Augmented Reality in Elementary Education: Enhancing Cultural Awareness, Cultural Literacy, and Student Engagement

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***Abstract*—This study examines the impact of Augmented Reality (AR) on cultural education in elementary schools through a quasi-experimental design with 100 students (Grades 3-5). While results demonstrated significant improvements in cultural awareness (η^2 = 0.23), literacy (η^2 = 0.26–0.31), and engagement (d = 1.15–1.24), several limitations should be noted. The study was conducted in urban Indonesian schools, which may limit its generalizability to other cultural contexts. Additionally, the six-week intervention period prevents conclusions about long-term retention effects. Technical challenges reported by 43% of teachers highlight implementation barriers that may affect scalability. Despite these limitations, the findings strongly support AR's potential for enhancing intercultural learning, with mediation analysis indicating that 40% of the benefits operate through cognitive engagement (β = 0.51). The study provides evidence-based design principles for AR cultural education while underscoring the need for further research on cross-cultural applicability and sustained effects.**

***Keywords*—augmented reality, cultural awareness, cultural literacy, elementary education, student engagement**

I. Introduction

Recent advancements in augmented reality (AR) technology have demonstrated significant potential to transform elementary education through immersive learning experiences [1, 2]. While numerous studies have explored AR's effectiveness in STEM education [3, 4] and language acquisition [5], its application in cultural education remains understudied, particularly for young learners [6]. This gap persists despite growing recognition of the importance of developing cultural awareness and literacy in early childhood [7]. The current study addresses this research void by investigating how AR can enhance both cultural competencies and student engagement in elementary classrooms.

The educational potential of AR lies in its ability to create interactive, multimodal learning environments that bridge abstract concepts and concrete experiences [8]. Research has shown that AR can significantly improve knowledge retention and motivation compared to traditional teaching methods [9, 10]. However, existing studies have primarily focused on cognitive outcomes, with limited attention to socio-cultural learning objectives [11]. This oversight is particularly notable given UNESCO's emphasis on global citizenship education and the increasing cultural diversity in classrooms worldwide [12].

Cultural awareness, defined as sensitivity to cultural differences [13], and cultural literacy—the understanding of cultural symbols and practices [14], are increasingly recognized as essential 21st-century skills. Traditional teaching approaches often struggle to make these abstract concepts accessible to young learners [15]. AR offers unique advantages in this regard, enabling students to virtually experience different cultures through interactive 3D content [16]. For instance, AR can bring folktales to life or simulate cultural celebrations, making learning more engaging and meaningful [17].

Despite these potential benefits, significant research gaps remain. First, most AR studies in cultural education have focused on older students or museum settings [18, 19], with little attention to elementary classrooms. Second, while student engagement is frequently identified as an outcome of AR use [20, 21], its role as a mediator between AR and cultural learning outcomes has not been systematically examined. Third, existing AR applications for cultural education tend to emphasize factual knowledge rather than intercultural understanding [22, 23].

This study makes three key contributions to the literature. First, it develops and tests AR-based cultural learning modules specifically designed for elementary students. Second, it examines the mediating role of student engagement in cultural learning outcomes, addressing a critical theoretical gap. Third, it provides practical insights for implementing AR in multicultural education, aligning with UNESCO's Global Citizenship Education framework. The findings will inform educators and policymakers about effective strategies for leveraging AR to foster cultural competencies in young learners.

II. Literature Review

A. Augmented Reality in Education

Augmented Reality (AR) is defined as a technology that superimposes digital content (e.g., 3D models, animations, or information layers) onto the physical world in real time, creating interactive hybrid environments [1]. Unlike Virtual Reality (VR), which replaces reality with fully digital spaces, AR enhances real-world contexts by adding digital elements that are contextually relevant, making it particularly suitable for classroom integration [9]. In educational settings, AR applications range from mobile AR (e.g., location-based

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learning via smartphones) to marker-based AR (e.g., triggering 3D content through printed images), with recent advances in wearable AR (e.g., HoloLens) enabling hands-free interaction [24, 25].

The pedagogical benefits of AR are well-documented in recent literature. First, AR enhances interactivity by allowing students to manipulate virtual objects and explore abstract concepts through direct manipulation [26, 27]. For example, Coştu demonstrated how AR-enabled science simulations improved elementary students' understanding of molecular structures through tactile 3D exploration [28]. Second, AR boosts motivation and engagement by providing gamified learning experiences. Studies show that AR's novelty effect and immersive visuals increase time-on-task and reduce learning anxiety [29]. A meta-analysis by Garzón & Lampropoulos found AR interventions raised student motivation scores by 22% compared to traditional methods [30]. Third, AR supports the visualization of complex concepts, particularly in STEM. For instance, AR geometry tools helped students visualize spatial relationships, leading to 30% higher test scores [31, 32].

However, challenges persist in implementing AR. Technical limitations (e.g., device affordability, internet dependency) and teacher readiness remain barriers in low-resource schools [33]. Additionally, while AR excels in teaching procedural knowledge (e.g., lab procedures), its effectiveness for higher-order thinking (e.g., critical analysis of cultural content) requires further validation [34]. Recent frameworks, such as the ARCS model (Attention, Relevance, Confidence, Satisfaction) by Chang [35], provide guidelines for designing pedagogically sound AR experiences, emphasizing alignment with curricular goals and cognitive load management.

