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Enhancing self-efficacy, attitudes, and motivation via AR in heritage learning

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Abstract

This study explores the pedagogical impact of an Augmented Reality (AR) application, "Time Traveler," designed to enhance elementary school students' engagement with Tainan's Japanese colonial architectural culture. The AR system, leveraging interactive 3D model rendering and context-aware information delivery, aimed to improve students' self-efficacy, learning attitudes, and motivation. A quasi-experimental design with pre/post-tests and Analysis of Covariance (ANCOVA) compared an experimental group using the AR instruction against a control group receiving traditional instruction. Results demonstrated that the AR group achieved significantly greater improvements in learning outcomes, motivation, attitudes, and self-efficacy. Qualitative interviews corroborated these findings, highlighting increased student satisfaction, deeper understanding, and enhanced motivation attributed to the interactive and immersive AR experience.

Keywords: augmented reality, historical architecture, cultural heritage education, self-efficacy, learning attitude, learning motivation, learning outcomes, educational technology, interactive learning, virtual-real integration, elementary school students

Introduction

Tainan City, a significant historical and cultural hub in Taiwan, possesses a rich heritage of architectural sites dating back to the Japanese colonial period. However, with the passage of time, these valuable cultural assets face the risk of being forgotten and overlooked. Traditional approaches to teaching history and culture, which predominantly rely on field trips and classroom lectures, encounter numerous challenges. For instance, field trips demand substantial time and resources, imposing considerable burdens on both educators and students in terms of scheduling and finances (Saidin et al., 2015). Moreover, conventional teaching methods often tend to be unidirectional, limiting effective student participation and resulting in superficial learning with constrained educational outcomes

(Saidin et al., 2015). Particularly in history and cultural education, students' understanding of historical knowledge can remain shallow, failing to stimulate their interest and motivation for learning (Yuen et al., 2011).

The integration of Augmented Reality (AR) technology, which facilitates virtual-real integration (the merging of virtual elements with the real world), for more adaptive and responsive experiences, offers a pathway to transcend the limitations of traditional pedagogy. By merging virtual elements with the real world, AR can enable students to experience historical scenes virtually, thereby enhancing immersion and increasing the enjoyment and engagement of the learning process (Saidin et al., 2015). AR technology is now widely applied in various fields, including social media, gaming, and education, providing interactive learning experiences that help maintain student focus (Hwang & Chang, 2016). Research indicates that AR is particularly well-suited for history education. For example, studies by Garzón (2021) and Kobayashi et al. (2025) have shown that AR can concretize abstract historical knowledge, aiding students in better understanding and mastering complex content.

Considering the current challenges in history and culture education and the capabilities of AR technology, this study aims to explore the specific impact of using AR in teaching historical architectural culture on students' self-efficacy, learning attitudes, and learning motivation. Self-efficacy refers to students' confidence in their ability to complete learning tasks. The immersive and interactive nature of AR-based learning can provide students with a greater sense of control, potentially enhancing their self-efficacy (Garzón, 2021). Learning attitude and motivation are core factors influencing learning outcomes. Studies suggest that AR can stimulate students' learning interest through interaction and enjoyment, fostering a positive attitude towards the subject matter (Kobayashi et al., 2025). Therefore, this research will employ experimental teaching and questionnaire surveys to analyze students' performance and feedback in an AR-integrated learning environment. The goal is to understand the role of AR technology as an educational tool in history teaching and to investigate its effects on students' self-efficacy, learning attitudes, and learning motivation.

This study aims to investigate the impact of integrating AR technology into the teaching of Tainan's architectural culture from the Japanese colonial period on students' self-efficacy, learning attitudes, and learning motivation.

The research questions addressed are as follows:

1. Does the integration of AR into teaching the architectural heritage of the Japanese colonial period enhance students' learning attitudes?
2. Does the integration of AR into teaching the architectural heritage of the Japanese colonial period enhance students' learning motivation?

3. Does the integration of AR into teaching the architectural heritage of the Japanese colonial period enhance students' self-efficacy?
4. Does the integration of AR into teaching the architectural heritage of the Japanese colonial period improve learning outcomes?

In the rest of the manuscript, we define "cultural understanding" for fifth-grade students not as the mastery of a comprehensive body of historical facts, but rather as the development of an initial awareness and appreciation for the cultural and historical significance of their local heritage. This is in line with the work of Schulz (2007), who emphasizes that the goal of cultural teaching in the early stages is to foster "cross-cultural understanding and intercultural competence" rather than encyclopedic knowledge. For fifth graders, this entails:

1. Recognizing Key Historical Periods and Styles: The ability to identify the Japanese colonial period as a distinct era in Tainan's history and to recognize the characteristic architectural styles of that period.
2. Understanding the Function of Historical Buildings: The ability to explain the original purpose and social function of the historical buildings (e.g., government offices, schools, department stores).
3. Developing a Sense of Connection to the Past: An emerging awareness of how the past has shaped their present environment and a sense of personal connection to the historical narratives of their city.

We define "historical thinking" for this age group as the foundational skills of historical inquiry, which include:

1. Asking Historical Questions: The ability to formulate simple questions about the past based on observations of the historical sites (e.g., "Why was this building built here?" "What was it like to live here during that time?").
2. Using Evidence: The ability to use visual information from the AR application and the physical site as evidence to answer historical questions.
3. Distinguishing Past from Present: The ability to compare and contrast the historical appearance and function of the buildings with their present-day form and use.

