A Pre-Test Post-Test Study Using the Design Thinking Framework to Evaluate an Augmented Reality Book for Informal Learning in Public Libraries

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ABSTRACT

Augmented Reality has been widely investigated as an educational technology that overlays digital content such as 3D models, animations, audio narration, and interactive quizzes onto physical media. Most existing studies on augmented reality books focus on formal education (schools, classrooms, and STEM learning). Only a small number examine how augmented reality books influence learning, engagement, or knowledge recall among public library users, especially younger children and casual readers. While Design Thinking is often used to create prototypes, few studies use its Testing phase to systematically evaluate learning effectiveness through repeated measurement. The present study aims to evaluate the effectiveness of an augmented reality book in enhancing students' knowledge recall and understanding of key places of interest. A set of questionnaires is being used to measure change in knowledge recall and understanding to the augmented reality experience. This study employed a quantitative research design to explore the effectiveness of an augmented reality book using a pre-test and post-test design. 70 participants in this study represented a broad spectrum of library users, supporting the inclusiveness of the study sample. Findings from pre-test and post-test results showed a significant increase in students' post-test scores, indicating improved knowledge recall and understanding. The positive gain score and paired t-test results further confirmed that the augmented reality book enhanced learning performance.

Keywords: effectiveness; design thinking; augmented reality; pre-test post-test; informal learning; public libraries

INTRODUCTION

Augmented reality has emerged as a significant educational innovation because it enhances printed materials with interactive digital elements such as three-dimensional models, animations, and audio narratives. When learners view a physical page through a mobile device, the overlay of dynamic content helps them interpret information that may be difficult to visualise through text and images alone Recent studies (2022–2024) consistently show that AR strengthens motivation, supports multimodal processing, and improves learning performance across age groups (Akşab et al., 2025; Masmuzidin et al., 2022). The integration of augmented content with traditional reading materials has given rise to augmented reality books, where printed pages serve as triggers for layered digital information. Over the past five years, empirical research has shown that these books improve comprehension, strengthen memory retention, and offer meaningful opportunities for exploratory learning beyond what conventional print-based approaches typically support (Cao et al., 2023; Garzón Álvarez, 2021). More recent works also highlights their potential in supporting visual reasoning, vocabulary development, and situated knowledge construction (Salehi, 2025; Siregar, 2025).

Despite this emerging evidence, most studies on augmented reality books have focused on classroom settings characterised by structured lessons, clear learning goals, and guided teacher facilitation. Far less attention has been given to their use in informal learning environments such as public libraries, even though libraries offer flexible, low-pressure settings where learners engage voluntarily and at their own pace. These self-learning environments are known to support curiosity-driven exploration, early literacy development, and equitable access to digital resources. However, the role of AR books in such community-based contexts remains largely unexplored, with limited empirical data available on how children interact with AR materials when support from instructors is minimal. Findings from semi-structured literacy programmes have shown that AR materials enhance motivation and comprehension (Al-Thani & Ahmad, 2025; Grace D et al., 2025) but studies conducted in fully open, ecological library settings are still scarce.

Malaysia provides a compelling context for investigating augmented reality-supported reading in libraries. Its extensive public library network and national emphasis on digital literacy have created opportunities for integrating emerging technologies into community learning spaces. Urban libraries in Kuala Lumpur function as accessible neighbourhood learning hubs, frequently visited by school-aged children for reading, homework preparation, and enrichment activities. Children often possess prior knowledge of major city landmarks, including KLCC Park, Tugu Negara, Petrosains, and Muzium Negara, through school excursions and family visits. When AR books depict these well-known places, learners can draw on their lived experiences to make sense of the multimedia representations, thereby reinforcing situated learning processes (Lave & Wenger, 1991; Wenger, 2022) . Cultural familiarity with the content enhances relevance, deepens comprehension, and supports strong cognitive connections between physical spaces and digital narratives (Kwiecien et al., 2025). This makes Kuala Lumpur an ideal setting for evaluating how AR books function within community learning ecosystems.

The development and evaluation of the augmented reality book in this study were guided by the Design Thinking framework, which emphasises empathy, iterative refinement, and evidence-driven improvement. Design Thinking has become increasingly recognised in educational technology development because it ensures that tools are grounded in learner needs and refined through cycles of prototyping and testing (Shé et al., 2022). However, few studies integrate Design Thinking with systematic quantitative evaluation, as many AR prototypes are assessed only descriptively or through usability feedback (Graser et al., 2024; Vogel et al., 2021). Embedding pre-test and post-test measurement directly within the Testing phase strengthens methodological coherence and allows researchers to examine whether AR books produce measurable learning benefits rather than solely positive user impressions. This approach also responds to calls in recent research for stronger empirical grounding in AR-based instructional design (Novawan et al., 2024).

