

# Augmented Reality Edu-tourism for Literacy and Numeracy: Analysis of the Learning Behavior Patterns of Elementary Students.

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Received : 14 August 2025  
Revised : 17 February 2026  
Accepted : 20 April 2026  
DOI : 10.26822/iejee.2026.445

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## Abstract

This research analyzes the learning behavior patterns of elementary school students in literacy and numeracy through Augmented Reality (AR) edu-tourism. Using a qualitative case study involving 53 fourth- and fifth-grade students in Bangka Belitung, Indonesia, data were gathered through direct observations, semi-structured interviews, and documentation. The results indicate that AR-based edu-tourism consistently fosters high engagement and active exploration across all learning sessions, with younger students demonstrating higher physical expressiveness. Collaborative patterns were particularly prominent, necessitated by shared device ratios which triggered natural peer-scaffolding and joint problem-solving among students. Furthermore, 3D visualizations of local tourism landmarks, such as Tanjung Kalian lighthouse and Jembatan Emas, acted as cognitive scaffolds that reduced extraneous load and facilitated embodied meaning-making by bridging abstract concepts with physical reality. While technical constraints and varying digital proficiencies were identified as challenges, these obstacles inadvertently promoted social constructivist behaviors through collective navigation and peer assistance. This study concludes that AR-based edu-tourism provides a situated learning environment that effectively contextualizes literacy and numeracy learning, offering significant implications for the implementation of the “Merdeka Belajar” curriculum in digital-age primary education.

## Keywords:

Edu-Tourism, Augmented Reality, Learning Behavior Patterns, Literacy, Numeracy

## Introduction

Elementary education is the foundation for the development of children’s academic and life skills. At this stage, basic skills such as literacy and numeracy are taught, which serve as the groundwork for further abilities in various subjects (Bonifacci et al., 2021; Muliantara & Suarni, 2022). Literacy encompasses not only the ability to read and write but also skills in interpreting and understanding information in various forms of media. Similarly, numeracy involves more



www.iejee.com  
ISSN: 1307-9298

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than just counting; it includes the ability to understand and apply mathematical concepts in everyday life contexts (Rakhmawati & Mustadi, 2022). These two skills are a top priority in the elementary education curriculum because they influence nearly all other aspects of learning (Mudzanatun, 2017)

Although literacy and numeracy are critically important aspects of elementary education, many students struggle to grasp the concepts being taught, especially when the material is abstract and not directly applicable to their lives. The results of the Indonesia National Assessment Program, which measured reading, math, and science skills for elementary school children, showed that students' reading ability is at 46.83% in the low category (Puspendik, 2018). In literacy, many students find it difficult to connect reading and writing lessons with their real-life experiences. Meanwhile, in numeracy, many students struggle to understand mathematical concepts such as basic operations, geometry, and algebra, which are often perceived as too abstract and disconnected from their real-world experiences.

This challenge drives the search for more engaging and effective learning methods. One of the solutions that has emerged in recent years is the use of technology in education (Grinshkun & Osipovskaya, 2020), one of which is Augmented Reality (AR). AR is a technology that combines elements of the real world with digital elements, creating an immersive experience that can interact with the real environment (Al-Ansi et al., 2023; Çetin, 2022). By using devices such as smartphones or tablets, students can directly interact with virtual objects displayed in the real world, enriching their learning experience (Bacca et al., 2014).

The use of AR in education not only changes how students learn but also how they interact with the subject matter. The results suggest that one of the most fundamental advantages of AR in education lies in its ability to support kinesthetic learning (Alzahrani, 2020). AR allows students to see and interact with information that previously existed only in text or two-dimensional images, making it more vivid and easier to understand (Ding, 2017). In literacy learning, AR can help students connect words with images or sounds, deepening their understanding of the texts they read. Meanwhile, in numeracy learning, AR can transform abstract mathematical concepts into more concrete visualizations, for example by displaying three-dimensional objects representing specific mathematical operations (İslim et al., 2024). Furthermore, research by Cao (2023) indicates that AR and VR technologies have strong potential as effective tools for visualizing mathematical concepts and models, which can significantly improve students' understanding.

One increasingly explored instructional approach is AR-based edu-tourism, which integrates learning activities with contextual exploration of environments relevant to students' everyday experiences. When combined with augmented reality technology, learning is no longer limited to textbooks or direct instruction but extends to interactive experiences that allow students to engage with digital content embedded in their physical or visual surroundings. Through AR-based edu-tourism, students can virtually explore places, objects, or representations related to lesson content and interact with three-dimensional models or informational overlays. In literacy learning, this approach enables students to engage with authentic texts in real or simulated environments, supported by AR-enhanced explanations and visual cues. In numeracy learning, students can explore mathematical concepts by observing and manipulating three-dimensional representations that support conceptual understanding (İslim et al., 2024; Koreňová & Gunčaga, 2018).

