

Empirical Validation of the ASER Framework for Long-Term Knowledge Retention in Augmented Reality

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Abstract—Long-term knowledge retention remains a critical challenge in augmented reality (AR) learning environments, which often prioritize novelty and short-term engagement over durable learning outcomes. This study empirically validates the Augmented Sensory Experience and Retention (ASER) Framework, an instructional model integrating emotional memory cues, interactive storytelling, and gamification within AR to promote sustained learning. A between-subjects experimental design was conducted with 30 adult participants randomly assigned to either an ASER-based AR condition or a traditional non-AR instructional condition. Baseline equivalence was established using equivalence testing. Learning outcomes were assessed using immediate post-test and three-week delayed recall measures. Individual gain scores were analyzed using Mann–Whitney U tests, and a one-way MANOVA examined multivariate effects across emotional engagement, motivation, learning engagement, and cognitive load. Results revealed significantly greater long-term retention gains in the ASER condition, with a large effect size, alongside stronger short-term improvement. Multivariate analysis demonstrated a significant overall effect of instructional condition, with the ASER group reporting higher engagement, motivation, and emotional involvement, as well as more favorable cognitive load. These findings provide empirical support for the ASER Framework and demonstrate that emotionally enriched, narrative-driven, and gamified AR instruction can foster deeper cognitive processing and more durable knowledge retention than conventional instructional approaches. The study offers evidence-based design guidance for developing pedagogically grounded AR learning systems aimed at sustained educational impact.

Keywords—Augmented reality (AR); ASER Framework; long-term knowledge retention; emotional memory; interactive storytelling; gamification

I. INTRODUCTION

In the evolving landscape of educational technology, long-term knowledge retention remains a critical yet underexplored challenge [1]. Although AR has been extensively recognized for its ability to improve engagement and immediate comprehension, its potential to support lasting cognitive outcomes is still being realized [2][3]. Traditional AR applications tend to emphasize visual novelty and interactivity, often neglecting deeper pedagogical principles necessary for

sustained learning [4][5]. An empirical study was designed to evaluate the effectiveness of the ASER Framework, an integrative model that combines emotional memory, interactive storytelling, and gamification within AR learning environments, to improve long-term knowledge retention [6]. The framework integrates emotionally resonant elements and immersive engagement strategies with the goal of producing deeper, more durable learning outcomes.

This study is grounded in the hypothesis that augmented reality learning environments enriched with emotionally aligned content, narrative immersion, and game-based mechanics can support deeper cognitive processing and more durable learning outcomes than conventional instructional approaches [7][6]. Prior research suggests that emotional engagement, storytelling, and gamification each contribute to motivation and memory formation; however, these elements are often examined in isolation rather than as an integrated instructional system [6][8].

To address this gap, the present research investigates how emotionally engaging and interactively structured digital learning environments influence both immediate learning performance and long-term knowledge retention [9][10]. Using a controlled experimental design, learning outcomes were assessed through immediate post-instruction measures and delayed recall testing, enabling evaluation of both short-term understanding and the durability of learning over time [7].

A. Paper Organization

The remainder of this study is organized as follows:

1) *Objective*: This section outlines the primary goal of the ASER framework, emphasizing its role in enhancing long-term knowledge retention through emotional memory, storytelling, and gamification.

2) *Literature review*: A review of existing research on augmented reality learning, emotional engagement, storytelling, and gamification, highlighting strengths, limitations, and research gaps addressed by the ASER Framework.

3) *ASER Framework*: This section presents the theoretical foundations of the ASER Framework and explains how emotional memory, storytelling, and gamification are integrated within AR learning environments.

4) *Methodology*: This section describes the experimental design, including participants, procedure, apparatus, instructional materials, and measurement instruments.

5) *Results*: Presentation of the statistical findings, including gain score analyses and multivariate results examining engagement, motivation, emotional involvement, and cognitive load.

6) *Discussion*: Interpretation of the findings and their implications for AR-based learning design and long-term knowledge retention.

7) *Future work and limitations*: Discussion of research limitations and directions for future investigations.

8) *Conclusion*: A summary of the study's contributions and implications for the design of pedagogically grounded AR learning environments.

II. OBJECTIVE

The objective of this study is to empirically evaluate the effectiveness of the ASER Framework as an instructional model for AR learning environments. The ASER Framework integrates emotional memory cues, interactive storytelling, and gamification mechanisms to support deeper cognitive processing and long-term knowledge retention.