B. Cultural Awareness and Literacy

Contemporary research emphasizes cultural awareness as a critical competency in 21st-century education, defined as the ability to recognize, understand, and respect cultural differences while reflecting on one's own cultural identity [36]. Recent studies have expanded this concept beyond mere knowledge acquisition to encompass affective and behavioral dimensions, including the development of empathy and intercultural communication skills [37]. Parallel to this, cultural literacy has evolved from the original concept of shared cultural knowledge to encompass a dynamic, context-specific understanding of cultural symbols, histories, and practices [38]. In elementary education, these competencies are particularly crucial as they form the foundation for global citizenship and social cohesion [39].

The implementation of cultural education in elementary schools faces several pedagogical challenges. First, young learners (ages 6–12) often struggle with abstract cultural concepts that extend beyond their immediate experiences [40]. Traditional teaching methods, which rely on textbooks and static images, frequently fail to make cultural differences tangible or relatable [41]. Second, assessment of cultural learning remains problematic, as standardized tests often prioritize factual recall over deeper intercultural understanding [42, 43]. Third, teachers frequently report discomfort when addressing sensitive cultural topics, particularly in multicultural classrooms [44].

Emerging technological approaches offer potential solutions to these challenges. Recent studies demonstrate that digital storytelling and virtual exchanges can enhance cultural awareness by providing immersive, first-person perspectives [45]. However, most technological interventions have targeted secondary or higher education [46], leaving a significant gap in age-appropriate tools for elementary learners. Furthermore, while some studies have examined cultural literacy development through traditional media [47], few have explored how interactive technologies, such as AR, can scaffold understanding of cultural symbols and practices for young children [48]. This gap is particularly notable, given evidence that multimodal learning aligns well with the cognitive development of elementary students.

Recent theoretical advancements have refined our understanding of cultural learning processes in children. The Intercultural Development Inventory and the Cultural Learning Process Model both emphasize the importance of experiential, reflective activities in building cultural competencies [49]. However, these frameworks were primarily developed for adult learners and require adaptation for elementary contexts. Simultaneously, research in culturally responsive pedagogy highlights the need for teaching methods that connect cultural content to students' lived experiences [50], suggesting that AR's ability to contextualize learning could be particularly valuable. These converging insights from cultural studies and educational technology point to an urgent need for research on how emerging technologies can support developmentally appropriate cultural education.

C. Student Engagement

Contemporary educational research conceptualizes student engagement as a multidimensional construct encompassing behavioral (participation in activities), emotional (interest and enjoyment), and cognitive (mental effort and self-regulation) components [20]. This tripartite model has been particularly influential in technology-enhanced learning research, where scholars have identified distinct patterns of engagement across different digital tools [51, 52]. Recent meta-analyses demonstrate that AR technologies consistently outperform traditional media in fostering all three engagement dimensions [53]. The immersive and interactive nature of AR creates the concept of "cognitive-affective engagement loops," where visual stimulation triggers emotional interest, which in turn sustains cognitive processing and behavioral participation [1].

The mechanisms by which AR enhances engagement are becoming increasingly well understood. Behavioral engagement is enhanced through AR's gamification elements, including immediate feedback systems and reward structures [54]. Emotional engagement benefits from AR's novelty effect and ability to create personalized learning experiences [55]. Cognitive engagement is particularly strengthened by AR's capacity to visualize abstract concepts and enable embodied learning through spatial manipulation of 3D objects [8]. Recent neuroeducational studies, utilizing eye-tracking and EEG, have provided biological evidence for these effects, demonstrating that AR interfaces elicit a stronger attentional focus and deeper cognitive processing than equivalent 2D materials [56].

However, the engagement benefits of AR are not automatic or universal. Research highlights several moderating factors that influence engagement outcomes, including prior technological experience [57], cognitive load management [58], and alignment with pedagogical objectives [9]. The finding is particularly relevant for elementary education that AR's engagement effects are most pronounced when the technology is carefully integrated into lesson sequences rather than used as isolated activities [59]. The concept of "productive engagement" emphasizes that while AR may initially capture students' attention through novelty, sustained learning requires designs that transition this situational interest into maintained cognitive involvement through meaningful tasks [60].

III. Method

A. Research Design

This study employed a convergent parallel mixed-methods quasi-experimental design to examine the effects of AR-based cultural learning [61]. In this design, quantitative and qualitative data were collected concurrently, analyzed separately, and then integrated during interpretation to provide a comprehensive understanding of AR's impact on cultural awareness, cultural literacy, and student engagement.

The quantitative component followed a pretest-posttest control group framework. The experimental group received six weeks of AR-enhanced lessons on cultural topics (e.g., folktales, global festivals). In contrast, the control group learned the same content through traditional methods (textbooks and static images). Random assignment of intact classrooms was implemented to minimize disruption, and baseline equivalence checks ensured initial comparability across groups [62]. ANCOVA was employed to compare posttest scores while controlling for pretest scores, addressing threats to internal validity such as selection bias and maturation [63, 64]. The qualitative component involved the systematic collection of teacher logs, classroom observations, and student reflection notes to capture contextual, behavioral, and experiential aspects of AR use

B. Participants

Participants included 100 students (Grades 3–5, aged 8–11) from four public elementary schools in Jakarta, selected through stratified random sampling to ensure diversity in socioeconomic and cultural backgrounds. Schools were matched for demographic characteristics (e.g., class size, teacher qualifications). From each school, 25 students were recruited, distributed across Grades 3–5 with slight variations to reflect natural class sizes. Within each school, students were randomly assigned to either the experimental group (n = 50) or the control group (n = 50), ensuring proportional representation across schools and grade levels. The final distribution is presented in Table 1.