In this study, AR-based edu-tourism is conceptualized as a learning approach that integrates local tourism, cultural, or environmental contexts with augmented reality technology to create interactive and context-rich learning experiences (Dede, 2014; Radianti et al., 2020). Through AR, students engage with digital overlays such as three-dimensional objects, visual narratives, and interactive prompts embedded in representations of local sites, enabling them to explore literacy and numeracy content in authentic learning situations. Unlike conventional educational tourism, which primarily emphasizes experiential exposure through physical visits, AR-based edu-tourism facilitates active exploration, conceptual interaction, and collaborative learning through digitally augmented environments. It is also distinct from generic AR-based learning, as learning activities are deliberately anchored in place-based and locally meaningful contexts rather than decontextualized classroom materials.

The use of AR-based edu-tourism in this study is theoretically grounded in situated learning theory (Lave & Wenger, 1991), embodied learning (Wilson, 2002), and social constructivism (Vygotsky, 1978). Situated learning theory posits that knowledge is constructed more effectively when learning occurs within meaningful and authentic contexts, while embodied learning emphasizes the role of physical interaction and spatial experience in supporting cognitive processes. From a social constructivist perspective, shared AR artifacts function as mediating tools that stimulate peer discussion, explanation, and collaborative problem-solving. Together, these theoretical perspectives explain why AR-based edu-tourism is expected to influence students' learning behavior patterns. Based on these theoretical foundations, the affordances of AR-based edu-

tourism were operationalized into observable learning behavior patterns, including students' engagement in learning activities, peer collaboration and verbal interaction, and strategies for linking textual, visual, and numerical information during literacy and numeracy learning.

The AR-based Edu-tourism approach offers several advantages, including increased motivation and student engagement. Abdullah et al. (2022) highlight that augmented reality has attracted significant attention in educational research due to its ability to increase interactivity with learning content and to visualize scientific phenomena, thereby reducing cognitive load and enabling more personalized learning experiences. Learning experiences involving technology allow students to be in a highly interactive and immersive learning environment, both mentally and physically. This learning involves presence-based technology that immerses students into a virtual learning environment capable of delivering material through narratives or challenges (Beck et al., 2024). Additionally, AR enables students to learn in a more contextualized and practical manner, making the material taught feel closer to their everyday lives. This not only enhances their understanding of the material but also helps them develop critical thinking and problem-solving skills in real contexts.

Although the use of AR in education has much potential, there are still challenges in its implementation, particularly related to students' learning behavior patterns. Students may struggle to adapt to new technologies or may become too focused on technological elements at the expense of concentrating on the subject matter itself. Therefore, it is important to understand how AR affects students' learning behavior patterns in the context of literacy and numeracy and how this technology can be utilized to create optimal learning experiences (Cadavieco et al., 2018).

### ***Literacy and Numeracy Learning in Elementary Schools***

In the context of elementary education, literacy and numeracy learning play a crucial role in equipping students with the basic skills needed for everyday life and their academic development. Literacy and numeracy are two core skills that serve as the foundation for accessing and understanding various information and solving mathematical problems encountered in their environment. In this study, literacy and numeracy learning refers to two interrelated fields, each with distinct characteristics and methods (Wood, 2017).

### **Literacy Learning**

Literacy is not limited to the ability to read and write; it also encompasses understanding, analyzing, and

applying information found in various forms of text. According to Febriyanto, (2016) and Parmini et al. (2023), 21st-century literacy involves the ability to use various media and sources of information, whether written texts, images, or videos, often requiring critical thinking and problem-solving skills. Effective literacy requires skills in filtering relevant information, understanding its context, and being able to communicate that understanding clearly. Therefore, literacy learning in elementary schools aims not only to introduce students to reading and writing skills but also to help them develop critical thinking abilities, analyze information, and communicate effectively.

In this context, Augmented Reality (AR) can enhance literacy learning by presenting information visually and interactively, allowing students to explore texts in a more engaging and contextual manner. The use of AR in literacy learning enables students to engage in a more immersive learning experience by connecting texts with images or virtual objects that provide deeper explanations (Familoni & Onyebuchi, 2024; Masneri et al., 2022). AR can also improve students' comprehension and interpretation of texts by giving them opportunities to see how information can be applied in various real-world contexts (Grinshkun & Osipovskaya, 2020).

### ***Numeracy Learning***

Numeracy refers to the ability to understand and use mathematical concepts in everyday life. According to Iswara et al. (2022), numeracy is more than just counting; it also includes skills in solving mathematical problems, applying numerical concepts in various situations, and making decisions based on mathematical understanding. Numeracy is a vital skill for addressing challenges related to an increasingly complex world and can be found in many aspects of life, from personal financial management to planning and decision-making in broader contexts.

Effective numeracy learning must include an understanding of basic mathematical concepts such as addition, subtraction, multiplication, division, as well as problem-solving skills. Similar to literacy learning, technology can also enhance the quality of numeracy education. AR can help students understand abstract mathematical concepts in a more concrete and visual way. For example, AR can be used to display three-dimensional objects representing mathematical operations or allow students to interact with virtual objects that help them understand the relationship between numbers and mathematical concepts. AR can enhance students' understanding of mathematical concepts by enabling them to see and manipulate objects that they would not physically be able to see or touch in the real world (Ahmad, 2021).