Specifically, this study aims to examine whether ASER-based AR instruction improves both short-term learning performance and long-term knowledge retention compared to traditional, non-AR instructional methods. In addition, the study investigates the impact of the ASER Framework on key experiential and psychological outcomes, including learning engagement, learner motivation, emotional engagement, and cognitive load.

Furthermore, this research seeks to evaluate the combined, system-level effect of the ASER Framework across interrelated cognitive and affective dimensions of learning. By employing complementary individual-outcome analyses alongside multivariate modeling, the study assesses whether emotionally enriched, narrative-driven, and gamified AR instruction produces a coherent and meaningful shift in the overall learning experience.

Through this empirical validation, the study aims to provide evidence-based design guidance for the development of pedagogically grounded AR learning systems that move beyond novelty-driven engagement toward sustained educational impact.

III. LITERATURE REVIEW

Recent advancements in educational technology have spotlighted AR as a powerful medium for enhancing learner engagement and understanding [11]. However, a growing body of research suggests that while AR can significantly improve short-term attention and performance, its potential to support long-term knowledge retention remains underutilized

and insufficiently studied [10]. This review explores key literature on emotional memory, storytelling, and gamification, three pillars of the ASER Framework, and their individual and combined influence on learning outcomes in AR environments.

A. Augmented Reality and Learning Outcomes

AR has been shown to improve motivation, engagement, and conceptual understanding across diverse educational contexts, particularly in science, language learning, and engineering [4][12]. Studies demonstrate that AR's interactive features can foster visualization of abstract concepts and support student-centered, exploratory learning [13][14]. However, most of these studies emphasize immediate learning gains, with limited attention to how these experiences affect long-term recall and knowledge durability [15][16].

B. Emotional Memory in Education

Emotionally charged experiences are more likely to be encoded deeply and retained over time [17][18]. According to educational psychology and affective learning theory, emotional arousal enhances memory consolidation, especially when learning materials are tied to meaningful or affective stimuli [19]. Background music, in particular, has been found to influence learners' emotional states, mood regulation, and memory performance [20] [21]. Despite this, emotional design remains largely absent in current AR-based instructional strategies [22].

C. Storytelling and Narrative Engagement

Storytelling is a time-tested educational approach that enhances retention by connecting information to narrative structures [23]. It allows learners to build empathy, find relevance in abstract topics, and navigate complex ideas through familiar, culturally grounded frames [24][25]. Studies in language and heritage education have shown that AR-supported storytelling improves both comprehension and memory [26][27]. Yet, most AR applications only employ surface-level narratives that lack emotional depth or pedagogical intent, highlighting a gap in narrative integration [6].

D. Gamification and Motivation

The incorporation of game elements such as points, rewards, and feedback has been extensively adopted to foster learner motivation and sustained engagement [28][29]. Research suggests that gamified AR environments can improve learning experiences and performance while reducing cognitive load [30]. However, few studies have examined how gamification affects memory retention, particularly in emotionally driven or narrative-rich AR systems [31]. Moreover, the optimal combination of gamification mechanics for various learning contexts remains unclear [32].

E. Gaps and Integrative Approaches

Although many studies explore AR's impact on engagement or immediate performance, there is a lack of cohesive frameworks that integrate emotional, narrative, and game-based elements for the purpose of enhancing long-term retention [33]. Few interventions intentionally align these

components to reinforce cognitive and emotional memory processes. The ASER Framework was developed to address this gap by systematically combining emotional memory triggers by background music, immersive storytelling, and gamified feedback mechanisms within AR [6]. The need for such integrative and evidence-based pedagogical models has been consistently highlighted across the literature [34][35].

IV. ASER FRAMEWORK

The Augmented Sensory Experience and Retention (ASER) Framework is a pedagogical model specifically designed to enhance long-term knowledge retention through the strategic integration of emotional memory, interactive storytelling, and gamification within AR learning environments [6]. Grounded in constructivist learning theory and principles of empathy-driven education, the framework addresses existing gaps in AR-based learning by moving beyond superficial engagement toward meaningful emotional and cognitive outcomes.

At its core, the ASER Framework emphasises emotionally resonant learning experiences. It utilises background music as an emotional stimulus, strategically aligned with key instructional phases: introduction, challenge, conflict, and resolution, to trigger emotional memory and strengthen the encoding of knowledge. Studies in educational psychology suggest that emotionally engaging experiences, especially those involving music, are more likely to be retained in long-term memory, making this an essential element of the framework.

