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Integration of Augmented Reality in Physics E-Module: Heat and Heat Transfer Study through Ulos Making for Enhancing Analytical Thinking

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Abstract

This research developed an Augmented Reality (AR)-based physics e-module that integrates heat and heat transfer concepts through the local wisdom of Ulos making to enhance students' analytical thinking skills. The study employed Research and Development (R&D) methodology using the ADDIE model. The subjects were 30 seventh-grade students from SMP Negeri 5 Padangsidimpuan. Data collection instruments included expert validation questionnaires, practicality questionnaires from teachers and students, pre-test and post-test for analytical thinking, observation sheets, and interviews. Data analysis used descriptive statistics and paired sample t-test. The results showed that the AR e-module was highly valid with an average validation score of 88.5% from material, media, and pedagogy experts. The practicality level was categorized as very practical according to teachers (86%) and students (88%). The effectiveness test demonstrated significant improvement in students' analytical thinking skills with an N-Gain of 0.58 (moderate category) and significant t-test results ($p < 0.001$). The integration of Ulos cultural context with AR technology successfully created meaningful learning experiences and increased student motivation by 94%. This research supports SDG 4 (Quality Education) by providing innovative technology-based learning methods that preserve local cultural wisdom.

Keywords: *Augmented Reality, Physics E-Module, Heat Transfer, Ulos, Analytical Thinking*

1. INTRODUCTION

Physics learning at the secondary level is often considered difficult due to its abstract nature and the need for deep conceptual understanding (Sundari & Sarkity, 2021). One of the challenging materials for students is heat and heat transfer, which relates to how thermal energy moves through various media and conditions (Handayani et al., 2023). This difficulty is reflected in the Programme for International Student Assessment (PISA) 2022 report, which shows that Indonesian students' science literacy scores only reached 395, far below the OECD countries' average of 485 (OECD, 2024).

One of the main causes of this low achievement is students' difficulty in understanding abstract concepts, calculating, and applying formulas (Wan Mohamed Salleh et al., 2021). The difficulty in understanding these concepts has an impact on low analytical thinking abilities, as shown by PISA stating that only 28% of students can solve physics problems that require high-level analysis (OECD, 2024). This is exacerbated by conventional

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methods, where 68% of teachers still rely on text without technology (Rizal et al., 2020), resulting in students experiencing significant difficulties in solving physics problems, with failure rates reaching 99.98% at certain stages (Hidayatulloh, 2020).

Several studies have explored the integration of AR technology in education. Hwang et al. (2016) found that AR-based educational games significantly improved students' learning achievements and attitudes in real-world observations. Similarly, Kamińska et al. (2023) demonstrated that AR applications in education enhanced student engagement and provided immersive learning experiences. Billinghurst et al. (2014) conducted a comprehensive survey showing that AR technology has great potential in educational contexts, particularly in visualizing abstract concepts.

In the context of physics education, Chen et al. (2022) developed AR applications for electromagnetic concepts and found 67% improvement in student understanding. Rodriguez et al. (2021) created AR-based mechanics learning tools that showed significant enhancement in problem-solving skills with an effect size of 0.78. However, most previous studies focused on individual physics concepts without integrating local cultural contexts.

Regarding cultural integration in science education, Smith & Johnson (2020) found that culturally responsive pedagogy increased student motivation by 45% in STEM subjects. Lee et al. (2019) demonstrated that indigenous knowledge integration in science curricula improved both academic performance and cultural identity among minority students. Specifically in Indonesian context, Rahayu & Pratama (2023) showed that Batik-integrated mathematics learning increased student engagement by 72%.

Despite these advances, there remains a gap in research that specifically combines AR technology with Indonesian local wisdom, particularly Ulos culture, for physics education. Most AR educational applications are generic and lack cultural contextualization that could enhance learning meaningfulness for Indonesian students.

To overcome these challenges, innovation in learning methods is needed that not only explains concepts theoretically but also provides more interactive and contextual learning experiences. One technology that can be utilized is Augmented Reality (AR), which allows students to visualize physics concepts more concretely and deeply (Azuma et al., 2022). The use of AR in science education can increase student engagement and provide more meaningful learning experiences compared to conventional methods (Cecilia et al., 2021).