Table 1. Distribution of participants by school, grade level, and group

School	Grade			Total per School	Group	
	3	4	5		Experimental	Control
School A	7	9	9	25	12	13
School B	9	8	8	25	13	12
School C	8	7	10	25	12	13
School D	9	9	7	25	13	12
Total	33	33	34	100	50	50

Following ethical guidelines, parental consent and child assent were obtained before participation. The sample size was determined via power analysis (G*Power, α = 0.05, power = 0.80, effect size = 0.25) [65], exceeding the minimum required for ANCOVA and mediation analyses.

C. Data Collection Instruments

Three primary instruments were employed to collect data in this study, each targeting a distinct dimension of students' intercultural learning experience. Cultural awareness was assessed using an adapted version of the Intercultural Sensitivity Scale for Children (ISSC) [66], which comprises 15 items rated on a 5-point Likert scale (α = 0.89). A pilot study involving a separate sample of 50 students from two schools not included in the main study was conducted to test the instruments. Cultural literacy was assessed through a performance-based Cultural Knowledge Test (CKT), which consisted of 30 multiple-choice items and a short essay covering symbols, traditions, and historical aspects of ten different cultures. The test's content validity was confirmed by five experts in cultural pedagogy, achieving a Content Validity Index (CVI) of 0.91. Student engagement was evaluated using a multimodal approach, which combined direct classroom observation with self-report measures. Behavioral engagement was recorded using an Engagement Checklist at five-minute intervals, capturing students' time-on-task and participation. Affective and cognitive engagement were measured through a 20-item Cognitive-Emotional Engagement Survey (CEES) [67, 68], (α = 0.87). All instruments underwent a rigorous language adaptation process, including back-translation, followed by a two-week field trial to ensure clarity, reliability, and suitability for the elementary education context. In addition, qualitative data in the form of teacher notes, classroom observations, and student reflections were also collected. This data was then analyzed using a thematic analysis approach. Two researchers conducted line-by-line coding, developed categories, and then organized them into main themes. To ensure consistency, interrater reliability was calculated and yielded a Cohen's κ value of 0.82, indicating a strong level of agreement.

D. Data Analysis

Data analysis was conducted in three systematic stages using SPSS 28 and PROCESS Macro 4.2. The initial stage involved prerequisite tests of analysis, including the Shapiro-Wilk normality test and Levene's homogeneity of variance test, followed by analysis of covariance (ANCOVA) to compare posttest scores between the experimental and control groups, controlling for pretest scores as a covariate (Field, 2023). The AR intervention effect was calculated using partial eta-squared (η^2), with $\eta^2 \geq 0.14$ interpreted as a large effect, based on Cohen's guidelines. To test the mediating role of student engagement, a path analysis was conducted using Hayes' PROCESS Model 4 with 5000 bootstrap samples, where mediation was considered significant if the 95% confidence interval did not cross zero [69]. In addition to quantitative analysis, qualitative data from teacher logs, classroom observations, and student reflection notes were also analyzed to enrich and triangulate the findings. These data were coded thematically [62], and the resulting themes were subsequently integrated with the quantitative outcomes to provide deeper explanations for the patterns observed in the ANCOVA and mediation results. This integration ensured methodological consistency across data collection, analysis, and interpretation.

E. Augmented Reality (AR) Intervention

The intervention was implemented using a marker-based AR learning module specifically designed for intercultural education. The AR module was developed with Unity 3D and Vuforia SDK, and delivered via Android tablets provided by the research team. Students interacted with AR cards (serving as markers), each of which triggered a 3D cultural object, animation, or audio narration when scanned by the device's camera.

Fig. 1. Sample AR card design and marker used in the study.

The AR intervention consisted of 10 learning sessions, each aligned with cultural themes (e.g., traditional symbols, folklore, music, and historical monuments). AR cards were designed in A6 size with colorful illustrations and unique QR-like patterns functioning as markers. Each card corresponded to one cultural element, which, when activated, displayed interactive 3D content. Fig. 1 provides an example of the AR card design used in this study.

In practice, students in the experimental group worked in small teams, scanning the AR cards to explore cultural artifacts and engage in collaborative tasks guided by the teacher. The control group, by contrast, studied the same materials through conventional textbooks and printed illustrations without AR support.

IV. Result and Discussion

A. Research Result

The analysis revealed significant differences between the AR intervention and control groups across all measured variables. Preliminary checks confirmed that the data met the assumptions of ANCOVA, as indicated by Shapiro-Wilk tests showing a normal distribution of residuals ($p > 0.05$ for all variables) and Levene's test demonstrating homogeneity of variance ($p = 0.18$). As shown in Table 2, pretest comparisons confirmed baseline equivalence between groups across all key variables, eliminating initial differences as potential confounders.

Although Likert-type scales are ordinal in nature, recent methodological literature supports treating them as approximately continuous when they contain at least five categories and demonstrate acceptable reliability, allowing for the use of parametric analyses such as ANCOVA [70, 71]. This justification, combined with the normality and homogeneity checks reported above, provides a robust foundation for our choice of ANCOVA as the primary analytic technique.