Literature Review

Augmented Reality

Augmented Reality (AR) integrates virtual information with the real world, leveraging technologies like image recognition and real-time interaction (Billinghurst et al., 2015). Key definitions include Milgram and Kishino's (1994) Reality-Virtuality Continuum, placing AR near reality within a Mixed Reality (MR) spectrum, and Azuma's (1997) three core characteristics: the combination of real and virtual objects, real-time interactivity, and

3D registration of virtual objects in the real world. AR's educational potential in areas such as intelligent object recognition, dynamic scene understanding, and adaptive content generation lies in creating personalized and immersive experiences that can enhance learning motivation and efficiency (Saidin et al., 2015).

AR technology is broadly categorized into marker-based and markerless AR. Marker-based AR relies on specific target objects, such as printed cards, QR codes, specific items, or images, for recognition. The use of markers ensures stability and reduces system errors. When a user points a device's camera at these markers, the system recognizes them and overlays virtual information onto the physical objects. The advantage of this technology lies in its relatively simple and precise development process, enabling the system to effectively identify targets and display virtual content accurately. However, marker-based AR has limitations. Firstly, markers must be sufficiently distinct for the system to achieve accurate recognition. If a marker is damaged or obscured, the system may fail to track it.

Markerless AR does not depend on specific physical targets for recognition. Instead, it analyzes features of the surrounding environment, such as color, shape, or depth information, through the camera to identify the scene and overlay virtual elements. The main advantage of markerless AR is its lower environmental dependency, making it suitable for a broader range of scenarios without the need to prepare specific markers, thus offering greater freedom. However, the primary challenges of markerless AR include higher development complexity and susceptibility to environmental changes, such as lighting conditions and scene complexity. Furthermore, development costs are relatively higher compared to marker-based techniques due to the increased resources required for environmental analysis.

The Time Traveler application developed in this research employs a hybrid approach, utilizing both markerless and marker-based AR. It uses markerless 3D object recognition to allow students to interact with physical models of the heritage sites, promoting hands-on exploration. Simultaneously, it uses marker-based recognition for story capsules (image markers) to deliver specific narrative content. This hybrid design was chosen to leverage the strengths of both technologies, providing both stability for content delivery and freedom for physical interaction, which aligns with constructivist learning theories where learners actively construct knowledge through interaction with their environment.

Application of Augmented Reality in Education

AR technology in education is increasingly recognized for enhancing student motivation and cognitive performance. It allows learners to interact with virtual objects in real scenes, making learning engaging, especially for complex concepts like geometry (Kaufmann & Schmalstieg, 2003), chemistry (Cai, Wang, & Chiang, 2014), and music (Guclu et al., 2021). AR can reduce cognitive load, deepen comprehension through interaction, and improve learning attitudes, particularly for abstract topics (Küçük et al., 2014; Cai et al., 2014). It fosters active exploration and is becoming a vital educational tool.

Historical Architectural Heritage

Historical architectural heritage is a vital cultural legacy, embodying a place's historical, social, and cultural memory, crucial for identity, education, and local development (Tweed & Sutherland, 2007). It plays a key role in forming local identity, connecting communities to their past (Rodwell, 2007). Economically, heritage sites drive cultural tourism and can be repurposed for modern societal functions (Harrison, 2013). As Lowenthal (1998) emphasized, these sites offer tangible connections to history, allowing experiential learning and providing valuable research data.

The Japanese colonial period (1895-1945) profoundly influenced Taiwan's urban development and architectural styles, particularly in Tainan, a major southern city that retains many representative buildings from this era. These structures not only bear witness to the historical process of colonial rule but are also an integral part of Tainan's cultural fabric. Architectural styles of the Japanese colonial period blended traditional Japanese construction techniques with Western modern architectural concepts, which were implemented in Taiwan. In Tainan, representative heritage buildings include the Tainan Weather Observatory and the National Museum of Taiwan Literature, among others. They reflect the social structures and cultural symbolism of the colonial era, showcasing a fusion of Japanese and Western architectural styles in their design.

Furthermore, the architecture of the Japanese colonial period has had a lasting impact on modern Tainan's urban development and heritage preservation policies. These buildings are not only testaments to the past but also influence Tainan's contemporary urban planning and cultural asset protection policies. For instance, many historical districts and heritage buildings in modern Tainan, after restoration and reuse, have become important resources for contemporary cultural education and tourism. As Chu and Lin (2001) noted in their research, public buildings from the Japanese colonial period were not only functional but also carried symbols of order under colonial rule, reflecting how Japanese colonial administration in Taiwan reinforced its influence through architectural space. Lin (2016) also mentioned how Japanese colonial policies influenced Taiwan's urban development through modern construction, with the architectural planning of the Japanese era in Tainan's historical streets becoming an asset for modern urban culture.

From a cultural and social functional perspective, buildings from the Japanese colonial period reflected the societal needs and power structures of the time. These buildings included not only government and religious sites but also public facilities such as schools and courts, manifesting the social functions under colonial rule. For example, the design of the Tainan District Court was not only practical but also symbolized the colonial authorities' emphasis on law and order, which had a profound impact on Taiwanese society at the time.