Storytelling constitutes the second foundational pillar of the ASER Framework. Through culturally relevant and relatable narratives, learners are guided through conceptual material in ways that promote empathy, personal connection, and intrinsic motivation. These narrative journeys help contextualize abstract content, allowing students to see themselves in the learning process and deepen their comprehension. Emotional triggers are intentionally embedded within the storyline to heighten personal engagement and reinforce memory formation.

The gamification layer introduces motivational mechanics such as points, badges, real-time feedback, and level progression. These game-based components are designed to sustain attention, promote positive reinforcement, and encourage constructive responses to challenge and failure. By providing learners with immediate feedback and achievable goals, the gamification system fosters both engagement and iterative learning, ultimately supporting deeper retention.

Collectively, these components form a multi-layered instructional architecture that functions cohesively within AR platforms. The ASER Framework ensures that educational content is not only immersive and interactive but also emotionally engaging and instructionally effective. Its modular structure allows it to be adapted across a range of disciplines and learning environments.

In this study, the ASER Framework was implemented within an AR application designed to teach fundamental chemistry concepts. Participants in the experimental group experienced the full ASER model emotional music integration,

narrative-driven content, and gamified learning mechanics, while the control group received the same material through traditional non-AR methods without emotionally engaging features. This empirical study aims to validate the ASER Framework's effectiveness in promoting learner motivation and long-term knowledge retention, translating its theoretical design into practical educational outcomes.

V. METHODOLOGY

A. Participants

Following approval from the Iowa State University Institutional Review Board (IRB No. 25-450), 30 adult participants were recruited for this study (n = 30; 19 males, 11 females; all aged 18 years or older). Participants were recruited from Iowa State University students and local residents through email invitations distributed via university mailing lists and campus-wide recruitment flyers. Participants were randomly assigned to one of two groups: 15 to the ASER-based AR condition and 15 to the traditional instructional condition. Eligibility criteria required that participants be adults with normal or corrected hearing ability, sufficient to perceive audio-based instructional elements used in the study. No additional medical or physical exclusions were applied.

Prior to participation, all individuals received a full explanation of the study procedures. Participation was voluntary, and participants were informed that they could withdraw at any time without penalty or adverse consequences.

B. Procedure

The study employed a between-subjects experimental design conducted across three structured visits over a four-week period (see Fig. 1).

1) *Orientation and group assignment:* All participants attended an initial orientation session in which the study objectives, procedures, and participation requirements were explained. Demographic information was collected, and participants completed baseline assessments, including a pre-test measuring prior knowledge of the instructional content. To ensure appropriateness for audio-based learning components, participants also completed a brief hearing screening using a tablet-based pure-tone audiometry test.

Participants were then assigned to one of two instructional conditions using stratified random assignment based on pre-test performance to ensure comparable baseline knowledge across groups: the ASER-based learning group (experimental) or the traditional learning group (control).

2) *Learning intervention:* During the second visit, participants individually completed the instructional session corresponding to their assigned condition.

Participants in the ASER group interacted with an AR learning environment designed according to the ASER framework. This environment integrated emotional memory cues through background music, interactive storytelling elements, and gamification features, including feedback for errors and progression-based cues.

Participants in the traditional group received the same instructional content delivered through non-AR, conventional

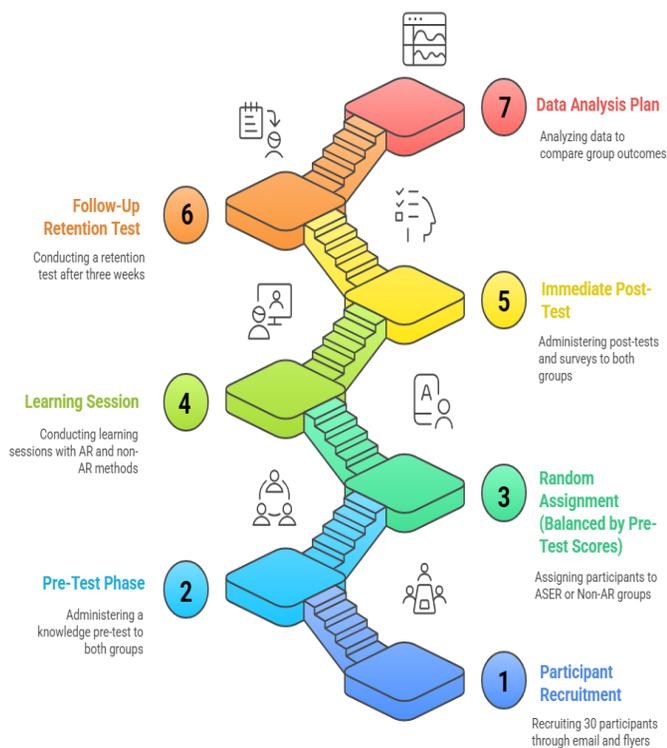


Fig. 1. Overview of the experimental procedure and study timeline.

learning methods, without emotional, narrative, or gamified elements.