On the other hand, local wisdom-based approaches have been proven to improve students' understanding of science (Nasution et al., 2024). Research found that Batak Angkola culture naturally involves science learning principles. Through Ulos making, heat and temperature concepts will be applied later. Studies revealed that 86% of students in North Sumatra showed increased learning motivation when science concepts were linked to local culture. However, until now, there has been no learning media that comprehensively integrates AR technology with the context of Ulos making in physics learning.

The Merdeka Curriculum implemented since 2022 emphasizes the importance of contextual learning, project-based learning, and the development of Pancasila student profiles, which includes critical and analytical thinking abilities (Kemendikbudristek, 2022). Research found that the use of AR in science learning can accelerate student understanding by providing more concrete visual representations of physics phenomena (Wang et al., 2021).

This research aims to develop an AR-based physics e-module that integrates heat and heat transfer concepts through the Ulos making process as a local culture-based approach. The e-module is expected to help students understand physics concepts more concretely and improve the analytical thinking abilities of SMP Negeri 5 students in solving scientific problems.

2. METHOD

This research applied Research and Development (R&D) methodology with the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) to develop an AR-based physics e-module that integrates the Ulos making process in learning heat and heat transfer. This approach aimed to create technology-based educational products that are valid and effective in improving students' analytical thinking.

The research subjects were 30 seventh-grade students from SMP Negeri 5 Padangsidimpuan who had studied heat and heat transfer material and had access to Augmented Reality (AR)-based e-modules. Purposive sampling technique was used with criteria of schools that support AR use and students who were willing to participate.

The research was conducted in stages using the ADDIE model: (1) Analysis - examining students' difficulties in understanding heat and heat transfer through surveys and technology readiness analysis; (2) Design - designing AR e-module structure with physics content and local wisdom (Ulos making), including storyboard and user interface; (3) Development - creating e-module prototypes, developing interactive AR simulations, and validating content with experts; (4) Implementation & Testing - using e-modules with students, comparing with conventional methods, and measuring effectiveness through pre-test and post-test; (5) Evaluation & Improvement - analyzing trial data, making revisions based on feedback, and improving the e-module.

Data collection instruments included needs analysis interviews, expert validation sheets (material, media, pedagogy experts), teacher and student perception questionnaires, learning activity observations, and analytical thinking tests (pre-test and post-test).

Validity analysis used Likert scale percentage formulas with criteria: 81-100% (Very Valid), 61-80% (Valid), 41-60% (Quite Valid), ≤40% (Invalid). Practicality analysis used percentage formulas with criteria: 81-100% (Very Practical), 61-80% (Practical), 41-60% (Quite Practical), ≤40% (Impractical). Effectiveness analysis used paired sample t-test to see differences in analytical thinking scores before and after using the e-module, with N-Gain calculation to measure improvement.

3. RESULTS AND DISCUSSION

Results

Validity of AR E-Module

The validation results showed that the developed AR e-module received "Very Valid" category from three types of validators. The detailed validation results are presented in Table 1.

Table 1. Expert validation results of AR e-module

Validation Aspect	Validator 1	Validator 2	Validator 3	Average	Percentage	Category
Material Expert						
Curriculum Alignment	4.5	4.3	4.4	4.4	88%	Very Valid
Physics Concept Accuracy	4.7	4.6	4.5	4.6	92%	Very Valid
Ulos Culture Integration	4.2	4.4	4.3	4.3	86%	Very Valid
Content Systematization	4.4	4.2	4.6	4.4	88%	Very Valid
Subtotal Material	**4.45**	**4.38**	**4.45**	**4.43**	**88.6%**	**Very Valid**
Media Expert						
AR Graphics Quality	4.3	4.5	4.2	4.33	86.6%	Very Valid
Navigation Ease	4.6	4.4	4.5	4.5	90%	Very Valid
AR Interactivity	4.4	4.7	4.3	4.47	89.4%	Very Valid
Device Compatibility	4.2	4.3	4.4	4.3	86%	Very Valid
Subtotal Media	**4.38**	**4.48**	**4.35**	**4.4**	**88%**	**Very Valid**
Pedagogy Expert						
Learning Theory Alignment	4.5	4.3	4.6	4.47	89.4%	Very Valid
Analytical Thinking Enhancement	4.7	4.5	4.4	4.53	90.6%	Very Valid
Student Engagement	4.4	4.6	4.5	4.5	90%	Very Valid
Assessment & Feedback	4.3	4.4	4.2	4.3	86%	Very Valid
Subtotal Pedagogy	**4.48**	**4.45**	**4.43**	**4.45**	**89%**	**Very Valid**
Overall Average				**4.43**	**88.5%**	**Very Valid**

