies at a given educational level.

The design of the application encompasses its appearance, program architecture, materials, and style. This includes creating a flowchart to illustrate the overall system workflow, a navigation structure to explain how the application operates, and a storyboard to depict the storyline or each scene in the application through animated images. The application flow is illustrated in Fig. 1.

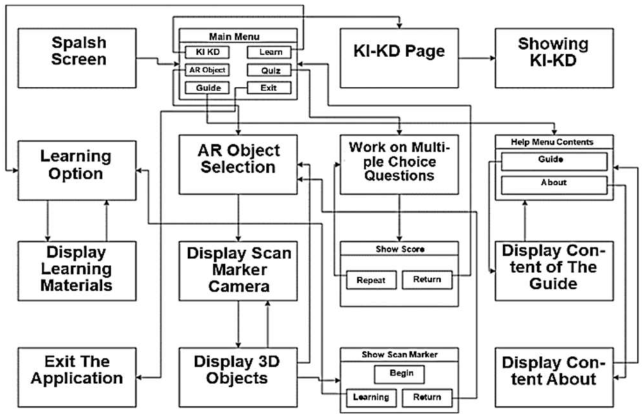


Fig. 1. The flow of learning media application using AR.

The learning media application includes several key features: the KI-KD menu, Learning menu, AR Object menu, Quiz menu, Guide menu, and Exit button. The KI-KD menu is aligned with the school curriculum. The Learning menu provides educational materials, including definitions, functions, shortcuts, and information about object locations. The AR Object menu enables users to view 3D objects through an AR camera by scanning specific markers. The Quiz menu is designed to evaluate users' understanding of the material and the objects being studied. The Guide menu contains a help section explaining the functionalities of the buttons, as well as an "About" section that provides information about the application developer and the associated organization.

Next, let's describe how AR works to add virtual objects to the real environment. The process involves the following steps: 1) The input device captures video and sends it to the processor; 2) The software in the processor processes the video and looks for a specific pattern; 3) The software calculates the position of the pattern to determine where the virtual object will be placed; 4) The software identifies and matches the pattern with the stored information; 5) Virtual objects are added based on the results of the information matching and placed at the pre-calculated position; 6) The virtual objects are displayed through the output device.

This study utilized the Marker-Based Tracking Method, which is one of the simplest AR tracking types frequently used by AR application developers. Marker-based tracking works as follows: the calibrated camera detects the marker and then calculates whether the marker matches one stored in its database. If the marker pattern matches, the system will render and display the corresponding object. Conversely, if the marker does not match, the system will not take any action.

AR employs uniquely patterned two-dimensional object markers, which can be detected using a webcam or computer camera. The application identifies the position and orientation of the marker and generates a virtual 3D point along the X, Y, and Z axes. This method relies on the Art Toolkit to implement marker-based tracking. The learning media application operates by using video tracking to determine the actual orientation of the pattern on the screen in real-time, along with the position of the camera. Once the initial camera position is established, a virtual camera can be placed at the same point, allowing the 3D object to be superimposed on the marker.

After the design is complete, the next step is to validate it with experts. Media experts are tasked with testing the level of media feasibility and providing suggestions to improve the specifications of the product being made. Suggestions from media experts will be used as reference material to improve this learning media companion application so that it can achieve the expected goals. Material experts, in this case, teachers, review the level of feasibility of the material contained in the application. User feasibility testing was carried out using the System Usability Scale (SUS) questionnaire [36] which was filled out by 16 prospective student users.

During the effectiveness testing stage, students were divided into experimental and control groups. 48 students from the control group carried out learning according to normal habits, while 48 students from the experimental group carried out the AR application. The paired sample test technique was used in the test. Non-parametric analysis was carried out to overcome data abnormalities. The total research sample consisted of 96 junior high school students from the city of Surakarta, Central Java, Indonesia.