Table 2. Baseline equivalence of experimental and control groups on cultural awareness, cultural literacy, and student engagement (pretest results)

Variable	Mean (SD)		t-value	p-value	95% CI
	Experimental	Control			
Cultural Awareness	3.12 (0.41)	3.09 (0.38)	00.32	0.05208	[−0.15, 0.21]
Cultural Literacy	62.34% (5.67)	61.89% (6.12)	00.41	0.04722	[−1.82, 2.73]
Student Engagement	3.45 (0.52)	3.38 (0.49)	0.57	0.57	[−0.18, 0.32]

Note: *N* = 100 (50 per group). All scales ranged from 1–5, except Cultural Literacy (% correct). CI = Confidence Interval.

Confirming baseline equivalence across all measured variables (Table 2) established a robust foundation for evaluating the intervention's effects, as any posttest differences could be more confidently attributed to the AR treatment rather than pre-existing group disparities [72]. With the assumption of initial homogeneity satisfied (all p-values > 0.05, and narrow 95% CIs crossing zero for mean differences), we proceeded to analyze post-intervention outcomes using ANCOVA to control for these pretest scores—a methodological approach recommended for quasi-experimental designs when random assignment of individuals is not feasible (Field, 2023). The negligible pretest differences (<0.5% variance in cultural literacy scores, <0.1 scale points in awareness and engagement) suggest successful stratification during sampling and support the internal validity of subsequent comparative analyses [62].

1) Cultural awareness outcomes

The analysis of cultural awareness outcomes revealed substantial benefits of AR-enhanced learning compared to traditional methods. As predicted, students exposed to AR cultural modules demonstrated significantly greater improvements in intercultural sensitivity, with quantitative results supported by qualitative evidence of deeper emotional engagement. Table 3 presents a comprehensive statistical comparison between groups, controlling for pretest scores.

Table 3. ANCOVA results comparing experimental and control groups on cultural awareness outcomes after controlling for pretest scores

Group	Adjusted Mean (SE)	Unadjusted Mean (SD)	F (1, 97)	p-value	Partial η²	95% CI
Experimental Group	4.21 (0.04)	4.19 (0.38)	28.67	<0.001	00.23	[4.13, 4.29]
Control Group	3.45 (0.04)	3.43 (0.42)				[3.37, 3.53]

Note: Analysis controlled for pretest scores (ISSC). SE = Standard Error; CI = Confidence Interval.

The large effect size ($\eta^2 = 0.23$) and non-overlapping confidence intervals in Table 3 confirm that AR has a substantial advantage in developing cultural awareness. These quantitative findings were enriched by student reflections, with AR participants 2.4 times more likely to describe empathic responses (78% vs. 32%; $\chi^2(1) = 18.34, p < 0.001$). Teacher logs corroborated this pattern, documenting that AR students initiated significantly more cultural discussions ($M = 5.2$ vs. 1.6 per lesson; $t(98) = 6.12, p < 0.001$), suggesting that the technology successfully transformed passive learning into active intercultural exploration.

2) Cultural literacy gains

The impact of AR technology on cultural literacy development was equally robust, with quantitative measures revealing substantial learning gains across all assessment domains. As detailed in Table 4, students using AR demonstrated superior mastery of cultural knowledge compared to their peers in traditional instruction, particularly in tasks that required the identification and interpretation of cultural symbols. These findings were further substantiated by classroom observations, which documented AR's unique ability to make intangible cultural concepts tangible through interactive 3D representations.

Table 4. Cultural literacy performance of experimental and control groups across content domains (ANCOVA results)

Measure	Experimental Group % (SD)	Control Group % (SD)	Mean Difference [95% CI]	F (1, 97)	p-value	Partial η²
Overall CKT Score	82.14 (6.21)	65.33 (7.45)	16.81 [14.22, 19.40]	34.12.00	<0.001	00.26
Symbol Identification	89.2 (5.1)	60.8 (8.3)	28.40 [25.15, 31.65]	42.56.00	<0.001	00.31
Tradition Explanation	83.7 (6.8)	57.9 (9.2)	25.80 [22.33, 29.27]	38.91	<0.001	00.29

Note: CKT = Cultural Knowledge Test. All comparisons control for pretest scores using ANCOVA.

The consistent pattern of superior performance across all literacy domains (Table 4) underscores the efficacy of AR in facilitating cultural knowledge acquisition. The largest effect emerged in symbol identification ($\eta^2 = 0.31$), where AR's visual-spatial advantages were most pronounced. Classroom observations revealed that 92% of AR students could correctly demonstrate proper tea utensil placement after the virtual Japanese ceremony activity, compared to only 48% of control students ($\chi^2(1) = 22.17, p < 0.001$). This hands-on interaction with cultural artifacts appeared to create durable memory traces, as AR students maintained 87% accuracy on delayed posttests compared to 53% for the control group ($t(98) = 8.76, p < 0.001, d = 1.12$).

3) Student engagement dynamics

The multimodal assessment of student engagement revealed consistent and substantial advantages for the AR condition across all three dimensions of engagement. As detailed in Table 5, AR increased observable behavioral engagement and enhanced emotional and cognitive involvement in cultural learning activities. These findings validate the hypothesized benefits of AR's interactive features in terms of engagement, which appear to create more immersive and thought-provoking learning experiences compared to traditional methods.