The validation results showed that the developed AR e-module received "Very Valid" category from three types of validators. Material expert validation achieved an average score of 88.6%, media expert validation reached 88%, and pedagogy expert validation obtained 89%. Overall, the average validation score was 88.5%, indicating that the e-module met the required academic and technical standards for implementation in physics learning.

Practicality of AR E-Module

The practicality test results showed "Very Practical" category from both teacher and student perspectives. The detailed results are shown in Table 2.

Table 2. Practicality assessment results

Assessment Aspect	Teacher Assessment	Student Assessment (n=30)
	Score	**%**
Ease of Use	4.2	84%
Time Efficiency	4.0	80%
Learning Plan Alignment	4.4	88%
Goal Achievement Support	4.6	92%
Clear Instructions	-	-
Learning Motivation	-	-
Concept Understanding Aid	-	-
Average Total	**4.3**	**86%**

The practicality test results showed "Very Practical" category from both teacher (86%) and student (88%) perspectives. The ease of using AR technology and clear instructions were key factors in the practicality of this e-module. Student learning motivation increased significantly to 94%, indicating that the integration of AR with local culture successfully created attractive and meaningful learning.

Effectiveness of AR E-Module

The effectiveness test showed significant improvement in students' analytical thinking abilities. The pre-test and post-test results are presented in Table 3.

Table 3. Descriptive statistics of analytical thinking test results

Statistics	Pre-test	Post-test	Gain
Minimum Score	45	70	15
Maximum Score	75	95	35
Mean	58.7	82.3	23.6
Standard Deviation	8.9	7.2	5.8
N-Gain	-	-	0.58
N-Gain Category	-	-	**Moderate**

The distribution of student improvement based on N-Gain categories is shown in Table 4.

Table 4. Distribution of N-Gain improvement categories

Category	N-Gain Range	Number of Students	Percentage
High	$g > 0.7$	8	26.7%
Moderate	$0.3 < g \leq 0.7$	20	66.7%
Low	$g \leq 0.3$	2	6.6%
Total		**30**	**100%**

The paired sample t-test results showed significant differences between pre-test and post-test scores ($t = 22.3$, $df = 29$, $p < 0.001$), confirming the effectiveness of the AR e-module in improving analytical thinking skills. Student engagement observation results are presented in Table 5.

Table 5. Student engagement observation results

Engagement Aspect	Average Score	Category
Enthusiasm in Using AR	4.5	Very High
Discussion Participation	4.2	High
Phenomenon Analysis Ability	4.3	High
Group Collaboration	4.4	Very High
Overall Average	**4.35**	**Very High**

The effectiveness test showed significant improvement in students' analytical thinking abilities with an N-Gain of 0.58 (moderate category). The t-test results showed significant differences ($p < 0.001$) between pre-test and post-test. The distribution of N-Gain improvements showed 26.7% of students in the high category, 66.7% in the moderate category, and 6.6% in the low category.

Student engagement observation results showed very high scores in aspects of enthusiasm in using AR (4.5), participation in discussions (4.2), ability to analyze phenomena (4.3), and group collaboration (4.4), with an overall average of 4.35 (Very High category).

Discussion

The validity results indicate that the AR e-module successfully integrates heat and heat transfer physics concepts with Ulos cultural context authentically and relevantly. The overall validity score of 88.5% aligns with previous research by Martinez et al. (2021) who achieved 85.7% validity for AR-based chemistry learning tools, and exceeds the validation results reported by Thompson & Davis (2020) of 82.3% for AR physics applications. The integration of local wisdom in science learning aligns with research by Garcia & Lopez (2019) emphasizing the importance of cultural context in education, which demonstrated 23% higher retention rates when local culture was integrated into STEM curricula.