As times change, educating the public about these heritage buildings has become an important issue. Lin (2023) mentioned that these buildings are not only historical witnesses but also part of contemporary cultural resources. Her research indicates that heritage tour education can effectively enhance students' understanding of historical culture and increase their awareness of the importance of preserving historical buildings. Through the protection of cultural assets and the integration of modern technology, these buildings have become important media for learners to understand history and culture.

Relevant Architectural Heritage Sites

1. Tainan University Hong-Lou (Red Building): Built in 1921, originally Tainan Normal School, a key Japanese colonial educational building integrating Japanese and Western Renaissance styles. Now part of National University of Tainan.
2. Tainan Weather Observatory: Established in 1901 for meteorological research, featuring Western classical design. Contributed to agricultural development and disaster prevention; now a meteorology museum.
3. National Museum of Taiwan Literature: Formerly Tainan Prefectural Hall (1896), a colonial government office. Established as a museum in 2003 to promote Taiwanese literature and culture.
4. Chihkan Tower (Fort Provintia): Originally Dutch Fort Provintia (1653), rebuilt multiple times. A significant historical, political, and military site, later used for education and public office during Japanese rule.
5. Hayashi Department Store: Built in 1932, a prominent Japanese colonial commercial building. Renovated and reopened in 2014 as a multifunctional cultural and commercial landmark.

Learning Motivation

Learning motivation, a key factor in learning effectiveness, is typically divided into intrinsic (interest-driven) and extrinsic (reward-driven) types (Deci & Ryan, 1985). Motivation influences learning strategies, effort, and persistence (Pintrich & De Groot, 1990), and is affected by students' task expectancy and value (Eccles, 1983), emotional responses (Pintrich et al., 1991), and attributions for success/failure (Weiner, 1985). It is dynamic and influenced by environment and experience (Ryan & Deci, 2000; Schunk et al., 2012).

Research consistently shows AR enhances learning motivation across disciplines. Studies indicate AR-based systems improve understanding and interest in puzzles, make engineering theories more visual and engaging (Kaur et al., 2020), increase motivation in visual arts (Di Serio et al., 2013), aid comprehension of abstract science concepts like electromagnetism (Ibáñez et al., 2014), and boost motivation in library resource use (Küçük et al., 2016). AR's immersive, interactive environments improve engagement and overall learning effectiveness.

Learning Attitude

Learning attitude, a student's evaluation of learning activities, significantly influences progress and outcomes. It encompasses emotional, cognitive, and behavioral responses, with positive attitudes correlating with higher achievement (Chen, 2003; Schunk & Meece, 2006). Cultural background can also affect learning attitudes. Generally, it is formed through experience and reflects tendencies towards learning elements, influencing behavior (Woolfolk, 2014).

Studies show AR positively impacts learning attitudes. For instance, AR improved elementary students' attitudes in pet owner responsibility education. In physics, AR combined with Problem-Based Learning enhanced attitudes (Fidan & Tuncel, 2019). Middle school science students using AR showed more positive attitudes than control groups (Sahin & Yilmaz, 2020). AR also improved attitudes and reduced cognitive load in English language learning (Kucuk et al., 2014). These findings highlight AR's positive influence on student learning attitudes.

Self-Efficacy

Self-efficacy, as defined by Bandura (1977), is an individual's belief in their capability to complete specific tasks. It influences academic engagement and performance (Zhang et al., 2014). It stems from four sources: mastery experiences (enactive attainment), vicarious experiences (observing others), verbal persuasion, and physiological/affective states. These factors collectively shape one's confidence when facing challenges.

High self-efficacy correlates with better performance and proactivity, while low self-efficacy can lead to anxiety and avoidance (Anthonysamy et al., 2020; Bandura, 1986). AR has shown promise in enhancing self-efficacy. Studies indicate AR improved self-efficacy in students with special needs (Alahmari et al, 2023), elderly individuals in oral health education (Worachate, 2023), students using AR library tours (Kannegiser, 2021), and students learning physics concepts (Cai et al., 2021). These findings suggest AR's interactive nature can bolster users' confidence in their abilities.

Developmental Characteristics of Fifth-Grade Students (Ages 10-11)

Fifth graders are in a transitional phase of cognitive development, moving from concrete operational thought to more abstract reasoning. While they are still grounded in the concrete world, they are beginning to develop the capacity for abstract thought, logical reasoning, and hypothetical thinking. As noted by English (1997), this is an ideal age to introduce more complex problem-solving activities. The “Time Traveler” application was designed to bridge this gap between concrete and abstract thinking by providing a concrete, interactive experience of abstract historical concepts. The 3D visualizations and interactive elements allowed students to manipulate and explore historical information in a way that was both engaging and cognitively accessible.

The motivational profile of fifth graders is characterized by a growing importance of peer relationships and a desire for autonomy and competence. As Kurdek and Sinclair (2000) found, peer relationships are significant predictors of academic outcomes in this age group. The gamified elements of our AR application, such as the leaderboard and the ability to share achievements, were specifically designed to leverage this social motivation. Furthermore, the application provided students with a high degree of autonomy in their learning, allowing them to explore the historical sites at their own pace and in their own way. This sense of control and competence is a powerful intrinsic motivator for this age group.

Fifth graders are naturally curious and enthusiastic learners, but they can also be easily disengaged if the learning activities are not perceived as relevant or meaningful. They are more likely to be engaged by active, hands-on learning experiences than by passive instruction. The “Time Traveler” application was designed to be a highly engaging, active learning experience that transformed the students from passive recipients of information into active explorers of the past. The interactive nature of the application, combined with the novelty of the AR technology, captured their attention and sustained their engagement throughout the learning process.