Although augmented reality books are gaining traction in education, research examining their effectiveness in public libraries, particularly within the Malaysian and broader ASEAN context remains limited. There is little evidence on how AR books support both factual recall and interpretive understanding in informal settings where engagement occurs voluntarily. This study addresses that gap by evaluating an AR book featuring key Kuala Lumpur attractions and assessing its impact on learners within an urban public library. By situating the evaluation within the Testing phase of the Design Thinking framework and employing a pre-test and post-test design, the study provides empirical insights into how AR books can support knowledge building in informal learning spaces. The findings contribute to ongoing conversations on digital literacy, experiential learning, and user-centred educational design in community environments.

LITERATURE REVIEW

Public Libraries as Informal Learning Spaces

Public libraries function as inclusive community learning spaces that support a wide range of literacy, digital, and enrichment activities. Unlike classroom environments that follow structured lessons and assessments, libraries offer learners the freedom to explore materials voluntarily and at their own pace. This flexibility supports curiosity-driven and self-directed learning, which has been shown to enhance intrinsic motivation and deepen engagement with educational resources (Snyder, 2025). These characteristics are particularly beneficial for For young readers, these informal environments reduce performance pressure and allow natural exploration, making them particularly suitable for interactive learning tools such as AR books.

In the Malaysian context, public libraries hold significant social and educational value. Malaysia maintains one of the most extensive networks of public libraries in Southeast Asia, reflecting decades of investment in community education and digital access. Many public libraries in Kuala Lumpur, Selangor, and the wider Klang Valley are strategically integrated into residential areas, making them easily accessible to school-aged children who visit regularly for reading, studying, or participating in enrichment programmes. These libraries also function as neighbourhood hubs where children naturally engage with learning resources during after-school hours and weekends. The presence of dedicated children's sections, multimedia corners, and reading programmes further strengthens the role of libraries as supportive environments for early literacy and digital literacy development (Sung et al., 2023).

Malaysia's public library network is one of the most extensive in Southeast Asia, reflecting long-standing national commitments to community access and digital inclusion. Urban libraries in Kuala Lumpur are located near major residential areas and are frequently used by schoolchildren for reading, homework, and technology-based learning. This creates a natural setting for AR interventions, as many children already possess informal knowledge of popular landmarks such as KLCC Park, Petrosains, Muzium Negara, Tugu Negara, and Perdana Botanical Garden. Situated learning theory suggests that connecting new information to familiar real-world experiences enhances relevance and meaning-making (Lave & Wenger, 1991; Wenger, 2022). This contextual alignment enhances relevance and helps learners anchor new knowledge within meaningful cultural and spatial frameworks. Recent research on informal learning emphasises that meaningful connections to personal experience strongly influence retention, comprehension, and long-term engagement (Pepper, 2024). Therefore, public libraries provide an ideal environment for introducing AR books that build on children's familiarity with local places while promoting deeper understanding through multimodal exploration (Rahim et al., 2024) .

Augmented Reality Books and Learning Outcomes

Augmented reality books represent a powerful hybrid learning tool that merges the physicality of printed materials with the dynamic interactivity of digital overlays. Through marker-based augmented reality, images or icons on book pages act as triggers that activate three-dimensional models, animations, voice narratives, and short videos when scanned with a mobile device. This interplay between print and digital media creates a multimodal reading experience that caters to diverse learning styles and supports different cognitive processes. The ability to interact with virtual objects embedded within a physical text enhances learners' spatial reasoning, promotes active exploration, and supports dual coding processes that combine verbal and visual representations for stronger memory formation (Mayer, 2021). These pedagogical advantages explain why augmented reality books have gained significant attention in the past decade, particularly in research focused on improving reading comprehension, engagement, and content retention.

Recent studies reinforce that augmented reality books are effective tools for enhancing both surface-level recall and higher-order comprehension. Garzón et al. (2020) analysed a broad range of augmented reality interventions and found substantial improvements in learner attention, motivation, and conceptual clarity, especially among younger users who benefit from engaging visualization. More recent study by Liu et al. (2024) reported that children using augmented reality picture books demonstrated significantly higher reading motivation and comprehension compared to peers using traditional print materials. These outcomes were attributed to the interactive and immersive nature of augmented reality content, which transforms passive reading into an exploratory process where learners can manipulate virtual objects, view animations related to the story or topic, and access layered information that deepens understanding.