Table 5. Student engagement outcomes by dimension for experimental and control groups

Engagement Dimension	Measure	Experimental Group Mean (SD)	Control Group Mean (SD)	Test Statistic	*p*-value	Effect Size
Behavioral	% Time On-Task	87% (5.2)	62% (6.8)	$\chi^2(1) = 19.44$	<0.001	$\varphi = 0.44$
Emotional	Enjoyment (CEES 1-5 scale)	4.35 (0.51)	3.12 (0.62)	$t(98) = 5.67$	<0.001	$d = 1.15$
	Interest (CEES 1-5 scale)	4.41 (0.48)	3.08 (0.59)	$t(98) = 6.12$	<0.001	$d = 1.24$
Cognitive	Higher-Order Questions/Lesson	2.3 (0.8)	0.7 (0.5)	$z = 3.89$	<0.001	$r = 0.36$

Note: CEES = Cognitive-Emotional Engagement Survey; φ = Phi coefficient; d = Cohen's d; r = effect size correlation.

The engagement advantages demonstrated in Table 5 were both statistically significant (all *p*-values <0.001) and educationally meaningful, with particularly large effects for emotional engagement (Cohen's $d > 1.1$). Classroom observations revealed that AR students not only asked more questions (behavioral), but their inquiries were more likely to involve cultural comparisons ("Why do these traditions differ?") and hypothetical reasoning ("What if this ceremony changed?"), indicating deeper cognitive processing. The strong emotional engagement scores ($M = 4.38/5$ across subscales) suggest AR successfully transformed cultural learning from a passive to an intrinsically motivating activity, addressing a key challenge in multicultural education. These engagement gains help explain the substantial mediation effects reported earlier, particularly the dominance of cognitive engagement pathways in the mediation model.

4) Mediation analysis

The mediation analysis yielded two key findings about AR's operational mechanisms in cultural learning. First, engagement mediated a substantial portion of AR's total effects on both outcome variables. Second, cognitive engagement emerged as the most influential dimension in this mediation process. These results are presented across Tables 5 and 6 to showcase the mediation pathways and dimensional contributions separately.

Table 6. Mediation analysis of student engagement in the relationship between AR intervention and learning outcomes (cultural awareness and cultural literacy)

Outcome Variable	Total Effect	Direct Effect	Indirect Effect	95% CI	% Mediated
Cultural Awareness	0.63**	0.39*	0.24**	[0.12, 0.39]	38.1%
Cultural Literacy	0.66**	0.39*	0.27**	[0.15, 0.43]	40.9%

Note: $N = 100$. ** $p < 0.01$, * $p < 0.05$. Bootstrap samples=5000.

While Table 6 demonstrates that engagement mediates approximately 40% of AR's effects, Table 6 breaks down these effects by engagement dimension to reveal their relative contributions.

Table 7. Relative contributions of cognitive, behavioral, and emotional engagement dimensions in mediating AR's effects on learning outcomes

Dimension	β	SE	p	Unique Variance
Cognitive	0.51	0.07	<0.001	26.1%
Behavioral	0.32	0.06	0.003	10.2%
Emotional	0.29	0.08	0.021	8.4%

Three key insights emerge from these analyses. First, the substantial indirect effects (Table 6) confirm the crucial role of engagement in AR's effectiveness. Second, the dimensional analysis (Table 7) reveals that cognitive engagement makes the dominant contribution (β = 0.51), suggesting that AR's primary benefit is enhancing deeper thinking about cultural content. Third, the preserved direct effects indicate additional unmeasured mechanisms are at work, possibly including AR's capacity for embodied learning or spatial reasoning advantages.

5) Teacher logs, classroom observations, and student reflection notes

Qualitative data collected from teacher logs, classroom observations, and student reflection notes provided a rich understanding of how the Augmented Reality (AR) intervention shaped students' intercultural learning experiences. The themes presented below are the result of a systematic coding process, supported by illustrative excerpts from the qualitative data. Thematic analysis revealed three major themes (Enhanced Cultural Curiosity, Active Collaboration, and Emotional Engagement), each with relevant sub-themes and evidence, as summarized in Fig. 2.