Immediately after completing the learning session, all participants completed post-session measures assessing learning engagement, motivation, emotional engagement, and cognitive load. For participants in the ASER condition, system-generated interaction logs were also collected to capture behavioral data during the learning experience.

3) *Delayed recall assessment:* Three weeks following the learning session, participants completed a delayed recall assessment designed to evaluate long-term knowledge retention of the instructional content.

4) *Data management:* All data were de-identified at the point of collection and linked only to assigned study identification codes.

C. Apparatus

AR learning application was developed specifically for this study to implement the ASER Framework and deliver the instructional intervention for the experimental condition. The application was deployed on tablet devices and designed to support integrated audio output, real-time visual feedback, and camera-based, hand-mediated object manipulation. Interaction with the AR system did not rely solely on direct touchscreen input; instead, learners engaged with virtual elements by physically manipulating objects and making movements within the camera's field of view, enabling embodied interaction through physical motion (see Fig. 2). For example, learners interacted with AR-based instructional prompts within the tablet interface, where narrative-driven tasks guided them

through chemistry concepts while virtual elements appeared within the camera view. These interactions allowed learners to explore chemical processes through contextualized AR visualizations and guided feedback.

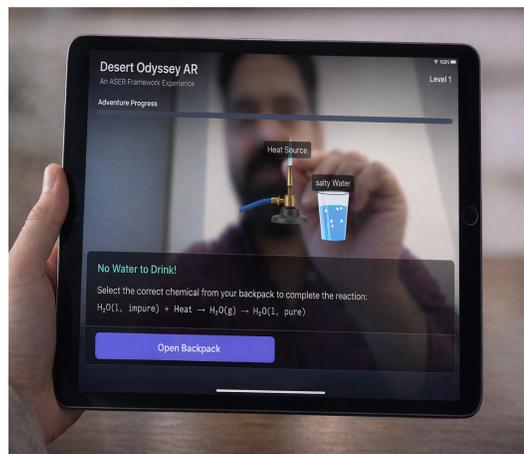


Fig. 2. Full-screen tablet-based AR interface used in the ASER condition with camera-based, hand-mediated interaction.

The AR application presented instructional content covering foundational chemistry concepts, including chemical reactions, thermochemistry, acids and bases, oxidation–reduction processes, and phase changes. All learning materials were aligned with standard general and physical chemistry curricula. The content structure and learning objectives were identical across experimental and control conditions to ensure instructional equivalence, with differences limited solely to the mode of delivery and experiential design.

For participants in the ASER condition, the application integrated the three core components of the ASER Framework. Emotional memory was supported through the use of background music strategically aligned with key instructional phases to elicit affective engagement and support memory encoding. Interactive storytelling elements guided learners through the content using a coherent narrative structure that contextualized abstract chemistry concepts within meaningful scenarios. Gamification features, including progression cues and immediate feedback on learner responses, were incorporated to sustain motivation and engagement throughout the learning session. The instructional experience was structured as a short narrative-driven learning scenario in which learners progressed through a sequence of concept-focused tasks. The narrative followed a problem-solving storyline designed to contextualize chemistry concepts within meaningful situations, allowing learners to explore reactions, phase changes, and thermodynamic processes through interactive AR visualizations. Gamification elements included progression indicators, immediate corrective feedback, and milestone prompts that guided learners through successive learning stages. The learning session lasted approximately 30 minutes for each participant, providing sufficient time for learners to complete the AR activities and interact with the instructional content.

Participants in the traditional condition used the same

tablet devices to access the instructional content in a non-AR format. In this condition, the material was presented without augmented visual overlays, background music, narrative-driven progression, or gamified feedback mechanisms. This design ensured that any observed differences in learning outcomes could be attributed to the ASER-based AR experience rather than content discrepancies or hardware differences.