AR technology affordances contribute to deeper comprehension and more accurate mental models of the depicted content. A growing body of recent literature emphasises the role of augmented reality in supporting knowledge transfer by enabling learners to reconstruct information using multimodal cues rather than relying solely on textual descriptions (Gatchalian & Leon, 2023). These consistent findings highlight the promise of AR books in supporting early literacy, content knowledge, and learner engagement. However, most of these evaluations have occurred within formal classroom environments, leaving a gap in understanding how AR books function in open, self-directed learning contexts such as public libraries.

AR in ASEAN and Malaysian Library Context

Across the ASEAN region, augmented reality has been increasingly adopted to support digital transformation initiatives in libraries, museums, and cultural institutions. National agencies and educational organisations have explored augmented reality as a means to expand public engagement, enhance cultural understanding, and promote digital literacy among visitors. In Singapore, for example, the National Library Board has piloted augmented reality-enhanced children's storybooks and interactive installations that blend physical stories with digital effects to encourage early literacy. In Indonesia, augmented reality-based science books have demonstrated positive effects on student engagement and biology comprehension, suggesting strong potential for augmented reality as a supplementary learning tool in both formal and informal settings (Abdilah & Wulandari, 2024). These regional developments illustrate growing recognition of augmented reality as a transformative educational medium capable of supporting diverse learning needs across different cultural contexts.

In Malaysia, the integration of augmented reality technology into public libraries is still at an emerging stage. While several academic libraries have begun adopting augmented reality for orientation activities and digital exhibitions, public libraries have more commonly focused on e-services, digital catalogues, and ICT literacy workshops. The use of augmented reality books specifically targeted at children's learning remains limited, and empirical evidence on their effectiveness in Malaysian library contexts is scarce. This gap represents an important opportunity for research, especially given Malaysia's emphasis on digital readiness and equitable access to emerging technologies. The Ministry of Education and various state-level library authorities have introduced initiatives promoting digital literacy and technology-enhanced learning, but augmented reality has yet to be extensively implemented or evaluated in library settings. Limited studies in related contexts indicate that Malaysian children respond positively to digital storytelling formats, suggesting that augmented reality books may be well suited to local learners' preferences and cultural experiences (bin Meor Othman et al., 2020). The present study contributes to this gap by examining how Malaysian young learner with an AR informational book in a real library setting, providing ecological validity that is underrepresented in regional AR literature.

Design Thinking as a Framework for Augmented Reality Book Evaluation within the Testing Phase

Design Thinking offers a robust framework for the development of educational technologies, including augmented reality books, because it emphasises user needs, iterative refinement, and creative problem-solving. The process comprises five interrelated phases; empathise, define, ideate, prototype, and test is represented in Figure 1. In the context of augmented reality book development, these phases allow designers to identify learners' cognitive and motivational needs, conceptualise multimedia features that support understanding, create prototypes that integrate printed and digital elements, and refine these prototypes based on user feedback. Design Thinking has gained prominence in education technology research as a means of producing human-centred innovations that are pedagogically meaningful and responsive to diverse learning contexts (Novawan et al., 2024).

Recent scholarship highlights the value of integrating Design Thinking with empirical evaluation. Ladachart et al. (2022) argue that Design Thinking encourages iterative improvement through cycles of prototyping and testing, but many educational technologies are assessed only qualitatively or at early design stages. These limits understanding of their actual learning impact. In the context of augmented reality book development, the Testing phase provides an ideal opportunity to incorporate structured evaluation instruments, such as pre-tests and post-tests, to measure learning outcomes alongside usability. By integrating assessment within the Design Thinking cycle, designers can ensure that augmented reality features not only engage learners but also improve comprehension and retention. This study builds on this idea by grounding its augmented reality book development in the Design Thinking framework and by conducting a quantitative evaluation aligned with the Testing phase to determine the book's effectiveness. Figure 1 shows how learning effectiveness evaluation is embedded within the Test phase of the Design Thinking model.

i. Pre-test (baseline)
ii. Interaction with AR book
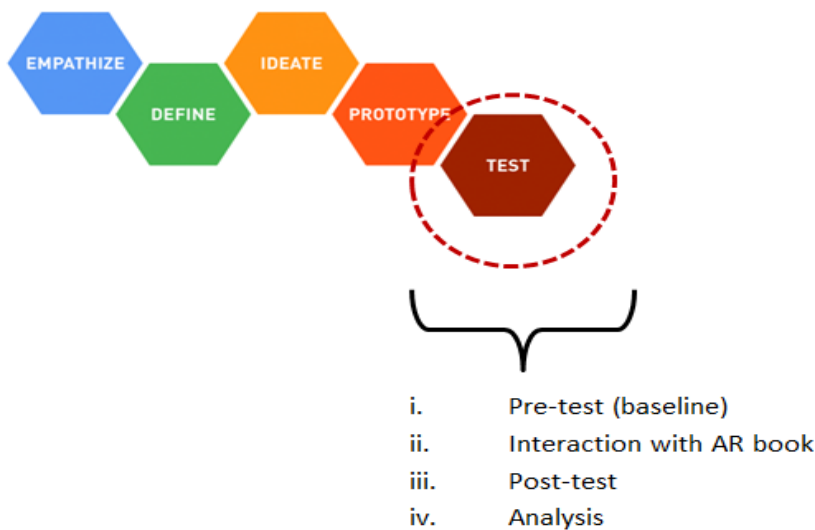iii. Post-test
iv. Analysis