Methodology

This study employed a mixed-methods research design to provide a more comprehensive understanding of the impact of the AR intervention. Our quantitative data (pre- and post-test scores) provided a broad overview of the intervention’s effectiveness, while the qualitative data, gathered through semi-structured interviews, were essential for exploring the nuances of the student experience and explaining the 'how' and 'why' behind the quantitative outcomes. We developed an AR application named “Time Traveler” to integrate AR into classroom teaching, providing elementary school students with a more vivid and engaging learning experience to understand the historical architectural culture of Tainan during the Japanese colonial period. This teaching model was also intended to enhance the flexibility and enjoyment of traditional teaching. The experiment was conducted with students from an elementary school in Kaohsiung City. The curriculum content was designed to align with the learning objectives of the fifth-grade social studies curriculum in Taiwan, specifically focusing on the unit of local history and cultural development. Learning effectiveness, learning motivation, learning attitudes, and self-efficacy were assessed using pre- and post-tests to understand the differences resulting from different learning models. The following sections detail the research flow and structure, experimental design, experimental procedure, the AR application, and assessment tools.

Research Flow and Structure

This study adopted a quasi-experimental design to empirically investigate the impact of AR technology on fifth-grade students' learning outcomes. The research framework proceeded through three systematic phases: literature review and curriculum design, development of the "Time Traveler" AR system, and a four-week experimental intervention. In this experimental design, the independent variable was the teaching method, contrasting AR-integrated instruction (experimental group) with traditional didactic instruction (control group). To comprehensively evaluate the intervention's effectiveness, learning achievement, learning motivation, learning attitude, and self-efficacy served as the dependent variables, measured via post-test scores. To ensure the validity of the results and control for baseline differences, pre-test scores for all four dimensions were utilized as covariates. Furthermore, several control variables were rigorously maintained to minimize confounding factors: all participants were fifth-grade students from the same school, and the same instructor delivered the curriculum content across both groups to prevent variations in teaching style.

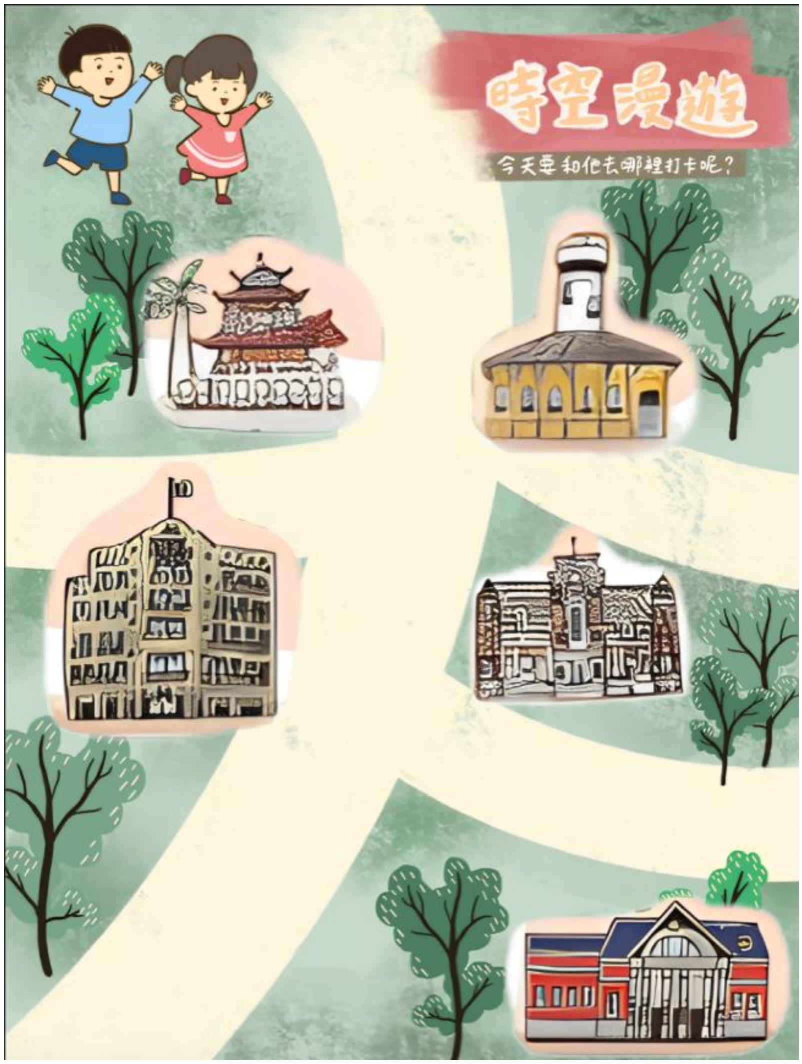
Experimental Design

System Development

The AR system required a screen to display virtual information. Among various display types (head-mounted, handheld, etc.), this system utilized a handheld approach with tablets. Figure 1 demonstrates the main user interface of the application. The AR application was developed using Unity with the Vuforia SDK for AR functionalities. Animations were created using Blender, and graphics were created using Procreate. The app features included a 360-degree view of architectural models, allowing students to rotate and examine heritage structures on their tablets. It also featured a “Past Traces” function, where scanning 3D-printed building models would trigger animations of historical figures and activities, and scanning “story capsule” image markers would provide knowledge about the heritage sites.