AR-based numeracy learning gives students the opportunity to experience mathematical concepts directly and more enjoyably, which can subsequently increase their motivation and engagement. With a more immersive and contextual learning experience, students are expected to develop a better understanding of the material taught while feeling more confident in facing mathematical challenges in everyday life (Nafi'an, 2024).

The Ministry of Education and Culture has proposed several indicators of numeracy skills: (1) The ability to use various numbers and symbols related to basic mathematics to solve problems in various everyday contexts; (2) The ability to analyze information presented in various forms (graphs, tables, charts, diagrams); (3) The ability to interpret analysis results for predictions and decision-making; and (4) aspects of life (Muniri et al., 2023).

#### *Literacy and Numeracy Learning through AR Edu-tourism*

In this study, literacy and numeracy are studied integratively using AR-based Edu-tourism, which allows students to learn while exploring their environment and interacting with virtual objects related to the subject matter. AR-based Edu-tourism provides experiences that are not only instructional but also contextual and enjoyable, thereby enhancing student engagement. In this regard, literacy and numeracy learning involves not only teaching theories or concepts but also understanding gained through direct experiences and active exploration supported by AR elements that present deeper visualizations and interactions (Karakus et al., 2019).

Literacy and numeracy are fundamental competencies that support children's academic development and life skills in the twenty-first century. At the elementary school level, these competencies form the foundation for students' ability to understand information, solve problems, and participate meaningfully in social and learning contexts. However, national assessment data in Indonesia continue to indicate that a significant proportion of elementary students demonstrate low proficiency in reading comprehension and basic mathematical reasoning, highlighting persistent learning challenges in literacy and numeracy education.

To address these challenges, recent educational research has increasingly explored the use of digital technologies, particularly Augmented Reality (AR), as innovative learning media. AR enables the integration of virtual objects into real-world environments, allowing abstract concepts to be visualized in concrete and interactive forms. Previous studies have shown that AR can enhance students' motivation, engagement, and conceptual understanding across

various subjects, including literacy and numeracy. Nevertheless, much of this research has focused primarily on learning outcomes or performance gains, with limited attention to students' learning processes and behaviors during AR-supported activities.

Despite the burgeoning literature on Augmented Reality (AR) in education, a critical synthesis of recent international studies reveals a disproportionate focus on quantitative academic achievement and system usability (AlGerafi et al., 2023; Alzahrani, 2020). While scholars have extensively documented the 'what' (learning outcomes), there is a profound scarcity of research addressing the 'how' specifically the micro-longitudinal behavioral patterns that manifest when AR is situated within place-based edu-tourism (Beck et al., 2024; Cadavieco et al., 2018). Current global trends in immersive learning often overlook the socio-pedagogical friction, such as peer-scaffolding and joint attention, that occurs under resource-constrained environments (Abdelmonem & Karawia, 2024).

Furthermore, existing AR-based learning studies are often conducted in decontextualized classroom settings, with learning content detached from students' local environments and lived experiences. In contrast, edu-tourism based learning, which utilizes local cultural, environmental, or tourism resources as learning contexts, has the potential to support situated and embodied learning by connecting academic content with authentic and meaningful experiences (Lave & Wenger, 1991; Wilson, 2002). Despite this potential, empirical research that integrates AR with edu-tourism contexts at the elementary school level particularly for literacy and numeracy learning remains scarce.

Consequently, few studies have qualitatively examined learning behavior patterns such as students' engagement, collaboration, verbal interaction, and meaning-making strategies when AR is implemented in these authentic settings. As a result, there is still insufficient empirical evidence explaining how and why AR-based edu-tourism influences elementary students' learning behaviors beyond measurable achievement outcomes.

To address these multifaceted research gaps, the present study investigates elementary students' learning behavior patterns during AR-based edu-tourism activities designed to support literacy and numeracy learning in Bangka Belitung, Indonesia. By employing a qualitative case study approach, this study aims to provide an in-depth understanding of students' engagement, interaction, and conceptual meaning-making processes within an authentic, context-rich learning environment. Specifically, this research seeks to map these behavioral dynamics to theoretical lenses of cognitive load, embodied learning, and social constructivism, offering a

nuanced perspective on how AR reconfigures the learning trajectory in primary education.

Accordingly, this study aims to examine how elementary students demonstrate learning behavior patterns, including engagement, collaboration, and meaning-making, during AR-based edu-tourism activities for literacy and numeracy learning. Based on the research gaps identified above, this study is guided by the following research questions:

1. How do elementary students demonstrate learning behavior patterns during AR-based edu-tourism activities for literacy and numeracy learning?
2. What forms of engagement, collaboration, and meaning-making emerge when students interact with AR edu-tourism content?
3. What challenges do students and teachers encounter during the implementation of AR-based edu-tourism learning?