Figure 1: Five phases in Design Thinking (Brown, 2008)

Figure 2 presents the conceptual framework that underpins this study, illustrating how augmented reality learning, situated learning theory, the Design Thinking Testing phase, and the public library environment interact to support meaningful learning outcomes. The AR book serves as the starting point by providing multimodal inputs such as three-dimensional models, multimedia overlays, and contextual narration. These features help transform abstract information into concrete, visually accessible representations that can be explored intuitively by learners. This digital content is then interpreted through situated learning processes, where learners connect the AR experiences to their own familiarity with Kuala Lumpur's landmarks, cultural settings, and spatial environments. Such alignment between prior knowledge and digital representations strengthens relevance, promotes deeper meaning-making, and reduces cognitive ambiguity.
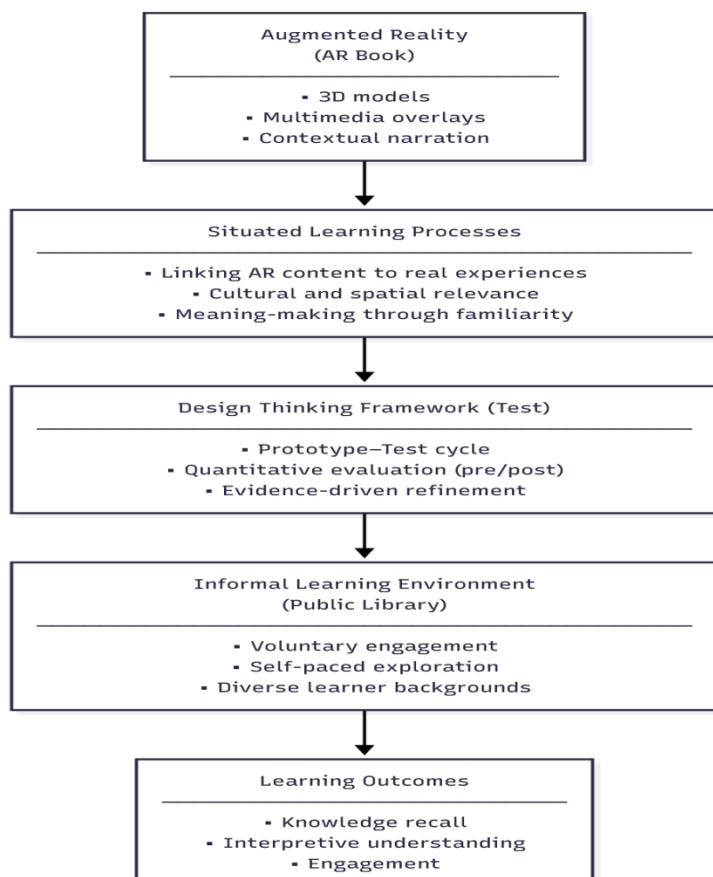

Figure 2: Interaction of AR book features, situated learning processes, the Design Thinking Testing phase, and informal learning environments leading to improved learning outcomes.

The Design Thinking Testing phase functions as the evaluative mechanism within the framework, linking the AR experience to a structured cycle of prototype refinement supported by pre-test and post-test measurements. This phase ensures that learning improvements are documented systematically rather than inferred through observation alone. The informal nature of the public library further shapes the learning process by offering a voluntary, self-paced environment that accommodates diverse user backgrounds. When these components converge, they produce enhanced learning outcomes, particularly in knowledge recall, interpretive understanding, and learner engagement. This framework highlights how AR books can operate effectively within community-based learning settings and demonstrates the potential of combining user-centred design with empirical evaluation to support educational innovation.