In the scenario, in the initial stage before learning, students from both groups were given the same pre-test questions. After both groups carried out the learning process with different media, then both groups were given the same post-test questions. The improvement in test results is measured using Eq. (1).

$$Gain\ score = \frac{Post\text{−}test\ score}{Ideal\ score - Pre\text{−}test\ score} \times 100\% \qquad (1)$$

where the post-test score is the score obtained after the test, the pre-test score is the score obtained before the test, and the ideal score is the maximum achievable score. Furthermore, interpreting the effectiveness of the Gain Score (GS) is GS<40 for ineffective, $40 \leq GS \leq 55$ for less effective, $56 \leq GS \leq 75$ for quite effective, and CS>75 for effective.

This study focuses on AR-assisted MS Word Tab Icon exploration. MS Word is a commonly used word-processing application for creating, editing, and formatting textual documents. This application offers a variety of features, allowing users to create memos, letters, and complex documents with images, clip art, colors, and borders. The main advantage of using MS Word is its efficiency in document processing, which saves time and effort. This study resulted in the development of product specifications for companion media that aim to introduce MS Word tab icons using AR tools to improve students' higher-order thinking skills. An example of this MS Word tab icon is shown in Fig. 2.

The next stage, namely the assembly stage, is the assembly stage of all objects that will be used in the application. At this stage, objects are made into 3D using Blender software version 2.83.20, Unity, and Vuforia. Blender software is used to create 3D objects and animations, while Vuforia is used to develop the marker database.

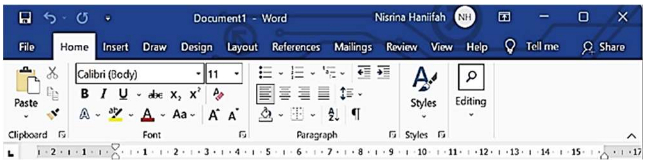


Fig. 2. Example of MS Word tab icon.

Furthermore, the learning media design results can be illustrated in Fig. 3. In the AR application, Fig. 3(a) displays the main menu options, including KI-KD, Learning, AR Objects, Quizzes, Guides, and Exit the application. Fig. 3(b) displays the KI-KD display.

(a) (b)
Fig. 3. Display of learning media application results. (a) AR main menu; (b) Result of selecting the "KI-KD" menu.

The instruments used to measure HOTS are shown in Table 1.

Table 1. HOTS indicators according to Bloom

Aspect of HOTS	Indicator	Description
Analysis-Inference	Differentiating	Sorting out the important parts of the problem. Sorting out the relevant parts of the problem.
	Organizing	Identifying the important and relevant parts of the problem so that complete information is obtained to solve the problem. Developing a way or strategy to solve a problem.
	Attributing	Determining the objectives or conclusions from the results of problem solving.

IV. Result and Discussion

A. Results

This study aims to create learning media to improve students' HOTS. The application developed is a learning media assisted by AR technology and can be accessed via Android smartphones. This MS Word Tab Icon Learning Companion Media is designed for 7th-grade students as part of the Information and Communication Technology Development curriculum with the subject matter of introducing MS Word tab icons. This learning media can be used as a flexible learning companion resource and can be accessed anytime and anywhere, not limited to face-to-face class hours. The development of this learning media involves the use of Unity software and the C# programming language. In addition, other software is also used such as Blender to create 3D objects, Canva for card marker displays, and Vuforia to upload card markers.

The feasibility test and media validation can be obtained by scoring through the results of a questionnaire filled by two media experts, namely Informatics Engineering Education Lecturers. The assessment scores obtained can be seen in Table 2.

Table 2. Media expert assessment results

No.	Indicator	Experts		S1	S2	Average S	m(c–1)	V
		1	2					
1	Attractive menu presentation	3	3	2	2	4	6	0.67
2	Matching letter presentation	3	4	2	3	5	6	0.83
3	Appropriate background presentation	2	4	1	3	4	6	0.67
4	Ease of using media	3	4	2	3	5	6	0.83
5	Ease of selecting menus on media	3	4	2	3	5	6	0.83
6	Using communicative language	4	3	3	2	5	6	0.83
7	Using standard sentences	4	4	3	3	6	6	1.00
8	Media content following KI-KD	2	4	1	3	4	6	0.67
9	Quiz according to the material	3	3	2	2	4	6	0.67
10	The attractiveness of the design display	3	3	2	2	4	6	0.67
11	Accuracy of object and text layout	3	4	2	3	5	6	0.83
12	Conformity of the presented 3D objects	3	4	2	3	5	6	0.83
13	Suitability of font size and type selection	3	4	2	3	5	6	0.83
14	Kemenarikan tampilan tombol(button) yang digunakan	3	4	2	3	5	6	0.83
15	The attractiveness of the 3D object shape used	3	3	2	2	4	6	0.67
16	Camera response in displaying objects when scanning markers	4	4	3	3	6	6	1.00
17	Media can be used smoothly without lag, crashes or hangs	3	4	2	3	5	6	0.83
18	Scan marker can be operated properly	3	4	2	3	5	6	0.83
Total		55	67					14.33