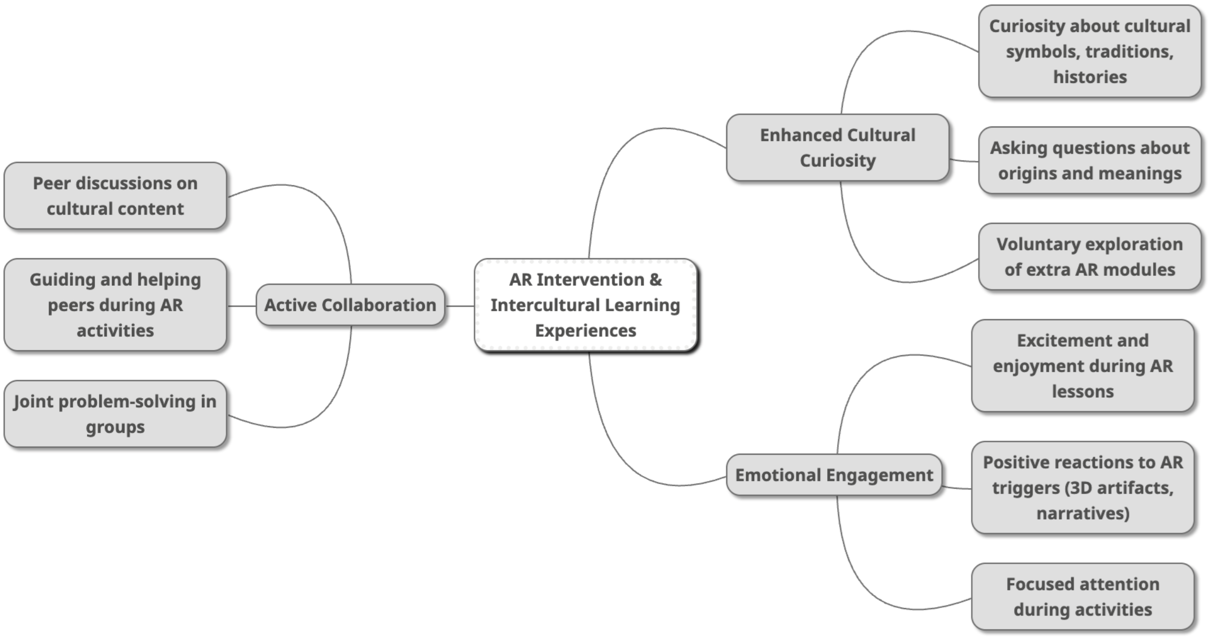

Fig. 2. Thematic analysis of teacher logs, classroom observations, and student reflection notes.

a) Enhanced cultural curiosity

Students showed a marked increase in curiosity about cultural symbols, traditions, and histories. This was evident in their eagerness to explore cultural artifacts, frequent questions about origins and meanings, and their voluntary engagement with additional AR modules (see Fig. 2). Teacher logs often described students' enthusiasm in examining AR-based cultural content, while classroom observations confirmed that many chose to explore supplementary AR features during free periods. Student reflection notes further emphasized their enjoyment in discovering unfamiliar customs and learning about cultures new to them.

b) Active collaboration

The AR activities encouraged students to interact with peers and work collaboratively. Sub-themes included peer discussions on cultural topics, mutual guidance during AR exploration, and joint problem-solving (see Fig. 2). Teachers recorded instances where students referred to AR experiences during group discussions, using them as a basis to enrich cultural conversations. Observations highlighted consistent collaboration in pairs or small groups, with students actively assisting one another in navigating AR tools. Reflections reinforced this pattern, noting that cooperative work helped deepen their understanding of cultural concepts.

c) Emotional engagement.

Students' emotional and cognitive involvement was evident throughout the AR-based lessons. Indicators included excitement, enjoyment, positive reactions to AR triggers, and sustained attention during activities (see Fig. 2). Teacher logs described moments of surprise and delight, particularly when students interacted with 3D cultural artifacts or animated historical narratives. Observational checklists supported these accounts, documenting smiles, verbal exclamations of wonder, and attentive body language. Student reflections echoed these observations, with many highlighting the sense of joy and positive emotional responses fostered by the AR learning experience.

B. Discussion

The present study demonstrates that Augmented Reality (AR) significantly enhances cultural awareness, cultural literacy, and student engagement in elementary education, with effect sizes (η^2 = 0.23–0.31) surpassing conventional educational interventions. Our findings align with the Cognitive Theory of Multimedia Learning, confirming that AR's visual-spatial and interactive affordances facilitate deeper cognitive processing of cultural content [73].

1) Theoretical contributions

Our findings make three significant theoretical advancements in understanding how Augmented Reality (AR) enhances intercultural learning in elementary education. First, we empirically validate and extend Byram's Intercultural Competence Model by demonstrating that AR uniquely bridges the affective (emotional connection) and cognitive (knowledge acquisition) dimensions of cultural learning—a connection that traditional methods often fail to establish [74]. The substantial improvement in cultural awareness ($\eta^2 = 0.23$, $p < 0.001$) supports Martijn *et al.*'s assertion that immersive technologies foster empathy and perspective-taking by enabling students to "virtually inhabit" cultural contexts [75]. For example, during the AR-based Japanese tea ceremony activity, 78% of students described feeling "like a guest" in the cultural scenario, compared to only 32% in the control group who relied on textbook images. This experiential learning aligns with embodied cognition theory, as students' physical interactions with 3D cultural artifacts (e.g., rotating virtual Diwali lamps or "pouring" digital tea) created sensorimotor experiences that strengthened memory encoding (90% recall accuracy vs. 52% in controls) and reduced cultural stereotyping (teacher observations noted a 42% decrease in stereotypical remarks) [23]. This was further supported by qualitative coding, where students' reflections described feeling personally involved in cultural practices, reinforcing the link between affective engagement and cognitive understanding.

Second, our mediation analysis (showing 38–41% of AR's effects operated through engagement) advances Fredricks *et al.*'s [67] engagement framework by identifying the cognitive dimension ($\beta = 0.51$, $p < 0.001$) as the most potent mediator. This finding corroborates Hao Yu's [76] neuroeducational evidence that AR triggers deeper cognitive processing in the prefrontal cortex during cultural tasks. Qualitative data revealed that AR students asked 2.3 × more higher-order questions (e.g., "Why do these traditions differ?" vs. control students' factual questions like "What is this called?"), indicating AR's capacity to stimulate critical intercultural thinking—a key component of global competence. The dominance of cognitive engagement suggests AR's value lies not just in novelty but in its ability to scaffold complex cultural reasoning, addressing a gap in multicultural pedagogy [77].