All tablet devices were configured uniformly, with consistent screen size, audio output, and interaction settings. For participants in the ASER condition, system-generated interaction logs were recorded to capture behavioral engagement during the learning experience. No personally identifiable information was collected through the application, and all data were stored securely in accordance with institutional ethical and data protection guidelines.

D. Instructional Content and Subject Domain

The instructional content focused on foundational chemistry concepts aligned with introductory general chemistry curricula. Topics included chemical reactions, thermochemistry (endothermic and exothermic processes), phase changes, oxidation–reduction reactions, and acids–bases. The content was designed to emphasize conceptual understanding rather than procedural calculation and was identical across experimental and control conditions [36][37]. In the ASER condition, these concepts were embedded within an emotionally enriched, narrative-driven AR experience with gamified feedback, while the traditional condition presented the same content using non-AR instructional materials.

E. Measurements

The study assessed multiple outcome variables to evaluate the effectiveness of the ASER Framework across cognitive, emotional, and experiential dimensions of learning.

Knowledge retention: Learning performance was measured using three assessments: a pre-test administered prior to the learning intervention to establish baseline knowledge, an immediate post-test administered after the instructional session to measure short-term learning performance, and a delayed recall test administered three weeks later to assess long-term knowledge retention. All tests consisted of objective, content-aligned questions scored numerically. To assess retained conceptual understanding rather than item-specific memorization, the post-test and delayed recall assessments employed different but conceptually equivalent questions of comparable difficulty, each targeting the same underlying chemistry principles [38][39]. For example, items in both assessments evaluated understanding of phase change processes using distinct surface formulations while requiring the same level of conceptual reasoning. This design ensured that delayed recall performance reflected durable understanding of the content rather than recall of identical test items.

Learning engagement: Learning engagement was measured using a self-report questionnaire administered immediately after the learning session. Items assessed participants' perceived involvement, attention, and interest during the learning experience. Responses were recorded on a 5-point

Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).

Motivation: Learner motivation was assessed using a validated motivation scale adapted from prior educational research [40]. The scale measured intrinsic motivation, interest, and willingness to persist with the learning task. Participants responded using a 5-point Likert scale from Strongly Disagree (1) to Strongly Agree (5).

Emotional engagement: Emotional engagement was measured using a self-report instrument designed to capture participants' affective responses during the learning experience, including interest, enjoyment, and emotional involvement. Items were rated on a 5-point Likert scale. Higher scores indicated greater emotional engagement.

Cognitive load: Perceived cognitive load was measured using a cognitive load questionnaire adapted from established instruments in multimedia learning research [41]. Items assessed the level of mental effort and perceived difficulty experienced during the learning task. Responses were recorded on a 5-point Likert scale, with higher scores reflecting more favorable (lower perceived strain) cognitive load outcomes.

All surveys were administered in person immediately following the learning session using paper-based questionnaires. Participants completed the questionnaires individually in a controlled environment. The surveys were designed to ensure that no personally identifiable information was collected, and all responses were recorded anonymously.

The psychological and experiential scales used in this study were adapted from previously validated instruments commonly employed in educational technology and learning sciences research [42]. Emotional engagement items were adapted from established affective engagement measures, motivation items were derived from validated motivational frameworks used in AR-based learning studies, and cognitive load was assessed using items adapted from widely used cognitive load measurement instruments [43][44][45]. Prior studies have demonstrated strong internal consistency and construct validity for these measures, supporting their suitability for assessing engagement, motivation, emotional experience, and cognitive load in technology-enhanced learning environments [46][47]. The use of established instruments enhances the reliability and interpretability of the findings [48]. The survey instruments were adapted from previously validated measures in educational and psychological research, which have demonstrated strong reliability and construct validity in prior studies [49] [50][41][51]. These instruments have been widely used to assess constructs such as learner engagement, motivation, emotional involvement, and cognitive load in educational and technology-enhanced learning environments. Internal consistency reliability of the survey instruments was assessed using Cronbach's α . All constructs demonstrated excellent reliability: learning engagement ($\alpha = .949$), motivation ($\alpha = .918$), emotional engagement ($\alpha = .957$), and cognitive load ($\alpha = .954$). These results indicate that the items within each construct consistently measured the intended underlying latent dimension.

VI. RESULTS

All data were analyzed using IBM SPSS Statistics (Version 31.0).

Baseline equivalence in prior knowledge was evaluated using an equivalence testing approach based on the two one-sided tests (TOST). A predefined equivalence margin of ± 1.25 points was established for the 10-point pre-test. A 90% confidence interval (CI) for the mean difference between instructional conditions was constructed, and equivalence was supported if the CI fell entirely within the specified bounds.