Based on Table 1, it can be analyzed as follows. The Eq. (2) for the feasibility test:

$$Feasibility\ (\%) = \frac{Score\ obtained}{Max\ Score} \times 100\% \quad (2)$$

The results of the feasibility test, obtained from the calculation with the formula above are 76.4% for media expert-I and 93.1% for media expert-II. Meanwhile, for the validity test, Eq. (3) is used.

$$Average = \frac{Sum\ of\ V}{Number\ of\ items} \quad (3)$$

The result obtained from Eq. (3) is 0.80. Based on Aiken's 18-table limit, the items are determined by the lower limit of 0.74 to the upper limit of 0.98. So, the results of the validity test in Table 1 show that 18 items have a V value of 0.80, so the validity is declared valid.

Furthermore, the assessment of the material expert with the subject teacher validator is presented in Table 3.

Table 3. Results of the material expert assessment

No.	Indicator	Experts	S Max	S1	m(c–1)	V
1	Completeness of materials	3	4	2	3	0.67
2	Depth of material	3	4	2	3	0.67
3	The truth of the material	4	4	3	3	1.00
4	Accuracy of facts and concepts in the material	4	4	3	3	1.00
5	The material presented is adapted to the facts that students have learned	4	4	3	3	1.00
6	Suitability of quiz questions	4	4	3	3	1.00
7	Correct use of spelling	4	4	3	3	1.00
8	Correct use of terms	4	4	3	3	1.00
9	The effectiveness of the sentences used	4	4	3	3	1.00
10	The language used is easy for students to understand	4	4	3	3	1.00
11	Attractive image presentation	4	4	3	3	1.00
12	Sequence of concept presentation	4	4	3	3	1.00
13	Clear 3D objects	4	4	3	3	1.00
14	Easy-to-understand image presentation	4	4	3	3	1.00
15	Scan Marker Card is easy and convenient	4	4	3	3	1.00
Total		58	60			14.33

Based on Table 2, by using Eqs. (2) and (3), the results of the feasibility test and validation test from material expert can be determined as 96.7% and 0.95 respectively. The results of the expert material feasibility test on AR learning media have a very feasible value. Based on Aiken's 15-table limit, the items are determined with a lower limit of 0.74 to an upper limit of 0.98. So, the results of the validity test show that fifteen items have a V value of 0.95, so they are declared valid.

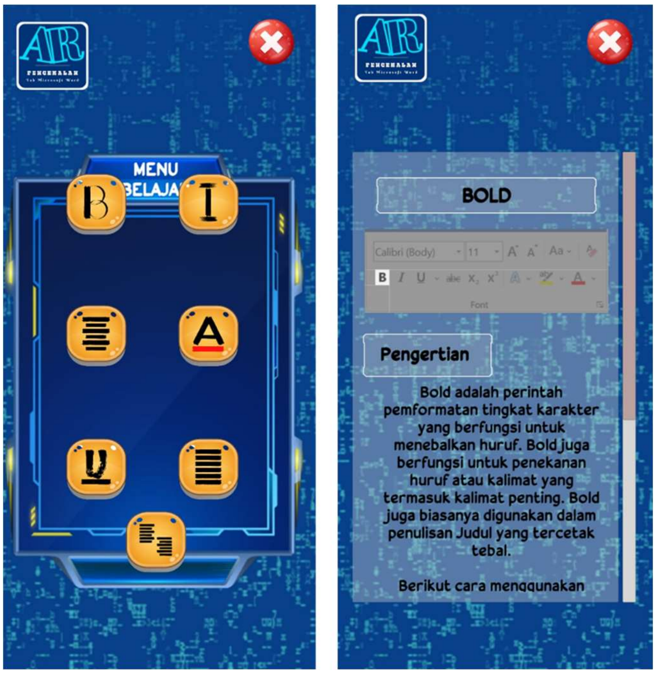
User assessment was conducted by sixteen students. User assessment was used to test the feasibility of the developed media. Users conducted the assessment by filling out at questionnaire from the SUS questionnaire. The scores generated from filling out the questionnaire are shown in Table 4.