METHODOLOGY

Research Design

This study employed a quantitative research design to explore the effectiveness of augmented reality book using a pre-test and post-test design. The study employed a one-group pre-test and post-test design, aligned with the Testing phase of the Design Thinking framework. This design was used to measure changes in learners' knowledge recall and interpretive understanding after interacting with the AR book. Although no control group was used, this design enabled the study to capture immediate learning gains produced by the AR intervention. One-group pre-test-post test was conducted. These measures change in outcomes (knowledge recall and knowledge understanding) attributable to the AR experience. This study enhanced the printed materials for augmented reality book and Situated learning theory has been integrated as a model of instruction in designing the prototype for these printed materials. Therefore, various multimedia elements like video, graphic, text and 3D objects were integrated into this prototype to achieve the intended purpose. This prototype using marker-based augmented reality where the digital world is anchored to the real world. To display any virtual object (animation or video or 3D image) right onto the pamphlet or page of a book, the user is pointing the camera at that particular page which consist of a distinctive picture as a marker on the page. This distinctive picture will be recognised and the virtual object tracked to the appropriate place on the page. Five main places of atttraction In Kuala Lumpur which are KLCC, Botanical Garden, Tugu Negara, Muzium Negara and Petrosains been introduced. These five attractions were selected because they represent Malaysia's cultural, historical, scientific, and environmental diversity. These places are familiar to Kuala Lumpur children and offer strong visual and interactive potential for augmented reality technology. Their rich visual elements and educational value make them ideal for an augmented reality-based learning resource.

Paticipants

A total of 70 young learners between the ages of seven and 15 participated voluntarily in the study at a public library in Kuala Lumpur. Participants represented diverse demographic backgrounds, reflecting the typical user population of urban community libraries.

Research Instrument

The research instrument used in this study is a structured questionnaire with two sections. The opening section captured demographic information such as age, gender, and level of study. Then the next section consists of 10 questions (multiple-choice and True-false) to assess participants' knowledge recall and understanding related to five places of interest in Kuala Lumpur. The post-test contains a comparable set of items to the pre-test, measuring the same knowledge areas; however, the questions are presented using different wording. The questionnaire was pilot tested to ensure understanding of the items, wording and adequacy of response. Appendix A shows an example of pre-test questions.

Data Collection

Data collection followed a structured process aligned with the Testing phase of the Design Thinking model. Upon arrival at the library's designated reading area, participants were briefed on the study objectives and provided consent. The researcher explained the use of the augmented reality book and the scanning procedure

for marker-based pages. Participants first completed the pre-test, which measured their initial knowledge of the selected Kuala Lumpur attractions. After the pre-test, each participant interacted with the augmented reality book at their own pace. They experienced the augmented reality tecnology included viewing three-dimensional visualisations, playing short multimedia clips, and reading contextual explanations displayed on their device screens. Immediately after completing the augmented reality experience, participants proceeded with the post-test. Both the pre-test and post-test were limited to ten minutes each, ensuring consistent exposure time across participants. The sequence of pre-test, intervention, and post-test ensured that any observed differences in scores reflected changes resulting from the experience experience rather than external factors.

Data Analysis

Data were analysed using SPSS Statistics version 25. The analysis included descriptive statistics to summarise participant demographics and overall performance patterns. Learning effectiveness was evaluated by comparing pre-test and post-test scores through mean score comparisons, gain percentage calculations, and paired sample t-tests. The threshold for statistical significance was set at $p < .05$. The use of paired t-tests enabled the study to determine whether the differences in scores were statistically meaningful. Although no standard deviations were recorded for the purpose of calculating effect sizes such as Cohen's d, the significant increase observed in the mean post-test scores provides strong evidence of learning improvement attributable to the AR book. Tables summarising demographic information (Table 1) and item-level performance comparisons (Table 2) were used to support the interpretation of the findings and to illustrate patterns in the data. The integration of these tables, along with the conceptual framework in Figure 2, provided a coherent representation of the methodological process and analytical outcomes.

RESULTS

Demographic Profile of Respondents

A total of seventy library users participated in this study. Their demographic characteristics are summarised in Table 1. The sample consisted of 34 males (47.8%) and 36 females (52.2%), indicating a balanced gender distribution. Participants represented a wide age range typical of public library visitors. The largest group comprised users below nine years of age (37.0%), followed by users above twelve years old (39.0%) and those aged ten to twelve (24.0%). This variation reflects the diversity of young readers who visit the library during school days and weekends.

The majority of respondents (69.5%) reported having prior exposure to augmented reality books, while a smaller proportion (6.6%) had never interacted with experience materials before. This distribution suggests that digital reading technologies are becoming more familiar among young users, which may facilitate the integration of augmented reality books into informal learning environments such as public libraries.

Table 1: Demographic Profile of Respondents (n=70)

Category	Sub-category	Frequency	Percentage (%)
Gender	Male	34	47.8
	Female	36	52.2
Age	Below 9 years	25	37.0
	10-12	18	24.0
	Above 12	27	39.0
Previous experience using augmented reality technology	Yes	64	69.5
	No	6	6.6

Pre-test and Post-test Performance

Learners demonstrated substantial improvement in their overall performance after using an augmented reality book. Table 2 presents the comparison of pre-test and post-test results across all ten items. Before interacting with the experience book, learners exhibited moderate baseline knowledge, with a mean pre-test score of 35.2. After interacting with the augmented reality book reading session, the mean post-test score increased to 56.28, representing an approximate gain of 30.1 percent. This improvement aligns with the purpose of the Design Thinking Testing phase shown earlier in Figure 1, where empirical feedback is used to validate and refine the educational prototype.