In this study, learning behavior patterns refer to observable and recurring student behaviors during learning activities, including engagement, peer collaboration, verbal interaction, and strategies used to link textual and visual information when interacting with AR media. Literacy is defined as students' ability to interpret and communicate meaning from written and multimodal texts, while numeracy refers to students' capacity to apply mathematical concepts and reasoning in contextualized situations. AR edu-tourism is conceptualized as the use of augmented reality technology to present local tourism and environmental content as interactive learning resources that support situated and embodied learning.

## Method

### Research Design

This study employs a qualitative research method with a case study design to analyze the learning behavior patterns of elementary school students in literacy and numeracy learning through Augmented Reality (AR) Edu-tourism. This approach was chosen because it allows the researcher to explore students' experiences, perspectives, and interactions in a more natural and contextual setting. The researcher observes, documents, and analyzes students' learning behavior patterns during the learning process involving AR-based Edu-tourism for literacy and numeracy content (Abdelmonem & Karawia, 2024; Daniel, 2016; Morgan et al., 2017).

### Participants and Research Setting

The participants in this study consisted of 53 students (28 males and 25 females) from the fourth and fifth-grade cohorts of a public elementary school in Bangka

Belitung, Indonesia. This specific age group (10–11 years) was selected through a purposive sampling strategy, as it represents a 'digital native' transition phase where students possess sufficient motor skills for mobile AR manipulation but are still developing abstract reasoning in literacy and numeracy. The school was selected as the research site due to its strategic implementation of AR-based learning activities and its role as a representative micro-context of the region, characterized by moderate digital access and a curriculum emphasis on local cultural heritage.

The inclusion of students from both grade levels aimed to capture variations in learning behavior patterns across upper elementary classrooms. In addition, two classroom teachers (one fourth-grade and one fifth-grade teacher) were involved as key informants to provide pedagogical context during the observation and interview processes.

Regarding the adequacy of the sample, N=53 is significantly larger than the typical threshold for qualitative case studies, which often prioritize a smaller number of units for depth. However, this sample size was determined by the principle of data saturation through group-level dynamics. By dividing students into 13 small groups, the researchers were able to observe repeated behavioral patterns across multiple units, thereby ensuring the internal validity of the findings. The adequacy is further reinforced by data triangulation, where observational data were cross-validated with semi-structured interviews from 10 selected students and the 2 lead teachers, providing a 360-degree view of the learning behavior patterns that a smaller sample might not capture.

## Data Collection Techniques

### Data were collected through several methods:

**Participatory Observation:** The researcher directly observes the learning process using AR. Observations are conducted to identify student behaviors, such as levels of engagement, interactions with AR media, and their understanding of the learning material.

**Semi-Structured Interviews:** Interviews were conducted with students and teachers to gain deeper insights into students' learning experiences, responses to the use of AR, and changes in their learning behavior patterns.

**Documentation:** The researcher collects documentation of student work, field notes during observations, and video recordings capturing student interactions with AR technology.

To ensure the validity and reliability of the observations, students' learning behavior patterns were operationalized into specific, observable

indicators. This operationalization served as the primary observation protocol to categorize field data into four dimensions: Engagement, Collaboration, Meaning-Making, and Technical Challenges. Table 1 presents the codebook used, including the indicators and data exemplars that guided the evidence-gathering process.

**Table 1.**  
*Codebook for Operationalizing Students' Learning Behavior Patterns in AR Environments*

Dimension	Observable Indicators	Exemplars (Data Excerpts)
Engagement	Sustained attention to AR content, active manipulation of digital objects, and verbal expressions of interest.	"I like learning this way because I can see the objects directly, not just imagine them. I want to try all the AR features" (S12).
Collaboration	Peer-scaffolding, device sharing, joint problem-solving.	"We took turns using the tablet. If my friend didn't understand, I explained it to him." (S19).
Meaning-making	Connecting digital visualizations with literacy/numeracy concepts and real-world contexts.	"Oh, I see! The 1:100 scale in this AR model means the real lighthouse is much taller than our school building!" (S22)
Technical Challenges	Experiencing 'technological friction' or requiring assistance with device operation.	"Sometimes the AR didn't appear, and I didn't know what to do." (S14)

## Procedure

### Research Preparation

**Selection of Location and Participants:** This research was conducted at SD STKIP Muhammadiyah Bangka Belitung based on specific criteria, such as having access to and infrastructure supporting AR technology, using AR in their curriculum, particularly in literacy and numeracy learning, and allowing the researcher to conduct observations and interviews.

**Ethical Approval:** Before commencing the research, the researcher sought permission from the school authorities for participation in the study. All data obtained were kept confidential, and participants' identities were protected to avoid potential bias.

### Learning Intervention: AR-based Edu-tourism Activities

To ensure intervention fidelity and allow for replication, the AR-based edu-tourism learning activities were implemented with a structured protocol. The key components of the intervention are detailed as follows:

1. **Intervention Dose:** The study consisted of four learning sessions, with each session lasting 70 minutes (totaling 280 minutes of exposure), integrated into regular literacy and numeracy lessons.