Based on the SUS instrument input from the user, the average score can be calculated with a result of 87. Related to the results of the average score calculation generated from user assessment using SUS, the result of 87 according to the SUS score grade shows an excellent rating.

Table 4. SUS result scores

No.	Score Result Count (SUS)										Sum	Value
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10		(Sum × 2.5)
1	3	2	3	2	4	2	4	2	4	2	28	70
2	3	3	4	2	4	3	3	3	3	3	31	78
3	3	3	3	3	4	4	3	4	3	2	32	80
4	4	4	4	4	4	2	3	4	2	2	33	83
5	3	3	4	2	4	4	4	4	4	4	36	90
6	3	3	4	2	4	2	4	4	3	2	31	78
7	4	4	4	4	4	4	4	4	4	4	40	100
8	3	4	3	4	3	4	4	4	4	4	37	93
9	4	4	4	4	4	4	4	4	4	4	40	100
10	3	4	3	2	4	3	4	3	3	2	31	78
11	4	4	4	4	4	4	4	4	4	4	40	100
12	4	4	4	4	4	4	3	4	4	2	37	93
13	4	4	4	2	4	4	3	2	3	2	32	80
14	4	4	4	4	4	4	4	4	4	4	40	100
15	4	4	3	3	4	4	2	1	4	4	33	83
16	4	4	4	3	4	4	3	4	4	2	36	90
Total												1389

In addition, the results of the learning media design can be illustrated in Fig. 4. In the AR application, Fig. 4(a) displays the Learning menu, while Fig. 4(b) displays the results of the Learning menu of Bold options.



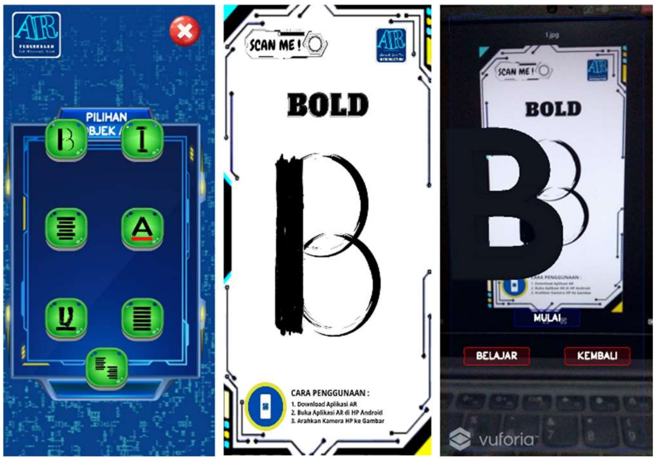
(a) (b)

Fig. 4. Display of learning media application results. (a) Result of selecting the "Belajar" menu; (b) Result of selecting the "B" menu.

This learning media has the following options: 1) KI-KD: presents the curriculum implemented by the school; 2) Learning: p6resents material about the object to be studied, including its meaning, function, shortcuts, and location; 3) AR Objects: displays an AR camera to scan markers to reveal 3D objects; 4) Quizzes: presents evaluations to measure the level of understanding of the material and objects studied; 5) Guides: contains help and about menu options. The help menu explains the use of buttons on the learning media, while the About menu provides information about the application maker and agency.

Then the results of the AR menu options are shown in Fig. 5.

Moreover, Fig. 6(a) shows the Quiz menu display. The quiz contains questions related to the material on the MS Word tab icons that have been studied. Switching to Fig. 6(b) shows the results displayed when the quiz question is answered correctly, while Fig. 6(c) shows the results when a quiz question is answered incorrectly.