The consistent increase in scores across items suggests that the augmented reality book enhanced both factual recall and interpretive understanding. These results reinforce the value of augmented reality as an interactive learning tool, especially when the content is embedded with visual aids, multimedia explanations, and three-dimensional representations of real-world locations.

Table 2: Results of Pre-test and Post-test

Questions	Pre-test	Post-test	Increment (%)
Knowledge recall			
Q1	39	62	32.3
Q2	36	59	32.6
Q3	37	56	27.1
Q4	34	53	27.4
Knowledge understanding/interpretation			
Q5	34	56	31.4
Q6	36	56	28.6
Q7	37	56	27.1
Q8	34	53	27.4
Q9	34	56	31.4
Q10	31	56	35.7
Mean	**35.2**	**56.28**	**30.1**

Item-Level Improvements in Knowledge Recall

Knowledge recall items (Q1-Q4) showed strong performance gains. As shown in Table 2, the correct responses for Q1 increased from 39 to 62, representing a 32.3 percent increment. This pattern continued across Q2 (32.6 percent gain), Q3 (27.1 percent gain), and Q4 (27.4 percent gain). These improvements indicate that augmented reality-based visualisation may help young learners strengthen factual memory by presenting information in dynamic, contextually meaningful forms.

For example, a student viewing three-dimensional visualisations of KLCC or the sculpture at Tugu Negara may form stronger associative links compared to reading static text alone. The augmented reality overlays appeared to support clearer recognition and retrieval of geographical and historical facts.

Improvements in Understanding and Interpretation

The interpretive items (Q5-Q10) also demonstrated clear improvement. Table 2 shows gains ranging from 27.1 percent to 35.7 percent across the six understanding-focused questions. The strongest improvement occurred in Q10 (35.7 percent), which required learners to identify the location of Tugu Negara. This result may be attributed to the augmented reality map overlay and visual markers embedded in the augmented reality book, which provided tangible spatial cues that may not be as salient in conventional print.

Understanding-based questions typically require deeper cognitive processing than simple recall. The significant gains observed across items suggest that the augmented reality technology effectively supported interpretive reasoning by integrating visual, textual, and situational cues. This aligns with existing literature on multimodal learning, where spatial representations and layered digital content enhance comprehension and interpretation.

Effectiveness of the Augmented Reality Book

The effectiveness of the augmented reality book was determined by comparing pre-test and post-test results. Findings showed a significant increase in students' post-test scores, indicating improved knowledge recall and understanding. The positive gain score and paired t-test results further confirmed that the augmented reality book enhanced learning performance. Table 3 shows the results on the effectiveness of the augmented reality Book.

Table 3: Results on The Effectiveness of Augmented Reality Book

Test	Mean (%)	t-value	p- value
Pre-test	50.3	15.97	0.000
Post-test	80.4	37.13	

The effectiveness of the augmented reality book was evaluated using pre-test and post-test scores. The pre-test results indicated a mean t-value of 15.97, reflecting students' baseline knowledge and understanding of the selected topics related to Kuala Lumpur attractions. After interacting with the augmented reality book, the post-test results showed a substantially higher mean t-value of 37.13. This marked increase in the t-value demonstrates that students' performance improved significantly after using the augmented reality learning materials. The higher post-test t-value indicates not only a measurable gain in knowledge recall and understanding but also a strong statistical significance in the difference between pre-test and post-test scores.

This study further investigates whether the augmented reality book affects learners' overall learning performance using the following hypothesis:

H_0: There is no significant difference between the pre-test and post-test scores of library users who use the augmented reality book.

The difference between the pre-test and post-test scores was statistically significant ($p = 0.000$, $p < 0.001$), indicating that the observed improvement was extremely unlikely to have occurred by chance. Since the p-value is below a significance level, the null hypothesis is rejected. These results suggest that the interactive and engaging features of the augmented reality book such as visualisation, contextual learning, and hands-on interaction significantly improved students' learning outcomes compared to their baseline performance.