Figure 1

The main menu interface of the “Time Traveler” application



The "Time Traveler" application was designed to create meaningful connections between sites, making the learning experience feel more coherent and personalized. It is powered by the Vuforia engine to deliver a comprehensive and adaptive educational tool.

AR System Development Tools

The AR application was developed using the Unity engine, a cross-platform tool for creating interactive 3D and 2D experiences, with C# as the primary scripting language. For AR functionalities, the Vuforia Engine SDK was integrated within Unity. Vuforia supports various target recognition methods, including the 3D object recognition utilized in this study for interacting with physical models of the heritage sites.

"Time Traveler" AR Curriculum

The "Time Traveler" AR curriculum centered on five historical buildings in Tainan's West Central District: Tainan Weather Observatory, Chihkan Tower, Tainan University Hong-Lou, National Museum of Taiwan Literature, and Hayashi Department Store. A narrative involving a "time traveler" character guided students. Using tablets with the AR app, students scanned 3D-printed models of these buildings and image markers ("story capsules") to access historical information, view 3D architectural models, and observe animations of historical figures and activities. Worksheets supported the learning process, encouraging exploration and documentation of findings related to each site's background and significance. A typical learning sequence for a student using the application was as follows: (1) Students selected a heritage site, such as the Hayashi Department Store, from the main menu. (2) Guided by their worksheet, they located the corresponding 3D-printed physical model of the building. (3) They pointed their tablet's camera at the model, which triggered the AR application to overlay a detailed virtual 3D model. Students could then rotate and zoom to examine its architectural features. (4) Next, they would find and scan the associated 'story capsule' image marker. (5) This would activate an animation depicting historical events or figures related to the site, providing narrative context. (6) Finally, students would use the information gathered to answer questions on their worksheet.

Participants

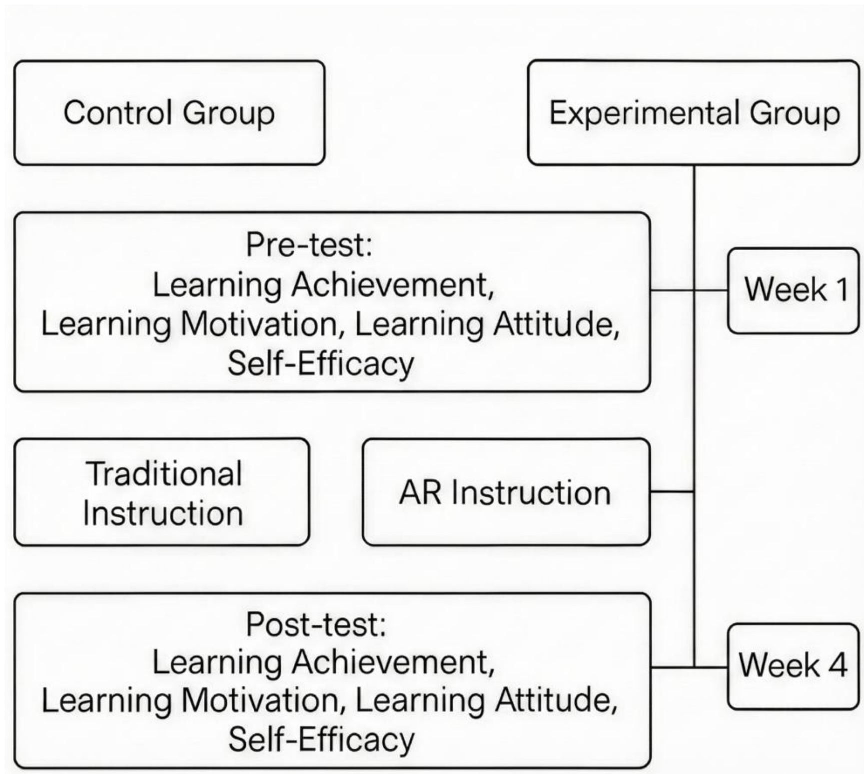
The participants in this study were fifth-grade students from two intact classes at an elementary school in Kaohsiung City. Due to school administrative constraints, random assignment of individual students was not feasible. Therefore, one class was assigned as the control group (n=24), and the other as the experimental group (n=25). This use of existing class groups is characteristic of a quasi-experimental design.

Experimental Procedure

This study employed a control group and an experimental group to investigate the impact of different teaching methods on student learning outcomes. The control group received traditional instruction using only school textbooks, while the experimental group received AR-enhanced instruction integrated into classroom teaching. Figure 2 shows the workflow of the experiment.

Figure 2

Flowchart of the instructional process for experimental and control groups



Assessment was conducted through pre-tests and post-tests covering historical knowledge, learning motivation, learning attitudes, and self-efficacy. Pre-tests were administered before the instruction began to ascertain students' baseline knowledge, initial motivation, and attitudes. Post-tests were conducted after the instruction concluded to evaluate changes in knowledge mastery, learning motivation, learning attitudes, and self-efficacy in both groups.