(a) (b) (c)

Fig. 5. Results of selecting the "OBJEK AR" menu. (a) AR Object menu options display; (b) AR marker of "BOLD"; (c) Screenshot of the AR camera directed at the card maker "BOLD".

(a) (b) (c)

Fig. 6. Quiz menu display. (a) Result of selecting the "KUIS" menu; (b) Display for correct quiz answers; (c) Display for wrong quiz answers.

AR-based learning media has been validated and evaluated as a media that is suitable for use. The next step is to test the effectiveness of the media product on students. Students will be divided into experimental and control groups. Testing will begin with a pre-test to assess students' initial abilities. At the end of the learning phase, both groups will be given a post-test. Both groups of students are given the same type of questions. The effectiveness testing technique uses the technique presented in Table 5.

Table 5. Effectiveness testing technique

Groups	Pres-Test	Treatment	Post-Test
Control	Yes	No	Yes
Experiment	Yes	Yes	Yes

The results of the Kolmogorov-Smirnov analysis showed that the significance value for each group in the pre-test and post-test was less than 0.05, indicating that the data distribution was not normal. In addition, the significance value for the pre-test results between the experimental and control groups was 0.833, which was greater than 0.05. This indicated that the pre-test scores for both groups were evenly distributed and had the same variance. This indicated that the two groups did not differ significantly in terms of diversity.

However, the homogeneity analysis of the post-test results between the experimental and control groups showed a significance value of 0.033, which was less than 0.05, indicating that the two groups had different variances, indicating an imbalance in diversity. After assessing both classes, the balance of abilities was evaluated. For this purpose, a non-parametric test was used because the data did not follow a normal distribution. The results of the analysis are presented in Table 6.

Table 6. Comparison of balance test results between two groups

Test Statistics	Pretest
Mann-Whitney U	1116.300
Wilcoxon W	2484.300
Z	−0.910
Asymp. Sig. (2-tailed)	0.361

The analysis in Table 5 shows that the significance value is 0.361, which is greater than 0.05. This indicates that there is no significant difference between the pre-test scores in the two groups. In conclusion, the experimental and control groups are balanced before any treatment is applied. The test results are presented in Table 7.

Table 7. Results of the non-parametric Wilcoxon Signed Rank Test in the experimental and control groups

Test Statistics	Pre-test exp-Post-test exp	Pre-test control-Post-test control
Z	-5.176^b	-5.177^b
Asymp. Sig. (2-tailed)	0.000	0.000

Note: b. Based on negative ranks.

The analysis presented in Table 6 shows a significance value of 0.00, which is lower than the significance level of 0.05 when comparing the pre-test and post-test scores of the two groups. This result shows a significant difference between the pre-test and post-test scores of the experimental and control groups. Therefore, it can be concluded that both groups have shown changes and differences in their abilities.

In Table 8, the comparison of post-test scores between the experimental and control groups shows a significant difference ($p < 0.05$), indicating that the treatment in the experimental group has a positive impact on the post-test results. After that, the effectiveness of AR can be analyzed by comparing the increase in scores from the pre-test results with the post-test. The results of the analysis of the increase in scores related to the analysis aspect and the inference aspect in HOTS can be seen in Table 9.

In the control class, the range of Gain Scores in HOTS was shown, with percentages ranging from 30.95% to 37.10% and an average of 34.02%, which placed it in the poor category. In contrast, the experimental class showed scores ranging from 87.77% to 89.87%, with an average of 88.82%, which was included in the effective category. Thus, it can be concluded that the experimental class showed a difference of 56.82% in the analysis aspect and 52.77% in the HOTS inference aspect when compared to the control class.

Table 8. The post-test score analysis results comparing the experimental and control groups

Test Statistics	Post-test
Mann-Whitney U	31.100
Wilcoxon W	1406.100
Z	−7.447
Asymp. Sig. (2-tailed)	0.000

Table 9. Description of the gain score for HOTS

Groups	Aspect of HOTS	
	Analysis	Inference
Experiment	87.77	89.87
Control	30.95	37.19

B. Discussion

In the study conducted by Sulistyanto *et al.* [19], AR media products were evaluated to determine their effectiveness. The results of this effectiveness test will recommend valuable insights for teachers regarding the importance of using learning media to improve students' HOTS.