2. **Task Sequence:** Each session followed a standardized four-stage sequence:
  - a. **Introduction (10 mins):** Teacher orientation to the learning objectives.
  - b. **Guided Exploration (30 mins):** Direct interaction with AR-based edu-tourism content.
  - c. **Collaborative Task (20 mins):** Small-group discussion and numeracy/literacy problem-solving.
  - d. **Consolidation (10 mins):** Reflection and sharing of findings.
3. **AR Assets & Platform:** Activities were developed using the Assemblr Edu platform. Assets featured 3D models and informational overlays of local heritage sites (e.g., Jembatan Emas, Tanjung Kalian Port, and the Indonesian Tin Museum).
4. **Technical Specifications:** The learning activities were accessed via Android-based tablets and smartphones (Minimum specs: 3GB RAM, Android OS 9.0) using the school's wireless network.
5. **Grouping & Collaboration:** Students worked in heterogeneous groups of 3–4. This setup promoted device sharing, turn-taking, and peer discussion.
6. **Teacher Orchestration:** The teacher acted as a facilitator using pedagogical prompts (e.g., "Which geometric shapes stabilize this bridge?") rather than direct instruction, providing support for both content understanding and technical friction.

### Development of Research Instruments

Research instruments were developed to support data collection. These instruments include:

**Observation Guide:** This contains aspects observed in student learning behavior, such as levels of engagement, interactions with AR technology, and understanding of literacy and numeracy concepts.

**Interview Guidelines:** These consist of open-ended questions for interviews with students and teachers. The interviews explore their experiences and perceptions regarding the use of AR in learning.

**Documentation Sheets:** These contain formats for recording student work results, photos, and relevant interaction videos.

### Data Collection Phase

**Learning Observations:** The researcher actively participates in the learning process while observing during classroom activities involving AR Edu-tourism. This observation aims to identify students' behavior patterns, levels of engagement, and their reactions

to using AR in literacy and numeracy learning. Observations were conducted over four learning sessions.

### Interviews

Interviews were conducted after the learning sessions to delve into the experiences of students and teachers regarding the use of AR in education.

- Students: Interviews with students asked about their experiences using AR, how AR helped them understand the material, and how they felt about their engagement in learning.
- Teachers: Interviews with teachers focused on how they used AR to teach literacy and numeracy, challenges faced, and observed changes in students' learning behavior patterns.

### Documentation

The researcher collected various student work results, including written assignments, tasks completed with the help of AR, and photos or videos documenting student interactions with AR media. This documentation supports findings from observations and interviews.

### Data Analysis

The collected data were analyzed using thematic analysis. The steps involved in data analysis include:

- Coding: Data from interviews, observations, and documentation were scanned to identify themes or categories relevant to students' learning behaviors, such as levels of engagement, understanding of literacy and numeracy concepts, and interactions with AR.
- Theme Grouping: Themes emerging from coding were grouped to address the research focus related to students' learning behavior patterns.
- Interpretation: The researcher interpreted data within the context of using AR for literacy and numeracy education and how AR played a role in enhancing student engagement and understanding.

### Data Validity

To ensure the validity and credibility of research findings, the researcher employed triangulation techniques by comparing data from various sources (observations, interviews, and documentation) and seeking feedback from participants on initial findings through member checking. Additionally, peer debriefing was conducted by discussing the research process with colleagues to ensure objectivity and accuracy of findings.

### Findings

This section presents the findings of the study based on classroom observations, interviews with students and teachers, and documentation of AR-based edu-tourism learning activities. The findings are organized according to recurring learning behavior patterns that emerged during data analysis, namely student engagement, collaboration, meaning-making, and implementation challenges.

#### Student Engagement during AR-based Edu-tourism

Consistently across all observed sessions, classroom observations indicated high levels of student engagement during AR-based edu-tourism activities, as reflected in sustained attention, active manipulation of AR content, and voluntary participation in learning tasks. Observations revealed that this high engagement was uniform across both fourth and fifth-grade groups, although the intensity of interaction varied; younger students tended to be more physically expressive, while older students displayed more sustained focus. Students appeared focused and motivated while interacting with AR materials integrated into literacy and numeracy lessons.

During AR-supported literacy activities, students studied a text about Tanjung Kalian Beach, Muntok, while simultaneously viewing three-dimensional representations of the beach and its lighthouse on their device screens. Through the Assemblr Edu application, students were able to virtually "visit" Tanjung Kalian Beach, which enabled them to engage with the text in a more contextual and visually supported manner. Figure 1 illustrates students exploring Tanjung Kalian Beach through AR-based edu-tourism activities.

Verbatim data further illustrate students' engagement with AR-based learning. A fifth-grade student expressed enthusiasm for the interactive features:

*"I like learning this way because I can see the objects directly, not just imagine them. I want to try all the AR features." (S12, Grade 5, ENG)*

Similarly, a fourth-grade student described increased focus during numeracy learning:

*"Usually I get bored when learning math, but when the AR appeared, I kept focusing because it felt like playing and learning at the same time." (S7, Grade 4, ENG)*

Despite generally high engagement, variations were observed depending on technical stability and device familiarity. A teacher noted that technical

constraints occasionally disrupted the focus of groups that experienced lag or those less accustomed to the interface:

*"Some students were very engaged, but a few lost focus when the device was slow or when they had to wait their turn." (T1, ENG)*

**Figure 1.**

*Students exploring Tanjung Kalian Beach through Augmented Reality Edu-tourism*



#### **Collaboration Patterns in AR-supported Learning**

Classroom observations indicated that AR-based edu-tourism activities consistently fostered collaborative learning behaviors among students. This pattern was largely necessitated by the device-to-student ratio (approximately 1:4), which naturally encouraged shared device use, peer explanation, and joint problem-solving. During AR-supported literacy tasks, students frequently negotiated turns when using the devices and supported one another in understanding the learning content.