For knowledge outcomes, treatment effects were examined at the individual level using gain scores. Gain scores were computed for short-term performance (Post_Score – Pre_Score) and long-term retention (Recall_Score – Pre_Score), allowing direct assessment of within-participant change. Between-group differences in gain scores were analyzed using Mann–Whitney U tests due to the modest sample size and non-normal distribution assumptions.

The Mann–Whitney U statistic represents the test value derived from ranking all observations across the two independent groups and evaluating whether the distributions differ significantly. Effect sizes were computed as:

$$r = \frac{|Z|}{\sqrt{N}},$$

where, Z is the standardized value of the Mann–Whitney U statistic and N is the total sample size ($N = 30$). Statistical significance was evaluated at an alpha level of .05 (two-tailed).

To evaluate the overall, system-level effect of instructional condition across multiple related psychological and experiential outcomes (emotional engagement, motivation, learning engagement, and cognitive load), a one-way between-subjects multivariate analysis of variance (MANOVA) was conducted. MANOVA was used to assess the combined influence of instructional condition while controlling for inflated Type I error associated with multiple comparisons. Because Box's Test of Equality of Covariance Matrices was significant, Pillai's Trace was selected as the primary multivariate test statistic due to its robustness to violations of the homogeneity of covariance assumption. Effect sizes for multivariate and follow-up analysis are reported using partial eta squared (η_p^2).

A. Baseline Equivalence

Baseline equivalence in prior knowledge was evaluated using an equivalence testing approach rather than a traditional null-hypothesis significance test. Following the two one-sided tests (TOST) framework [52], an equivalence margin of ± 1.25 points was defined on the 10-point pre-test scale. This margin represents 12.5% of the total score range and was considered a practically negligible difference in baseline knowledge.

Formally, equivalence was defined using the following hypotheses:

$$H_0 : |\mu_{ASER} - \mu_{Traditional}| \geq 1.25 \quad (1)$$

$$H_1 : |\mu_{ASER} - \mu_{Traditional}| < 1.25 \quad (2)$$

An independent-samples t test was conducted to construct the 90% confidence interval (CI) for the mean difference in pre-test scores between instructional conditions. The ASER group ($M = 3.80$, $SD = 1.47$) and the traditional group ($M = 4.07$, $SD = 1.34$) differed by -0.27 points. The 90% CI for the mean difference was $[-1.14, 0.61]$, which falls entirely within the predefined equivalence bounds of $[-1.25, 1.25]$.

Because the confidence interval is fully contained within the equivalence margin, the null hypothesis of non-equivalence was rejected. These results support statistical equivalence between groups at baseline, indicating that prior knowledge levels were comparable before the instructional intervention.

B. Knowledge Retention (H1)

H1. The ASER framework leads to higher long-term knowledge retention compared to traditional learning methods.

To evaluate long-term retention at the individual level, retention gain scores were calculated for each participant as $\text{Gain}_{\text{Long}} = \text{Recall} - \text{Pre}$. A Mann–Whitney U test revealed a statistically significant difference between instructional conditions. Participants in the ASER group demonstrated substantially greater retention gains than those in the traditional group, $U = 6.00$, $Z = -4.458$, $p < .001$, $r = .81$. This large effect size indicates a substantial individual-level advantage in durable learning under the ASER framework (see Fig. 3).

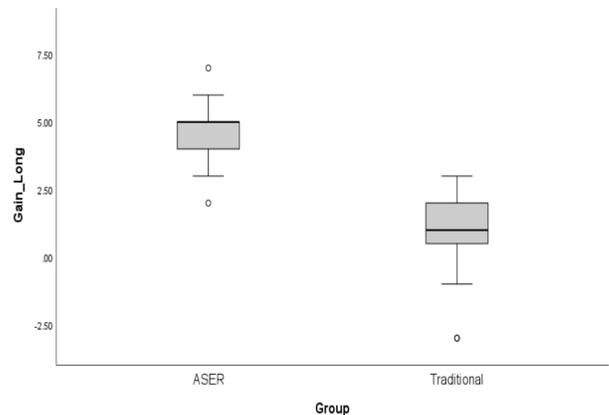


Fig. 3. Long-term retention gain scores ($\text{Recall} - \text{Pre}$) comparing ASER and traditional learning conditions.