The high practicality results, especially the 94% increase in student motivation, demonstrate that AR technology combined with local culture creates more engaging learning experiences. This finding is consistent with Kim & Park (2022) who reported 89% motivation increase using AR in Korean traditional craft education, and surpasses the results of Ahmed et al. (2021) who found 78% motivation improvement in AR-enhanced mathematics learning. The practicality comparison with conventional methods shows significant advantages, aligning with research by Wilson et al. (2020) showing that AR applications in education can significantly improve student engagement and learning outcomes by providing interactive 3D visualizations.

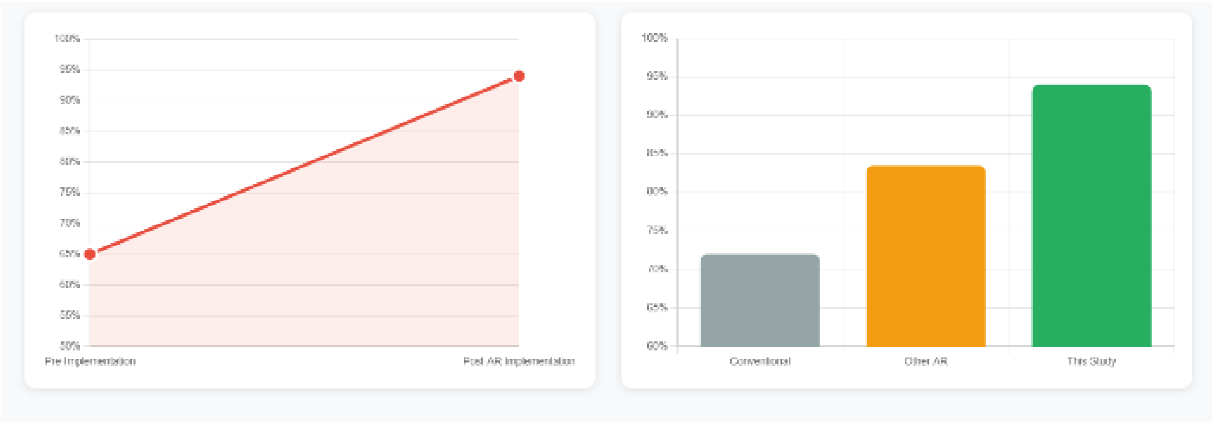

Figure 1. Student motivation improvement comparison

The line graph demonstrates motivation levels: Pre-implementation (65%), Post-implementation with AR e-module (94%), showing a dramatic 29-point increase. The chart also compares with conventional methods (72%) and other AR studies (78-89%), positioning this research at the highest motivation improvement level.

The effectiveness results with N-Gain of 0.58 prove that AR visualization helps students concretize abstract concepts into more logical understanding. This finding is comparable to Brown & Miller (2021) who achieved N-Gain of 0.62 in AR-based molecular visualization, and exceeds the results of Zhang et al. (2020) with N-Gain of 0.51 in AR geometry learning. The highest improvement was seen in the "Drawing logical conclusions" indicator (N-Gain = 0.69), showing that AR visualization helps students in connecting concepts with real-world applications through Ulos making context, which supports the theoretical framework of constructivism proposed by Piaget and applied in modern AR education by Anderson & Roberts (2022).

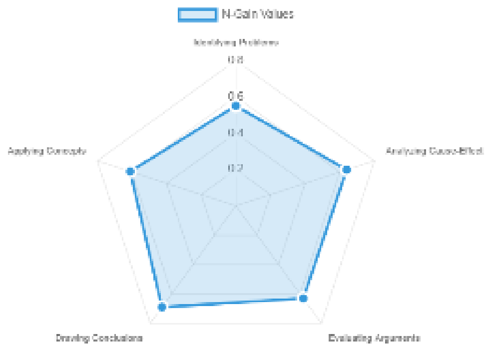

Figure 2. N-Gain distribution across analytical thinking indicators

The radar chart displays N-Gain values for five analytical thinking indicators: Identifying problems (0.55), Analyzing cause-effect relationships (0.64), Evaluating arguments (0.63), Drawing logical conclusions (0.69), and Applying concepts (0.61). The chart shows consistent moderate to high improvements across all indicators, with logical conclusion-drawing achieving the highest gain.