**Figure 2.**

*Students collaborating to find out about tourist objects*



As illustrated in a group activity exploring historical stories from the Indonesian Tin Museum, students worked collaboratively to identify key information about the museum and its history. Using AR, they virtually examined three-dimensional representations of historical artifacts, which encouraged discussion, information sharing, and collective problem-solving within their groups. Figure 2 illustrates students

collaborating to explore tourism-related objects through AR-based edu-tourism activities. Figure 2. Students collaborating to find out about tourist objects.

Verbatim data further demonstrate these collaborative patterns. A fourth-grade student stated:

*"We took turns using the tablet. If my friend didn't understand, I explained it to him." (S19, Grade 4, COL)*

Similarly, a fifth-grade student explained:

*"We discussed the answer together because the AR object showed many details." (S3, Grade 5, COL)*

Despite these positive interactions, variations in participation equality were observed. In some groups where roles were not clearly defined, one student tended to dominate the device, while others participated more passively unless guided by the teacher:

*"Some students dominated the device, so others participated more as observers unless guided by the teacher." (T2, COL)*

#### **Conceptual Linkage and Meaning-Making**

Students demonstrated meaning-making strategies by connecting AR visualizations with textual and numerical concepts. AR visuals supported students in interpreting abstract content and relating it to real-world contexts.

**Figure 3.**

*Students exploring various flat shapes at observed tourist sites.*



In numeracy activities, for example, observations showed students applying geometric concepts to local tourism contexts. As shown in Figure 3, students actively identified characteristics of flat shapes such as triangles and rectangles embedded in the architecture of Jembatan Emas (Golden Bridge) and Tanjung Kalian Port. Instead of memorizing definitions, they pointed out the physical angles and sides of the

AR structures to solve problems.

*"The numbers made sense after I saw how they worked in the AR model." (S9, Grade 5, MM)*

Teachers noted that AR supported conceptual understanding, although scaffolding remained necessary.

*"Oh, I see! The 1:100 scale in this AR model means the real lighthouse is much taller than our school building!" (S7, Grade 4, MM)*

**Challenges in Implementing AR-based Edu-tourism**

Although AR-based edu-tourism positively influenced learning behaviors, the implementation process was not without obstacles. Classroom observations and interview data highlighted several challenges, primarily related to technical constraints and variations in students' digital proficiency, which occasionally disrupted the flow of learning.

**Technical Constraints** Technical issues were the most frequently observed challenge. This included internet latency (lag), particularly caused by high bandwidth requirements for rendering complex 3D objects, difficulties in scanning AR markers due to lighting conditions, and device responsiveness. When these technical glitches occurred, some students experienced a temporary loss of focus or frustration.

*"Sometimes the AR didn't appear, and I didn't know what to do." (S14, Grade 4, CH)*

*"I had to wait because only one phone was working well." (S21, Grade 5, CH)*

These technical interruptions often required the teacher to shift from a facilitator role to a technical support role, momentarily pausing the instructional momentum to resolve device issues. Digital Skill Disparities and Variation Another significant challenge was the gap in digital skills among students. While some students intuitively navigated the AR interface, others required constant guidance to perform basic gestures like rotating or zooming in on the 3D objects for instance, when exploring the detailed architecture of Jembatan Emas.

The frequency of these disruptions varied significantly by group composition. Observations showed that groups containing at least one 'tech-savvy' student resolved navigation issues independently, whereas groups with uniformly low digital familiarity experienced prolonged pauses. This disparity affected group dynamics, as students with lower digital confidence tended to become passive observers.

*"Differences in digital skills meant some students needed constant assistance, which slowed down group work." (T2, CH)*

**Positive Behavioral Adaptation** However, it is worth noting that these challenges often triggered peer-scaffolding behaviors, where more digitally skilled students assisted their peers. This dynamic inadvertently fostered a deeper level of collaboration and collective problem-solving.

**Frequency and Variations in Learning Behavior Patterns**

The study identified significant variations in how students interacted with the AR content, with behaviors appearing at different frequencies across the four sessions. Engagement was the most consistent behavior, observed in over 85% of students throughout all sessions. However, the nature of this interaction was primarily mediated by prior digital fluency. While students with high smartphone familiarity navigated the AR interface with minimal hesitation, students with lower digital exposure (approximately 30% of the participants) initially exhibited 'technological friction' during the first two sessions, requiring more direct scaffolding from teachers or tech-savvy peers.