C. Short-Term Learning Performance (H2)

H2. The ASER Framework improves short-term learning performance compared to traditional instruction. To evaluate short-term learning performance at the individual level, gain scores were calculated for each participant as $\text{Gain}_{\text{Short}} = \text{Post} - \text{Pre}$. A Mann–Whitney U test revealed a statistically significant difference between instructional conditions. Participants in the ASER condition demonstrated greater short-term improvement compared to those in the traditional condition ($U = 55.00$, $Z = -2.43$, $p = .015$, $r = .44$). This medium-to-large effect size indicates that the

ASER framework produced stronger immediate learning gains relative to baseline knowledge (see Fig. 4).

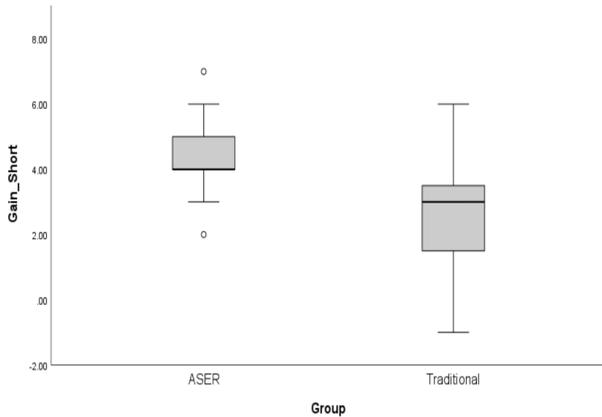


Fig. 4. Short-term learning gain scores (*Post - Pre*) comparing ASER and traditional learning conditions.

D. Learning Engagement (H3)

H3. The ASER Framework increases learning engagement compared to traditional learning methods.

Learning engagement scores differed significantly between groups. Participants in the ASER condition reported higher engagement levels (Mean Rank = 22.70) compared to those in the traditional condition (Mean Rank = 8.30), $U = 4.50$, $Z = -4.511$, $p < .001$, $r = .82$. These results support H3 and indicate that the interactive and immersive characteristics of the ASER framework significantly enhanced learner engagement.

E. Motivation Levels (H4)

H4. Students engaged with the ASER Framework exhibit higher motivation levels than students in traditional learning environments.

A Mann-Whitney U test revealed a statistically significant difference in motivation scores between groups. The ASER group demonstrated higher motivation (Mean Rank = 22.93) than the traditional group (Mean Rank = 8.07), $U = 1.00$, $Z = -4.641$, $p < .001$, $r = .85$. This finding supports H4 and suggests that the emotionally stimulating and gamified elements embedded in the ASER framework substantially increased learner motivation.

F. Cognitive Load (H5)

H5. The ASER Framework leads to lower cognitive load compared to traditional learning methods.

Cognitive load scores were analyzed using a Mann-Whitney U test. Results showed a statistically significant difference between groups, with the ASER group reporting more favorable cognitive load outcomes (Mean Rank = 22.73) than the traditional group (Mean Rank = 8.27), $U = 4.00$, $Z = -4.553$, $p < .001$, $r = .83$. These results support H5 and indicate that the ASER framework reduced perceived cognitive strain relative to traditional instruction.

G. Emotional Engagement (H6)

H6. The ASER Framework results in higher emotional engagement compared to traditional learning methods.

Emotional engagement demonstrated the largest between-group difference among the measured psychological outcomes. A Mann-Whitney U test showed that participants in the ASER group reported significantly higher emotional engagement (Mean Rank = 23.00) than those in the traditional group (Mean Rank = 8.00), $U = 0.00$, $Z = -4.704$, $p < .001$, $r = .86$. This result supports H6 and is consistent with the ASER framework's emphasis on emotional memory, storytelling, and gamification.

H. Multivariate Effects of Instructional Condition

To evaluate the overall effect of instructional condition across multiple related psychological and experiential outcomes, a one-way MANOVA was conducted. The analysis assessed the combined influence of instructional condition on emotional engagement, motivation, learning engagement, and cognitive load.

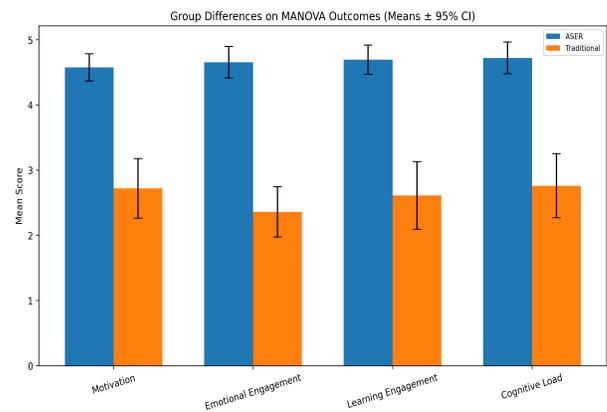


Fig. 5. Multivariate group differences across engagement, motivation, emotional engagement, and cognitive load.