DISCUSSION

The findings of this study demonstrate that the augmented reality book significantly enhanced learners' factual recall and interpretive understanding of Kuala Lumpur's major attractions. This improvement was evident across all test items and age groups, as reflected in the performance patterns summarised in Table 2. The consistent gains observed between the pre-test and post-test suggest that augmented reality books can serve as an effective learning tool within informal learning environments, particularly public libraries where learners engage

voluntarily with educational content. The use of augmented reality as a multimodal enhancement to printed materials appears to support both attention and memory processes, enabling learners to access information through visual, auditory, and situational cues. The integration of visual, auditory, and textual elements enabled learners to form clearer mental models of the landmarks, reinforcing earlier studies that highlight augmented reality's capacity to strengthen both memory encoding and conceptual understanding (Garzón Álvarez, 2021; Latif et al., 2024).

The substantial improvement in knowledge recall items suggests that augmented reality visualisations played a central role in strengthening learners' memory of factual information. According to dual coding theory, learners retain information more effectively when verbal and nonverbal representations are combined, as both cognitive processing channels reinforce each other during encoding (Lazaro & Kim, 2024). In this study, factual details such as landmark identification and key attributes were supported by three-dimensional models and interactive graphic overlays, enabling learners to construct mental images that facilitated recall during the post-test. The increase in correct responses for Q1 through Q4, ranging from 27 percent to 32 percent, is consistent with this theoretical mechanism. augmented reality materials appear to reduce cognitive abstraction and make factual content more concrete, enabling learners to process information more rapidly and with greater clarity. This observation supports the work of Shelton and Hedley (2004) who found that augmented reality improves accuracy in knowledge recall tasks by presenting information through visually rich formats that reduce cognitive ambiguity.

While memory enhancement accounted for part of the learning improvement, the significant gains in interpretive questions reveal that augmented reality also supported deeper cognitive processes such as understanding, explanation, and inference. The improvements across Q5 through Q10, which required learners to explain significance, identify purpose, and interpret spatial or historical context, show that augmented reality provided interpretive cues that extended beyond simple information presentation. Research in educational psychology suggests that multimodal learning environments strengthen comprehension by scaffolding complex information through concrete visual supports (Bujak et al., 2013). In this study, the augmented reality book likely supported interpretive reasoning by enabling learners to visualise locations as immersive three-dimensional scenes rather than static images. The gains observed for interpretive items align with findings from Yang et al. (2025), who reported that augmented reality books enhance not only comprehension but also narrative understanding by prompting deeper engagement with contextual details.

The demographic patterns observed in Table 1 provide insight into how augmented reality materials function in diverse learner populations. Younger children, who often rely more heavily on visual and experiential learning strategies, may have benefited from the interactive features of the augmented reality book that simplified abstraction and supported meaning-making. Older participants, who possess higher baseline knowledge of Kuala Lumpur landmarks due to age-related exposure through school and family visits, may have used augmented reality content to refine existing mental representations. These patterns echo prior research indicating that augmented reality bridges developmental differences by offering flexible multimodal cues that align with different cognitive and experiential profiles (Chen et al., 2023). The broad age distribution in this study strengthens the ecological validity of the results by demonstrating effectiveness across groups typical of public library settings.

The use of the Design Thinking framework also contributes to the coherence and rigour of the intervention. The Testing phase, illustrated earlier in Figure 1, provided a structured pathway for implementing pre-test and post-test measurement, ensuring that feedback was grounded in quantifiable evidence rather than subjective impressions. By embedding the pre-test and post-test design into the Testing phase, this study demonstrates how Design Thinking can be broadened beyond prototyping to include empirical validation. This expands on current literature, where many augmented reality projects rely primarily on qualitative feedback or user satisfaction data without measuring actual learning outcomes (Lin et al., 2024). The results indicate that user-centred design and structured evaluation can complement each other, allowing augmente reality book designers to refine content based on systematic learning outcomes rather than anecdotal feedback.

The strong statistical significance observed in the paired t-tests confirms that the augmented reality intervention had a meaningful educational impact. Although effect size values could not be calculated due to the absence of

standard deviations, the magnitude of the gain score and the consistency of improvements across items provide credible evidence of learning enhancement. This aligns with meta-analytic findings showing that augmented reality interventions typically yield medium to large educational effects, especially when integrated with contextualised and interactive content (Garzón Álvarez, 2021). Additionally, the improvements observed reinforce the value of augmented reality technology in supporting informal learning, a domain where self-directed exploration, curiosity, and voluntary engagement often enhance knowledge construction in ways that differ from formal instruction.

The context of the public library setting is particularly important in interpreting these results. Public libraries provide a unique learning ecology characterised by open access, limited instructional guidance, and spontaneous engagement. Augmented reality books appear well-suited to such environments because they offer embedded guidance within the learning experience itself. Learners can explore at their own pace while receiving real-time feedback and contextual explanations through the augmented reality interface. This self-contained instructional support aligns with studies indicating that augmented reality can function as a scaffolded learning tool that compensates for the absence of direct teacher facilitation (Li & Zaki, 2024). In this study, learners were able to navigate the augmented reality experience with minimal assistance, demonstrating the accessibility and usability of the augmented reality book as an independent learning resource.