Furthermore, variations were observed in social dynamics across the groups. In the majority of groups (10 out of 13 groups), a 'distributed leadership' pattern emerged where students successfully engaged in turn-taking and peer-scaffolding. However, in three specific groups, a 'dominant driver' behavior was observed, where one student controlled the device for the duration of the task while others remained as passive observers. These frequencies and variations highlight that the impact of AR edu-tourism is not monolithic but is significantly influenced by the learner's technical readiness and the social structure of the peer group.

To synthesize the observational and interview data presented in the previous sections, Table 2 provides a comprehensive summary of the key behavioral indicators and representative responses across the four identified themes.

**Table 2.** Summary of Observational Findings on Students' Learning Behaviors in Literacy and Numeracy through AR Edu-tourism

Observed Aspect	Behavioral Indicators	Observation Notes
Engagement	Enthusiasm in following instructions, persistence in using AR applications	Most students immediately attempted to scan AR objects without being prompted; some expressed excitement when the 3D objects appeared on their screens.
Collaboration/ social interaction	Peer discussion, collaboration within groups	While observing the Golden Bridge in AR, groups of 4-5 students discussed and compared triangular structures on the pillars. Some students helped peers who struggled with operating the application.

Observed Aspect	Behavioral Indicators	Observation Notes
Content Understanding (meaning-making)	Ability to link AR visuals with literacy/ numeracy concepts	In geometry tasks, students successfully identified triangles and rectangles in the bridge structure. During the Tanjung Kalian text activity, students connected the 3D visualization of the lighthouse with the written description.
Motivation and Confidence	Willingness to ask/ answer questions, initiative to explore	Several students confidently demonstrated how to rotate 3D objects for their peers. Others initiated questions such as, "Why does the bridge use triangles, Miss?"
Technical Challenges	Difficulties in navigating the app, device limitations	Six students struggled to focus their cameras to display AR objects. Teachers provided direct assistance to prevent disruption to the learning flow.

### Discussion

The findings of this study demonstrate that AR-based edu-tourism significantly alters student learning behavior patterns by transforming abstract literacy and numeracy tasks into interactive, multi-sensory experiences. This discussion maps these observed behaviors to three primary theoretical mechanisms: the optimization of cognitive load, the facilitation of embodied and situated learning, and the reinforcement of social constructivism through peer interaction.

The high levels of engagement and improved meaning-making observed in Sections Engagement and Conceptual Linkage and Meaning-Making can be explained through Cognitive Load Theory. Traditional literacy and numeracy instruction often impose a high extraneous cognitive load, as students must use significant mental effort to visualize abstract concepts, such as the scale of historical landmarks or geometric properties (Ahmad, 2021; AlGerafi et al., 2023).

In this study, AR acted as a cognitive scaffold. By providing three-dimensional visualizations of the Tanjung Kalian lighthouse and Jembatan Emas, the technology reduced the mental "imagination gap" for students. This allows working memory to focus on higher-order tasks like analysis and problem-solving (Abdullah et al., 2022; Alzahrani, 2020). The enthusiasm expressed by students (e.g., S12 and S7) confirms that when the visual "concreteness" of a lesson is increased, satisfaction and focus naturally follow, echoing the systematic benefits of AR in primary education (Basumatary & Maity, 2023; Çetin, 2022).

The physical behaviors observed such as students

rotating their devices and moving their bodies to explore AR markers highlight the role of Embodied Cognition (Wilson, 2002). Unlike traditional desktop learning, AR edu-tourism requires physical interaction, which grounds abstract numeracy concepts in a concrete, place-based context (Cadavieco et al., 2018). When students identified flat shapes on the architecture of Jembatan Emas, they were not merely observing; they were engaging in situated learning (Lave & Wenger, 1991).

This "place-based" approach is particularly vital in the Indonesian context, where there is a recognized gap between theoretical literacy and its practical application in real-world environments (Muliantara & Suarni, 2022; Rakhmawati & Mustadi, 2022). By "visiting" local tourism sites through AR, students moved beyond rote memorization toward authentic meaning-making, a process essential for developing 21st-century competencies (Parmini et al., 2023; Febriyanto, 2016).

The collaborative patterns identified in Section Collaboration Patterns in AR-supported Learning, characterized by peer explanation and joint problem-solving, strongly resonate with Social Constructivism (Vygotsky, 1978). Interestingly, the technical challenges and limited device access (1:4 ratio) identified in this study did not solely hinder learning; they acted as catalysts for social interaction.

These constraints forced students into a "shared attention" state, where more digitally proficient students acted as the "More Knowledgeable Other" (MKO). This created a Zone of Proximal Development where technical navigation and conceptual understanding were co-constructed (Abdelmonem & Karawia, 2024; Masneri et al., 2022). This peer-scaffolding behavior proves that AR-based learning is inherently social, promoting communication skills that are foundational to modern literacy (Mudzanatun, 2017; Wood, 2017).