Various findings of current research and studies show the significant effectiveness of using AR media compared to traditional models for the learning process. The effectiveness of AR-assisted media has been tested with various test variables, as shown by Mufit and Dhanil [20], Yoo [28], and Han *et al.* [37].

There are many reasons why the use of AR media can have a positive impact on students' cognitive abilities. For instance, Manuri and Sanna [35] observed that AR-supported learning media can foster a fun learning environment. In addition, Yoo [28] showed that AR can improve comprehension, memory retention, concentration, and interaction, and offer a more engaging learning environment compared to traditional methods.

Ay *et al.* [26] emphasized that AR can improve concentration and help students understand the subject through visualization using a card marker camera. Another study by Chang *et al.* [38] showed that teachers can effectively convey concepts to students by integrating AR-supported learning materials before their lessons.

However, this study has attempted to empower AR in improving HOTS. This study has shown that the use of AR-assisted media has a positive impact on improving students' HOTS through various test analyses. The test results show that AR-based learning media is very effective in improving HOTS according to Anwar *et al.* [18]. Post-test analysis has revealed a significant difference in scores between the experimental group and the control group, where the experimental group showed a higher percentage increase in all aspects of high-level thinking skills. The results of the analysis show a comparison of the increase between the two classes which reveals that the inference aspect increased by 89.87% in the experimental class, compared to 37.19% in the control class. Meanwhile, the analysis aspect showed an increase of 87.77%, compared to 30.95%. Based on the comparison of the percentage increase in the analysis and inference aspects, it can be concluded that AR-assisted learning media has been proven to improve students' high-level thinking skills. These results are in line with the findings in Islami and Ansyah [14], Alamsyaha *et al*. [31], and Kurniawan *et al*. [39], which shows that implementing learning devices that are in line with the natural learning process and student needs can improve students' HOTS.

AR-assisted learning media has several limitations in terms of its use which are influenced by several factors, namely: 1) Occlusion Virtual objects will only appear when the marker is captured by the camera. This limits the size or movement of the virtual object. This also means that if the user covers the pattern on the marker with their hand or another object, the virtual object will disappear. 2) Distance is also a problem in optical tracking, as markers move away from the camera, they occupy fewer pixels on the camera screen, and may not be detailed enough to correctly identify the pattern on the marker. This result is obtained by moving the marker away from the camera until at a certain distance the 3D virtual object above the marker disappears. 3) Light: The light factor that can be captured by the camera lens also plays an important role because if the marker is displayed to the camera when the light conditions are dark/low light, or the light conditions are very bright/glare, the camera will have difficulty recognizing the marker and the virtual object cannot appear.

The positive results of the AR application used to assist learning have indicated that the use of suitable media in the learning process will have a very big impact on achieving the targeted learning objectives.

V. Conclusion

This research has produced significant results regarding the development of AR-assisted learning media. The findings can be summarized as follows: 1) The use of the Design Based Research method has successfully produced AR-assisted learning media designed to empower higher-order thinking skills among junior high school students. This learning media can also be adapted for use at various school levels; 2) AR media is effective in improving analysis and inference skills with the percentage increasing to 87.77% and 89.87% from the original 30.95% and 37.19%. This highlights the recommendation for teachers to include AR-based learning media in their teaching, as this media attracts students' interest and creates a conducive learning environment that motivates students to improve their higher-order thinking skills; 3) The adaptability of AR learning media makes it suitable for various learning contexts, with the potential to stimulate further research in the field; and 4) AR-assisted media is especially useful for subjects involving abstract and complex concepts.

The limitation of the results of this study is that the learning material used as content is still very simple so this opens up opportunities for further research both on the breadth of the material and the diversification of diverse materials. Another limitation is that the tracking technique still uses markers so that in the future the performance of AR using the markerless tracking technique can be studied.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Fieldwork, conducting literature reviews, and drafting the entire article were carried out by the first author. Meanwhile, application testing, analysis of findings, review of research methodology, data entry, statistical analysis, and interpretation of the results were carried out by the other authors. All authors had approved the final version.

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