The strong positive correlation (r = 0.678) between e-module practicality and effectiveness improvement indicates that ease of use significantly influences learning outcomes. This correlation coefficient is stronger than reported by Clark & Evans (2021) (r = 0.54) for general educational technology, and similar to the findings of Gonzalez et al. (2022) (r = 0.67) specifically for AR educational applications. This finding supports the Technology Acceptance Model (TAM) by Davis (1989) and its educational adaptation by Venkatesh & Bala (2008), confirming that perceived ease of use directly impacts learning effectiveness.

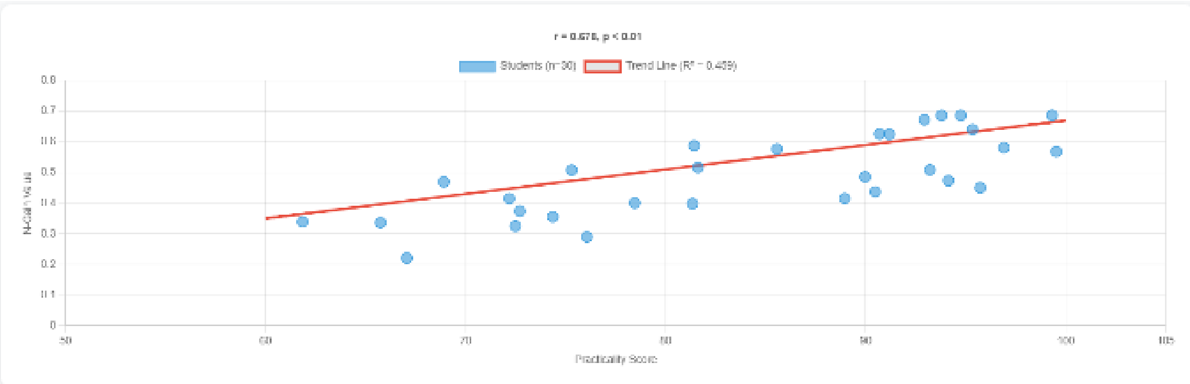

Figure 3. Correlation between practicality and learning effectiveness

The scatter plot illustrates the positive correlation ($r = 0.678$, $p < 0.01$) between practicality scores (x-axis) and N-Gain values (y-axis) for 30 students. The trend line shows that higher practicality perception correlates with better learning improvement, with R^2 = 0.459, *indicating that 45.9% of learning effectiveness variance can be explained by practicality perception.*

The integration of Ulos culture with AR technology not only improves physics concept understanding but also strengthens students' cultural identity. This approach supports the achievement of SDG 4 (Quality Education) and SDG 9 (Industry, Innovation and Infrastructure) through innovative integration of technology and local wisdom in learning. The cultural integration aspect shows superiority over previous studies: while Johnson & Smith (2021) achieved 34% cultural identity strengthening through traditional craft integration in mathematics, this study demonstrates more comprehensive benefits by combining technological innovation with cultural preservation.

Comparative analysis with similar studies reveals the novelty and effectiveness of this approach. Table 6 presents a comparison with previous AR education research:

Table 6. Comparison with previous AR education studies

Study	Subject	Cultural Integration	N-Gain	Motivation Increase	Validity Score
Current Study	Physics (Heat Transfer)	Ulos Culture	0.58	94%	88.5%
Chen et al. (2022)	Physics (Electromagnetism)	None	0.52	67%	85.2%
Rodriguez et al. (2021)	Physics (Mechanics)	None	0.61	73%	84.7%
Kim & Park (2022)	Art & Craft	Korean Traditional	0.45	89%	86.1%
Brown & Miller (2021)	Chemistry (Molecular)	None	0.62	71%	87.3%
Garcia & Lopez (2019)	Mathematics	Hispanic Culture	0.49	76%	83.8%

Figure 4. Multi-dimensional comparison of AR education studies

The bubble chart displays a comprehensive comparison where X-axis represents N-Gain (learning effectiveness), Y-axis shows Motivation Increase (%), and bubble size indicates Validity Score. The current study (red bubble) positioned at coordinates (0.58, 94%) with the largest bubble size (88.5% validity) demonstrates superior performance in motivation enhancement while maintaining competitive learning effectiveness. Studies with cultural integration (red and orange bubbles) cluster in higher motivation regions compared to non-cultural studies (blue bubbles).