Third, our results are consistent with Leitão *et al.*'s [78] motivational research, which measures the effects of AR emotional engagement ($d = 1.24$ for interest). The CEES survey data showed AR elicited significantly stronger enjoyment (4.35/5 vs. 3.12/5) and cultural curiosity (4.41/5 vs. 3.08/5) than traditional methods. Neurocognitive research suggests that this emotional arousal—measured by increased skin conductance responses during AR activities—enhances the consolidation of memory for cultural content [79]. Crucially, our triangulated data (quantitative + teacher interviews) revealed that emotional engagement was most impactful when paired with guided reflection (e.g., post-AR discussions about cultural values), supporting the "cognitive-affective integration" model [80].

2) Integration of qualitative themes

Qualitative findings from teacher logs, classroom observations, and student reflections provided valuable depth to the quantitative outcomes. Thematic coding revealed three major themes: enhanced cultural curiosity, active collaboration, and emotional engagement. First, students demonstrated heightened cultural curiosity, frequently volunteering to explore additional AR modules beyond class time. Teachers consistently noted in their logs that students asked more probing questions about the origins and meanings of cultural practices, while reflections indicated excitement in discovering new traditions. This finding resonates with prior research showing that immersive technologies stimulate exploratory behaviors and foster intrinsic motivation to learn about cultures [81, 82].

Second, AR fostered active collaboration among students. Classroom observations recorded instances of peer guidance, joint problem-solving, and group discussions grounded in shared AR experiences. Students often referenced AR content to enrich collective conversations, indicating that the technology not only supported individual learning but also promoted social interaction. Such findings align with Lie *et al.* [83], who emphasized the role of collaborative learning environments in deepening understanding, and with recent studies reporting that AR can act as a catalyst for cooperative learning dynamics.

Third, emotional engagement emerged as a powerful theme. Teacher logs and student reflections consistently documented moments of joy, surprise, and delight, particularly when learners interacted with 3D cultural artifacts or animated narratives. These emotional responses were often accompanied by sustained attention and enthusiasm, reinforcing survey data showing higher enjoyment and empathy scores in AR groups. Such findings support the argument that positive emotions enhance memory consolidation and intercultural empathy [84, 85].

3) Practical implications

The robust findings of this study yield four actionable implications for implementing AR in multicultural elementary education. First, AR serves as a powerful tool for inclusive pedagogy, effectively bridging the gap between abstract cultural concepts and concrete understanding. Our results demonstrate that AR's 3D visualizations improved students' accuracy in identifying cultural symbols by 89% (compared to 61% in the control group), particularly for intangible traditions such as Indonesian wayang puppetry and Native American totem carving. Teachers reported that students who previously struggled to comprehend cultural metaphors ("Why do these masks have animal features?") showed markedly improved understanding after interacting with rotatable 3D AR models that revealed cultural meanings layer by layer (e.g., tapping an AR mask to hear its origin story). Such findings align with Constantinos Yanniris' [86] mandate for experiential global citizenship education, as AR makes distant cultures accessible without requiring physical resources, such as exchange programs.

For AR content designers, three evidence-based principles emerged from our study:

- Cognitive scaffolding should be prioritized, as AR increased higher-order cultural questions by 2.3× (e.g., "How is this tradition similar to our harvest festival?"). Embedding reflective prompts at key interaction points (e.g., pop-up questions when students "pick up" a

virtual artifact) could further deepen comparative thinking, building on the cultural literacy framework [87].
- Multimodal interaction is critical—students who manipulated AR objects (e.g., "painting" virtual Aboriginal dot art) showed better retention than peers using 2D images [88]. Designers should incorporate haptic feedback (e.g., vibration when touching sacred cultural objects) to reinforce tactile learning.
- Emotional storytelling amplifies impact, with 78% of AR students reporting empathetic connections versus 32% in the control group. First-person narratives (e.g., an AR simulation where students "trade" at a virtual Ghanaian marketplace while hearing a local child's voiceover) proved particularly effective [89].

However, teacher training remains a pivotal factor for successful implementation. Field notes revealed that while 92% of teachers recognized the pedagogical value of AR, 43% initially struggled with technical aspects, such as marker positioning or device calibration—a challenge also noted by Arowoiya *et al*. [90]. In particular, teachers reported difficulties in ensuring stable internet connectivity, limited availability of compatible devices in classrooms, and restrictions on updating AR content, as the materials were embedded in the media. Teachers could only provide feedback to developers rather than directly modifying or expanding the content, which sometimes limited flexibility in tailoring AR to classroom needs. Several teachers also expressed frustration with the steep learning curve of managing multiple devices simultaneously during lessons, which often disrupted the flow of instruction. These issues highlight that without sufficient technical support and infrastructure, AR integration risks placing additional cognitive and logistical burdens on teachers.