During the experiment, students in the experimental group learned through the AR application, engaging in more intuitive and interactive learning experiences within a blended virtual and real environment. For example, they could observe animated historical figures within the virtual scenes. Small tasks were incorporated during AR use to make the learning process more engaging. The control group received traditional instruction, primarily through teacher lectures and textbook study. The curriculum materials centered on five well-known historical sites in Tainan's West Central District: Tainan University Hong-Lou, Tainan Weather Observatory, National Museum of Taiwan Literature, Chihkan Tower, and Hayashi Department Store. These locations were chosen due to the rich historical significance of the West Central District and the close proximity of these sites, all within walking distance of each other. A virtual character was designed to connect the narratives of these five sites.

Experimental Process Record

The experiment spanned four weeks (two hours/week). Week 1 involved pre-tests and an introduction to the course and AR technology. Week 2 focused on instruction about the historical architectural culture of the five selected sites. Week 3 was dedicated to hands-on student exploration using the AR application and group discussions. Week 4 included post-tests, sharing of learning outcomes, and course feedback.

Research Instruments

To evaluate cognitive learning outcomes, a Learning Achievement Test was developed by two experienced elementary teachers. This instrument, with a maximum score of 100, was designed to cover the social studies curriculum content. It included various question types intended to assess not only factual recall but also specific cultural understanding and historical thinking skills, such as analyzing images and comparing historical contexts. Direct assessment was conducted via this test, while indirect assessment was inferred from student interactions and qualitative feedback.

To assess the affective domains, three scales were adapted and validated for fifth-grade students. The Learning Motivation Scale was adapted from the Motivated Strategies for Learning Questionnaire (MSLQ) by Pintrich et al. (1991), consisting of 31 items rated on a 5-point Likert scale. Its internal consistency was high, with Cronbach's α coefficients of 0.913 for the pre-test and 0.935 for the post-test. For learning attitude, the Learning Attitude Scale was adapted from Korkmaz (2012). This 17-item instrument demonstrated strong reliability, with Cronbach's α values of 0.906 (pre-test) and 0.956 (post-test). Finally, Self-Efficacy was measured using a 10-item scale adapted from Ng and Lucianetti (2016) and Schwarzer (1993), which yielded Cronbach's α coefficients of 0.774 and 0.872 for the pre- and post-tests, respectively. All scales underwent expert review by two elementary teachers and a professor in educational technology to ensure content validity and wording appropriateness for the target age group.

Qualitative Data Collection and Analysis

Interview Procedures

We conducted semi-structured interviews with a representative sample of students from the experimental group. A semi-structured format was chosen to allow for flexibility and to enable us to probe for deeper insights based on the students' individual responses. This approach is supported by DiCicco-Bloom and Crabtree (2006), who note that semi-structured interviews are a powerful tool for "foster[ing] learning about individual experiences and perspectives on a given set of issues".

Ensuring Trustworthiness

We took steps to ensure the trustworthiness of our findings, drawing on the framework proposed by Lincoln and Guba (1985). We established credibility through prolonged engagement, member checking, and peer debriefing. We provide a detailed description of the context to allow readers to judge transferability. A detailed audit trail ensures dependability, and a reflexive journal was maintained to ensure confirmability.

Qualitative Results

The thematic analysis of the semi-structured interviews revealed four key dimensions regarding the students' experience with the AR intervention.

The first major theme was **enhanced interactivity and engagement**, which emerged as the primary driver of student participation. Participants consistently identified the interactive features of the AR system as a key factor in sustaining their attention. For instance, Student A remarked, "*It was way more fun than just reading a book. I liked that you could actually touch the screen and make things happen. It made me want to find all the secrets.*" This sentiment was reinforced by Student B, who highlighted the gamified elements, noting, "*I didn't know history could be like a game. The points and the badges made me want to learn more so I could beat my friends. It was exciting.*" These responses suggest that the tactile and competitive aspects of the application successfully transformed the learning experience from passive observation to active participation.

Regarding the **comprehension of historical concepts**, the data indicated that the AR application facilitated a clearer grasp of abstract ideas. Students reported that visualizing buildings in their original contexts helped bridge the gap between textual descriptions and concrete understanding. The ability to manipulate 3D models allowed them to visualize architectural features and scales that are otherwise difficult to comprehend through traditional static images, thereby deepening their cognitive connection to the subject matter.

The analysis also revealed a marked increase in **learning motivation and interest**, driven largely by the novelty and narrative structure of the tool. Students expressed a genuine curiosity about local history that extended beyond the immediate classroom requirements. Many participants noted that the "Time Traveler" narrative sparked a desire to explore other historical sites in Tainan, indicating that the intervention successfully triggered situational interest that contributed to sustained motivation.

Finally, the feedback reflected overwhelmingly positive **attitudes toward AR instruction**. Students described the AR-integrated approach as a welcome departure from traditional didactic instruction. This positive reception created a supportive learning atmosphere, where students felt more willing to express their thoughts and participate in group discussions compared to conventional lecture-based settings.

In summary, the qualitative data strongly supported the efficacy of the AR intervention. Students consistently reported that the application transformed a typically passive subject into an active exploration. While some minor technical challenges were noted initially, most were overcome with guidance. While these qualitative insights illustrate the nuances of the students' positive experiences, the following section presents the statistical analysis to objectively measure the intervention's impact on learning achievement and affective outcomes.

Quantitative Results

This study aimed to explore the effectiveness of an AR-integrated teaching approach for Tainan's architectural culture during the Japanese colonial period. The experimental group (N=25) utilized an AR application, compared to a control group (traditional teaching, N=24). This section details the comparison of the two groups in terms of learning achievement, learning motivation, learning attitudes, and self-efficacy. SPSS was used for data analysis, employing Analysis of Covariance (ANCOVA) to assess the impact of the AR intervention.