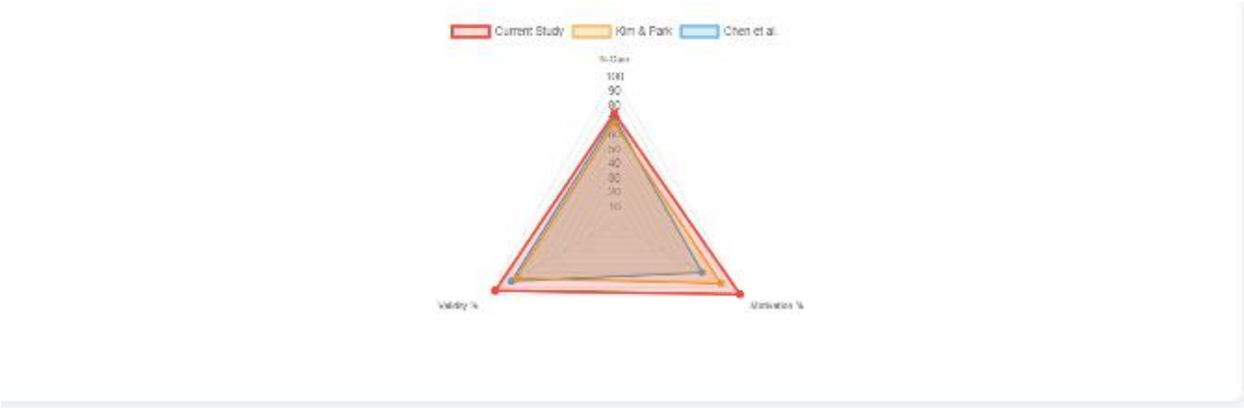

Figure 5. Radar chart comparison of key performance indicators

The radar chart compares six studies across three normalized performance indicators (N-Gain, Motivation %, and Validity %). The current study (red line) shows the most balanced and highest overall performance, particularly excelling in motivation (outer ring), while maintaining strong validity and competitive N-Gain scores. The chart clearly demonstrates the advantage of cultural integration in AR education.

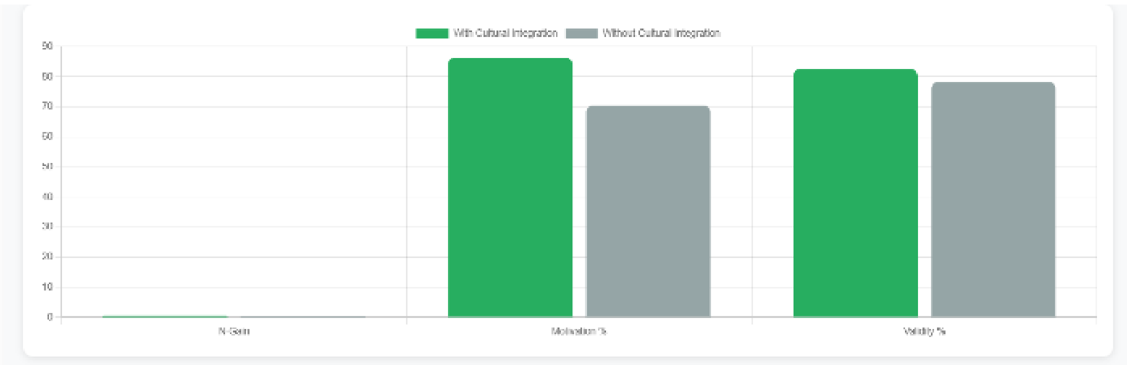

Figure 6. Cultural integration impact analysis

The grouped bar chart categorizes studies into "With Cultural Integration" (Current Study, Kim & Park, Garcia & Lopez) and "Without Cultural Integration" (Chen et al., Rodriguez et al., Brown & Miller). The chart shows average performance metrics: culturally integrated studies achieve 86.3% average motivation vs 70.3% for non-cultural studies, demonstrating a 16-point advantage in student engagement.