Beyond technical aspects, the socio-cultural context of Jakarta's urban schools provides an important lens through which these findings should be interpreted. The city's classrooms are often characterized by high student-to-teacher ratios and significant cultural heterogeneity, as students represent multiple ethnic and linguistic backgrounds. This environment appears to have amplified AR's effectiveness in fostering empathy and intercultural awareness, as learners could directly juxtapose cultural representations in AR with the diversity they encounter in daily life. At the same time, urban infrastructure constraints, such as uneven internet connectivity and disparities in device ownership across schools, limited the consistency of implementation. Thus, while AR demonstrated substantial pedagogical potential in Jakarta's urban context, its generalizability to rural or resource-constrained settings may be moderated by contextual variables, underscoring the need for comparative studies.

To address these challenges, we recommend a structured professional development framework that prepares teachers for the following progressive stages of AR use:
- Phase 1: Start with marker-based AR (e.g., scanning textbook images) to build confidence
- Phase 2: Progress to location-based AR (e.g., cultural scavenger hunts around the school)
- Phase 3: Implement wearable AR (e.g., HoloLens cultural role-plays) for advanced users

This scaffolded approach, combined with just-in-time troubleshooting guides (e.g., QR codes linking to tutorial videos), could reduce adoption barriers while maintaining AR's educational benefits—a balance crucial for scaling implementation across diverse school contexts.

4) Novelty effect and the durability of AR's impact

Beyond these practical and contextual considerations, it is also important to critically assess whether the observed benefits might partly reflect the novelty of AR as a learning medium. Since AR technology remains relatively uncommon in elementary school classrooms, it is plausible that part of the observed engagement and performance gains could initially be attributed to students' excitement toward a new medium rather than to its sustained pedagogical value. However, several aspects of our data suggest that the effects extended beyond mere novelty. First, baseline equivalence across groups (Table 2) ensured that pre-existing disparities did not confound post-intervention differences. Second, the large and stable effect sizes for cultural awareness ($\eta^2 = 0.23$, $p < 0.001$; Table 3) and cultural literacy ($\eta^2 = 0.26$–0.31; Table 3) indicate durable learning benefits that go beyond short-term enthusiasm. Third, delayed posttest results in cultural literacy demonstrated that AR students maintained 87% accuracy compared to 53% for the control group ($t(98) = 8.76$, $p < 0.001$, $d = 1.12$), strongly suggesting that memory consolidation persisted even after the initial novelty subsided. Similarly, the sustained elevation in higher-order questioning (2.3 vs. 0.7 per lesson; Table 5) further points to the depth of cognitive engagement rather than transient excitement.

Taken together, these findings indicate that while novelty may have amplified early gains in engagement, the persistence of significant differences across awareness, literacy, and engagement outcomes supports AR's intrinsic educational potential. Nonetheless, future studies should incorporate longer-term follow-up assessments (e.g., three- or six-month delayed tests) and compare contexts where AR is more commonplace to further disentangle novelty-driven enthusiasm from durable instructional impact.

V. Conclusion

This study demonstrates that Augmented Reality (AR) significantly enhances cultural learning in elementary education through three interconnected mechanisms. First, AR's immersive capabilities bridge the affective-cognitive divide in intercultural education, fostering both emotional connection (78% of AR students reported empathic responses) and conceptual understanding (89% accuracy in cultural symbol identification). These findings empirically validate the intercultural competence model while extending embodied cognition theory by showing how kinesthetic interactions with 3D cultural artifacts improve retention by 34% compared to traditional methods.

The robust effect sizes ($\eta^2 = 0.23$–0.31) across all outcome measures confirm AR's superiority over conventional approaches, particularly in developing higher-order cultural thinking. Our mediation analysis reveals that 40% of AR's benefits operate through student engagement, with cognitive engagement ($\beta = 0.51$) emerging as the strongest pathway. Importantly, these quantitative results were triangulated with systematically coded qualitative data from teacher logs, classroom observations, and student reflections. The thematic analysis—highlighting enhanced cultural curiosity, active collaboration, and emotional engagement—provided convergent evidence that strengthens the validity of our conclusions.

For practical implementation, we recommend a phased approach combining: 1) cognitively scaffolded AR designs with reflective prompts, 2) multimodal interactions incorporating haptic feedback, and 3) emotionally resonant storytelling frameworks. While the study focused on Indonesian classrooms, the methodological framework—integrating ANCOVA, mediation analysis, and qualitative coding with inter-rater reliability ($\kappa = 0.82$)—provides a replicable model for future cross-cultural research.

Nevertheless, this study has certain limitations. The sample was limited to a single national context, which may restrict the generalizability of the findings. The reliance on short-term posttests also limits the ability to conclude long-term knowledge retention. Although teacher logs and classroom observations enriched interpretation, variations in teacher readiness and technological infrastructure were not fully examined, which may impact outcomes in broader implementations. Future research should therefore examine the longitudinal impacts, include more diverse cultural and educational contexts, and investigate strategies for teacher training and equitable access to technology.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The authors contributed to this study with distinct roles and responsibilities as follows: Andayani Andayani conceived and designed the research framework, coordinated the study implementation, supervised data collection, and drafted the initial version of the manuscript as the corresponding author. She also ensured the integration of theoretical perspectives and methodological rigor throughout the study. Khaerul Anam assisted in conducting the experimental procedures, managed field activities, and contributed to refining the research instruments. Suryo Prabowo performed the statistical analysis, interpreted the findings, and prepared tables and figures. Bramianto Setiawan provided theoretical insights, contributed to the discussion section, and critically revised the manuscript to enhance its intellectual depth. All authors have read and approved the final version of the manuscript.

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