Learning Achievement

To assess the impact of AR integration on learning achievement, a comparison was made between the control and experimental groups. First, a homogeneity of regression slopes test was conducted. The results showed that the interaction effect of group * pre-test score was not significant ($F(1, 45) = 0.293$, $p = .591$), indicating that the regression slopes were homogeneous, allowing for ANCOVA.

Levene's test for homogeneity of error variances was also not significant ($F(1, 47) = 0.007$, $p = .935$), indicating that the error variances were equal across groups, satisfying the assumption for ANCOVA.

Table 1 presents the ANCOVA results for learning achievement. After controlling for pre-test scores, there was a significant difference between the groups ($F(1, 46) = 4.434$, $p = .041$). The adjusted mean score for the experimental group ($M_{adj} = 90.866$) was significantly higher than that of the control group ($M_{adj} = 86.577$), representing a medium-to-large effect size (Hedge's $g = 0.611$).

Table 1

ANCOVA summary for learning achievement

Source	df	Adjusted Mean (Experimental)	Adjusted Mean (Control)	F-value	p-value
Between Groups	1	90.866	86.577	4.434	.041*

Note: $p < 0.05$

This result indicates that after controlling for pre-test scores, the AR-integrated teaching approach was significantly more effective in improving students' learning achievement than traditional instruction.

Learning Motivation

To evaluate the effect on learning motivation, the adapted MSLQ learning motivation subscale was used. The homogeneity of regression slopes test indicated that the interaction effect of group * pre-test motivation score was not significant ($F(1, 45) = 3.880$, $p = .055$), meeting the ANCOVA assumption.

Levene's test for homogeneity of error variances was not significant ($F(1, 47) = 0.747$, $p = .392$).

Table 2 shows the ANCOVA results for learning motivation. A significant difference was found between the groups ($F(1, 46) = 4.291$, $p = .044$). The adjusted mean motivation score for the experimental group (M_adj = 3.726) was significantly higher than that of the control group (M_adj = 3.393), representing a medium effect size (Hedge's *g* = 0.601).

Table 2

ANCOVA summary for learning motivation

Source	df	Adjusted Mean (Experimental)	Adjusted Mean (Control)	F-value	p-value
Between Groups	1	3.726	3.393	4.291	.044*

Note: $p < 0.05$

Learning Attitude

For learning attitude, the adapted scale by Korkmaz (2012) was used. The homogeneity of regression slopes test showed no significant interaction ($F(1, 45) = 0.806$, $p = .374$).

Levene's test was not significant ($F(1, 47) = 1.332$, $p = .254$).

Table 3 presents the ANCOVA results for learning attitude. There was a significant difference between the groups ($F(1, 46) = 4.506$, $p = .039$). The adjusted mean attitude score for the experimental group (M_adj = 3.850) was significantly higher than that of the control group (M_adj = 3.448), representing a medium-to-large effect size (Hedge's *g* = 0.616).

Table 3
ANCOVA summary for learning attitude

Source	df	Adjusted Mean (Experimental)	Adjusted Mean (Control)	F-value	p-value
Between Groups	1	3.850	3.448	4.506	.039*

Note: p < 0.05

Self-Efficacy

To assess self-efficacy, the adapted scale was used. The homogeneity of regression slopes test indicated no significant interaction (F(1, 45) = 0.617, p = .436).

Levene's test was not significant (F(1, 47) = 2.057, p = .158).

Table 4 shows the ANCOVA results for self-efficacy. A significant difference was found between the groups (F(1, 46) = 7.713, p = .008). The adjusted mean self-efficacy score for the experimental group (M_adj = 4.406) was significantly higher than that of the control group (M_adj = 4.061), representing a large effect size (Hedge's *g* = 0.806).

Table 4
ANCOVA summary for self-efficacy

Source	df	Adjusted Mean (Experimental)	Adjusted Mean (Control)	F-value	p-value
Between Groups	1	4.406	4.061	7.713	.008**

Note: **p < 0.01

Discussion

The findings of this study demonstrated that integrating Augmented Reality (AR) into the curriculum significantly enhanced fifth-grade students' learning achievement, motivation, attitudes, and self-efficacy compared to traditional methods. These results align with the growing body of literature supporting the pedagogical benefits of AR in educational contexts. By consolidating the quantitative statistical outcomes with qualitative insights, several key patterns emerged regarding how AR facilitates historical understanding and engagement.

Regarding learning achievement, the AR-integrated instruction led to significantly higher academic performance than the traditional approach. This finding corroborates previous research by Fonseca et al. (2014), which highlighted AR's capacity to improve academic outcomes through visualization. The qualitative data provided context for this improvement; students reported that the 3D visualizations helped them concretize abstract historical concepts. By transforming static text into tangible, manipulable virtual objects, the "Time Traveler" application allowed students to actively explore architectural details that are otherwise difficult to conceptualize, thereby deepening their cognitive grasp of the subject matter.