While AR provides significant benefits, the variation in digital proficiency and infrastructure remains a challenge. For AR-based edu-tourism to effectively address the numeracy literacy gap identified by the Indonesian Ministry of Education (Badan Penelitian dan Pengembangan, 2019), teachers must balance their roles as facilitators of technology and mentors of conceptual understanding (Iswara et al., 2022; Nafi'an, 2024). The transition to "Education 4.0" in Indonesia requires not just the presence of AR tools, but a pedagogical shift toward student-centered, collaborative environments that mitigate digital disparities (Al-Ansi et al., 2023; Grinshkun & Osipovskaya, 2020).

This interaction demonstrates that the teacher's role remains central in an AR-supported environment.

The observed variations in student behavior highlight the role of Digital Readiness and Social Mediation in AR environments. The 'technological friction' experienced by low-fluency students aligns with the Cognitive Load Theory, where limited prior technical knowledge increases the intrinsic load, momentarily diverting focus from the pedagogical content. Conversely, the transition from 'dominant driver' to 'distributed leadership' in some groups suggests that AR-based edu-tourism can serve as a catalyst for Social Constructivism, provided that teacher scaffolding is present to balance group dynamics. This study thus suggests that pedagogical design must account for these individual differences to optimize learning outcomes.

### Conclusion

This study concludes that AR-based edu-tourism serves as a powerful bridge between abstract academic concepts and real-world contexts in primary literacy and numeracy. The findings highlight a significant shift in student learning behavior moving from passive reception to active, embodied exploration. By reducing extraneous cognitive load through 3D visualizations and fostering social constructivism through shared digital artifacts, AR technology enables students to engage with local tourism heritage in a way that is both intellectually stimulating and emotionally engaging.

While technical constraints and digital skill disparities remain as challenges, they inadvertently foster peer-scaffolding and collaborative problem-solving. Ultimately, the integration of AR in edu-tourism does not just modernize the classroom; it recontextualizes learning as a situated, social, and physically active process.

### Pedagogical Implications

Based on the findings, several pedagogical implications for educators and policy-makers are proposed:

1. Strategic Grouping for Peer Scaffolding: Since digital proficiency varies, teachers should intentionally form heterogeneous groups where "tech-savvy" students can assist their peers. This minimizes the burden on the teacher for technical support and maximizes collaborative learning opportunities.
2. Contextual Content Design: Educational content should prioritize local landmarks and tourism sites. Grounding lessons in familiar environments (situated learning) significantly reduces the cognitive effort required to process new literacy and numeracy information.
3. Balanced Teacher Roles: Teachers must be prepared to oscillate between being a pedagogical facilitator and technical troubleshooter. Training programs should focus not just on how to use AR applications, but on how to integrate them into inquiry-based lesson plans.
4. Addressing the Digital Divide: For AR-based edu-tourism to be inclusive, schools must address infrastructure readiness, particularly device compatibility and high-bandwidth internet access. Hybrid models where AR is used in turns or through shared screens can be a temporary solution to resource scarcity.

### Limitations and Future Research

While this study provides valuable insights into student behavior in AR-based edu-tourism, it acknowledges several limitations that should be considered.

1. Sample and Generalizability: First, the scope was limited to a single elementary school in Bangka Belitung with a relatively small sample size (N=53). Thus, the findings may not be fully generalizable to diverse geographical or socio-economic contexts across Indonesia.
2. Novelty Effect: Second, as the AR intervention was conducted over a specific period, the high levels of engagement observed might partially stem from a "novelty effect," where students are excited by the newness of the technology rather than the pedagogical content itself.
3. Qualitative Boundaries: Finally, this research relied heavily on qualitative observations and interviews. While rich in detail, it does not quantify the direct impact of these behaviors on measurable learning outcomes (e.g., standardized test scores).
4. To address these limitations, we propose the following follow-up research:
5. Mixed-Methods Approach: Future studies should employ a mixed-methods design, combining qualitative behavioral analysis with quantitative pre-test and post-test measures to statistically correlate specific AR interactions with literacy and numeracy score improvements.
6. Comparative Studies: We recommend comparative research to evaluate the effectiveness of AR edu-tourism against traditional field trips or non-AR digital learning. Additionally, comparing different grade levels or urban versus rural school settings would provide a more nuanced understanding of how digital proficiency variations influence learning trajectories.
7. Longitudinal Tracking: Longer-term longitudinal studies are needed to determine if student engagement and collaborative behaviors persist after the initial novelty of AR technology has diminished.

## Acknowledgements

The authors would like to express their sincere gratitude to the Ministry of Education, Research, and Technology of the Republic of Indonesia (Kemdiktisaintek) for funding this research through the 2024 research grant program. The authors also extend their appreciation to the Principal of SD STKIP Muhammadiyah Bangka Belitung for the valuable support and collaboration during the research process.

## Ethical Statement

This study has been conducted in accordance with ethical research standards. All participants were informed about the purpose of the study, and consent was obtained prior to data collection. Any images used in this study have been published with appropriate permission.

## AI Disclosure Statement

The authors used AI-based tools to assist with language editing and paraphrasing to improve the clarity and readability of the manuscript. All ideas, data analysis, and interpretations presented in this study are the original work of the authors.

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