The focus on Kuala Lumpur attractions further contributed to the relevance and effectiveness of the augmented reality book. Situated learning theory posits that learners develop stronger understanding when content is tied to real-world contexts that they can recognise or relate to. This alignment between prior knowledge and multimedia representations may have contributed to the strong gains in interpretive understanding, as learners were able to contextualise the digital information within real-world settings (Dunleavy & Dede, 2013; Lave & Wenger, 1991; Wenger, 2022). Because many participants had prior exposure to the featured landmarks, the augmented reality book leveraged existing knowledge structures, enabling learners to integrate new information more effectively. This phenomenon may partly explain why interpretive understanding improved substantially across items, as learners were able to connect augmented reality content with personal experiences and familiar environments.

Finally, this study contributes methodological value by demonstrating how informal learning research can be integrated with structured educational evaluation. Public library contexts present challenges such as varied user motivation, inconsistent attention spans, and heterogeneous demographic composition. Yet, the gains observed here suggest that augmented reality books can overcome these challenges by creating engaging learning moments that capture attention and convey information effectively. This reinforces the idea that augmented reality has significant potential not only in classrooms but also in broader community learning spaces where learners engage through self-selected activities.

CONCLUSION

This study examined the effectiveness of an augmented reality book designed to enhance learners' understanding of Kuala Lumpur attractions within an informal public library setting. The results showed substantial improvements in both factual recall and interpretive understanding, demonstrating that augmented reality materials can support meaningful learning even in unguided, community-based environments. The alignment between multimodal augmented reality features and the Testing phase of the Design Thinking framework highlights the value of combining user-centred design with structured empirical evaluation. Conducting the study in a real library context further emphasises the potential of augmented reality books to foster curiosity-driven and self-paced learning among diverse user groups.

The findings also suggest that augmented reality books can complement public library programmes, particularly those focused on digital literacy, heritage education, and place-based exploration. The ability of learners to connect AR representations with familiar real-world experiences underscores how augmented reality supports deeper comprehension by strengthening contextual associations.

Limitations and Future Work

Despite promising results, several limitations must be acknowledged. The absence of a control group restricts the ability to attribute learning gains solely to the augmented reality technology intervention. Although improvements were substantial, stronger causal claims require comparative or experimental designs. Additionally, standard deviation values were not recorded, preventing calculation of effect size metrics commonly used in high-impact educational research. Collecting complete descriptive statistics in future studies will strengthen methodological rigour.

The study was conducted in a single public library in Kuala Lumpur, which may limit generalisability to other regions or countries. Although participants represented diverse demographics, expanding sampling to multiple libraries, including rural and suburban communities, would enhance external validity. Another limitation concerns the short-term nature of the evaluation, as only immediate post-test results were obtained. Longitudinal measures such as delayed post-tests are needed to assess the durability of augmented reality-supported learning.

Additional limitations include the voluntary participation of learners, which may introduce self-selection bias, and the absence of qualitative data capturing learners' experiences, cognitive load, or interaction challenges. Incorporating interviews, observations, or think-aloud protocols would provide richer insight into how learners navigate AR features and what design improvements may be needed.

Future research should introduce control groups, collect complete statistical datasets, and conduct multi-site or cross-cultural studies to broaden generalisability. Longitudinal evaluations can examine retention and transfer. Expanding augmented reality content to include cultural heritage, science, history, or multilingual materials would increase educational relevance.

From a practical perspective, public libraries could incorporate augmented reality books into reading programmes, digital literacy workshops, and thematic learning events. Establishing dedicated augmented reality stations, training staff, and collaborating with cultural institutions may further strengthen community engagement. With continued refinement, augmented reality books have the potential to become key components of inclusive and innovative library-based learning ecosystems.

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APPENDIX A

Pre-Test Questions

Questions	
Knowledge recall	
Q1	Which landmark is known for being one of the tallest twin towers in the world?
Q2	Who designed the sculpture of Tugu Negara?
Q3	Petrosains is an outdoor theme park.
Q4	Muzium Negara is located in Putrajaya.
Knowledge understanding/interpretation	
Q5	Why is KLCC Park considered an important green space in the city?
Q6	What is the main purpose of Petrosains within Suria KLCC?
Q7	Perdana Botanical Garden is often visited for educational trips because it…
Q8	Muzium Negara helps students understand Malaysia better by…
Q9	Tugu Negara was built to commemorate soldiers who…
Q10	What is the main purpose of Muzium Negara in Kuala Lumpur?