In terms of learning motivation and attitudes, the experimental group showed a marked improvement, supporting the findings of Saidin et al. (2015) and Khan et al. (2019). This shift from passive reception to active participation was largely driven by the application's specific design features. As observed in the interviews, the gamified elements—such as points, badges, and leaderboards—fostered a competitive yet enjoyable environment. This aligns with Lampropoulos et al. (2022), who noted that gamification positively affects engagement. Furthermore, the narrative-driven interaction with the virtual guide provided a compelling context for learning, transforming the experience into an immersive story. This synergistic effect of gamification and storytelling successfully triggered students' intrinsic curiosity and sustained their positive attitudes toward history learning.

A crucial finding of this study was the significant enhancement of self-efficacy in the AR group, which exhibited a large effect size. This result supports Bandura’s (1977; 1986) social cognitive theory, which posits that mastery experiences are a primary source of self-efficacy. The hands-on nature of the AR tasks provided these mastery experiences. Although students initially faced minor technical challenges, overcoming them to successfully navigate the virtual environment likely bolstered their confidence. This aligns with studies by Alahmari et al. (2023) and Zhang et al. (2014), suggesting that the interactive success inherent in well-scaffolded AR activities empowers students to believe in their own learning capabilities.

However, interpretation of these findings should consider certain limitations. Specifically, the statistical analysis did not apply a correction for multiple comparisons (e.g., Bonferroni) across the four dependent variables. While the results showed significance at the $p < .05$ level, future research should apply such corrections to yield more robust statistical conclusions. Despite this, the consistent triangulation of quantitative gains with positive qualitative feedback provides strong evidence for the efficacy of the intervention.

Conclusion and Recommendations

This study investigated the impact of integrating AR technology into teaching the architectural culture of Tainan from the Japanese colonial period on fifth-grade students’ learning achievement, learning motivation, learning attitudes, and self-efficacy. These findings contribute to the existing literature by providing empirical evidence of AR's effectiveness in the specific context of cultural heritage education for elementary students. Unlike studies focusing solely on cognitive gains, our research demonstrates a holistic impact. Based on the quantitative data analyzed using ANCOVA and qualitative data from student interviews, the following conclusions are drawn:

1. AR-integrated teaching significantly improves learning achievement: Students in the experimental group, who received AR-enhanced instruction, demonstrated significantly higher gains in learning achievement compared to the control group receiving traditional instruction ($p = 0.041$). This suggests that AR can make historical content more accessible and understandable, leading to better academic performance.
2. AR-integrated teaching significantly enhances learning motivation: The experimental group showed significantly greater improvement in learning motivation ($p = 0.044$). The interactive and immersive nature of AR appears to transform learning from a passive activity to an engaging exploration, thereby boosting students' intrinsic drive to learn.
3. AR-integrated teaching significantly fosters positive learning attitudes: A significant improvement in learning attitudes was observed in the experimental group ($p = 0.039$). AR's interactive tasks encouraged active participation, leading to a more positive disposition towards the learning process and subject matter.
4. AR-integrated teaching significantly increases self-efficacy: The experimental group exhibited significantly higher gains in self-efficacy ($p = 0.008$). The hands-on, mastery-oriented experiences within the AR environment likely empowered students, increasing their confidence in their ability to learn and succeed.

These findings collectively indicate that AR technology offers distinct advantages over traditional teaching methods in the context of historical architectural education for elementary school students. The immersive and interactive qualities of AR contribute to a more holistic and impactful learning experience, positively influencing cognitive, motivational, attitudinal, and self-perceptual outcomes.

Recommendations for Future Research and Practice

Based on the study' s findings and limitations, several recommendations are proposed to advance the application of AR in education.

First, **refining system design and interactivity** is crucial for future iterations. While the "Time Traveler" application was generally well-received, incorporating more sophisticated dialogue systems with virtual characters could enhance user empathy and engagement. Future development should also focus on optimizing 3D object scanning to reduce sensitivity to specific angles and exploring AI algorithms for adaptive learning to personalize the educational experience.

Second, future implementations should focus on **enhancing instructional scaffolding**. Although the AR intervention was beneficial, some students initially struggled with operational aspects. Incorporating robust onboarding strategies to familiarize students with AR controls is essential to minimize initial frustration and ensure a smoother learning curve. Furthermore, linking tasks more cohesively to create a stronger narrative flow could deepen memory retention.

Third, it is recommended to **integrate AR activities with local curricula and daily life**. Connecting historical content to the students' community context can foster a stronger resonance with the subject matter. Furthermore, the AR framework developed for this study is highly adaptable and could be applied to other historical or cultural heritage sites, offering a flexible pedagogical tool for broader educational contexts.

Finally, **future research directions** should include expanding participant demographics to different age groups (e.g., middle or high school) and conducting longitudinal studies to assess the long-term impact on knowledge retention and motivation. Comparative studies isolating specific AR features—such as marker-based versus markerless interactions—would also help identify the most critical design elements for enhancing specific learning outcomes.

Abbreviations

AR: Augmented Reality; ANCOVA: Analysis of Covariance; MR: Mixed Reality; MSLQ: Motivated Strategies for Learning Questionnaire; SDK: Software Development Kit

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Author’s contributions

Hao-Chiang Koong Lin conceptualized the study, designed the methodology, developed the AR application, and conducted the formal data analysis. Ruei-Shan Lu conducted the formal data analysis, wrote the methods and results sections, and provided project support. Chun-Hsiung Tseng provided technical support, as well as writing and editing support. Tao-Hua Wang conducted the experiments, gathered the data, and provided editing support. All authors contributed to writing and revising the manuscript.

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Declarations

Competing interests

The authors declare that they have no competing interests.

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