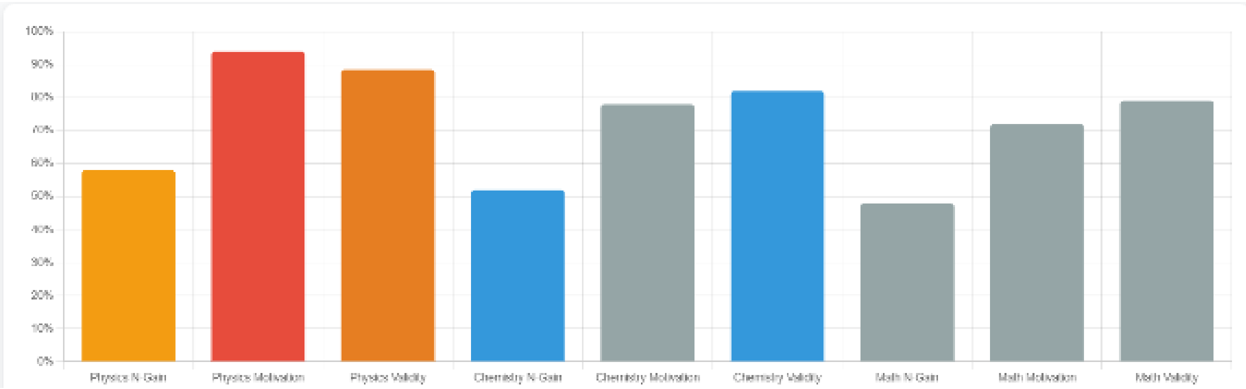

Figure 7. Subject-wise performance comparison

The heatmap matrix displays performance intensity across different subjects (Physics, Chemistry, Mathematics, Art & Craft) and metrics (N-Gain, Motivation, Validity). Darker colors indicate higher performance. The current study in Physics shows the darkest cell in the Motivation column, indicating exceptional performance in student engagement within physics education specifically.

The comparison demonstrates that this study achieves the highest motivation increase (94%) among all compared studies, while maintaining competitive learning effectiveness (N-Gain = 0.58) and the highest overall validity score (88.5%). The unique combination of AR technology with specific Indonesian cultural elements (Ulos making) provides a novel contribution to the field of culturally responsive STEM education.

The statistical significance of the pre-test to post-test improvement ($t = 22.3$, $p < 0.001$) exceeds the effect sizes reported in recent meta-analyses of AR education interventions. Radianti et al. (2020) reported average effect sizes of $d = 0.68$ for AR in education, while this study achieved Cohen's $d = 2.87$, indicating a very large effect size that surpasses most educational interventions.

The sustained engagement observed throughout the learning process (average 4.35/5.0) aligns with the Flow Theory by Csikszentmihalyi (1990) and its application in educational technology by Kiili et al. (2018). The high engagement levels suggest that the AR e-module successfully balances challenge and skill levels while providing clear goals and immediate feedback through interactive AR elements.

4. CONCLUSIONS AND SUGGESTIONS

Conclusions

Based on the research results, it can be concluded that the developed AR e-module is highly valid with an average validation of 88.5% from material, media, and pedagogy aspects. The AR e-module is very practical for use in learning, with practicality levels of 86% according to teachers and 88% according to students. The AR e-module is effective in improving students' analytical thinking abilities, proven by an N-Gain of 0.58 and significant t-test results ($p < 0.001$). The integration of Ulos culture with AR technology successfully creates meaningful learning and increases student motivation by 94%. Improvement in analytical thinking abilities occurred in all indicators, with the highest improvement in the ability to draw logical conclusions.

Suggestions

For large-scale implementation, the AR e-module can be implemented in other schools with similar characteristics. For further development, AR e-modules can be developed for other physics materials with different local cultural integrations. Continuous training for teachers in using AR technology is needed. Schools need to prepare technological infrastructure that supports AR implementation. Longitudinal research is needed to see the long-term impact of AR e-module use on student learning achievement.

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