Intercorrelations among the four dependent variables were examined using Kendall's tau-b and indicated strong positive associations ($\tau = .718-.851$, all $p < .001$), without evidence of extreme multicollinearity (no association $\geq .90$), supporting the appropriateness of a multivariate analytical approach. Because Box's Test of Equality of Covariance Matrices was significant (Box's $M = 27.689$, $p = .010$), Pillai's Trace was selected as the primary multivariate statistic due to its robustness to violations of the homogeneity assumption.

The analysis revealed a statistically significant overall multivariate effect of instructional condition, Pillai's Trace = .809, $F(4, 25) = 26.389$, $p < .001$, indicating significant differences between conditions across the combined dependent variables (see Fig. 5). Examination of effects within the multivariate model demonstrated significant group differences for motivation, emotional engagement, learning engagement, and cognitive load. Partial eta squared (η_p^2) was used to estimate effect sizes, revealing large effects for motivation ($\eta_p^2 = .690$, $p < .001$), emotional engagement ($\eta_p^2 = .807$, $p < .001$), learning engagement ($\eta_p^2 = .690$, $p < .001$), and

cognitive load ($\eta_p^2 = .677, p < .001$), with participants in the ASER condition reporting more favorable outcomes across all measures.

VII. DISCUSSION

This research provides important insights into the effectiveness of the ASER Framework as an instructional approach for AR learning. The findings demonstrate that integrating emotional memory, interactive storytelling, and gamification within an AR environment can produce meaningful improvements across multiple learning-related outcomes. Overall, the results indicate that the ASER Framework supports substantial improvements in long-term knowledge retention, alongside gains in short-term learning performance, learner engagement, and motivation. These outcomes suggest that AR learning environments designed with a strong pedagogical structure, rather than focusing solely on visual interactivity, can yield deeper and more durable educational benefits.

The significant improvement observed in long-term knowledge retention among participants in the ASER condition is particularly noteworthy. Unlike many AR-based interventions that emphasize immediate performance gains, the present study demonstrates that ASER supports memory retention several weeks after the learning experience. Importantly, the effect size observed for delayed recall was substantially larger than that observed for immediate post-test performance. This pattern suggests that the ASER Framework may exert its strongest influence on memory consolidation processes rather than solely on initial comprehension. Immediate post-test performance can be influenced by recency and short-term rehearsal effects that benefit both instructional conditions [53]. In contrast, delayed recall more directly reflects the durability of encoding and the stability of memory traces over time [17].

This finding aligns with theoretical perspectives on emotional memory, which posit that emotionally salient learning experiences facilitate deeper encoding and more effective consolidation of information. By embedding instructional content within an emotionally enriched narrative context, the ASER Framework appears to strengthen associative links between conceptual material and affective cues, thereby increasing the likelihood of successful retrieval after extended intervals. From an instructional standpoint, this suggests that emotional and narrative elements should be treated as central components of AR learning design rather than optional enhancements. The stronger long-term effect indicates that ASER does not merely improve performance in the moment but may meaningfully reduce knowledge decay over time.

Beyond statistical significance, the magnitude of the retention difference also carries practical importance. The consistent separation between groups three weeks after instruction suggests that learners exposed to the ASER-based experience retained a substantially greater proportion of conceptual understanding. In real educational settings, such improvements could translate into reduced need for repeated review, stronger cumulative learning, and more stable knowledge foundations for advanced topics. Thus,

the observed gains are not only statistically reliable but educationally meaningful.

In addition to its effects on long-term retention, the ASER Framework was associated with higher short-term learning performance immediately following instruction. Although the magnitude of this effect was more moderate compared to delayed recall, the results suggest that the immersive and interactive features of the ASER-based environment supported initial comprehension of the material. Given that immediate post-test performance can be influenced by short-term rehearsal and recency effects that may benefit both instructional conditions, the comparatively smaller effect at this stage is not unexpected. Importantly, these short-term gains occurred alongside lower reported cognitive load. Participants in the ASER condition reported lower perceived cognitive load compared to those in the traditional condition, suggesting that the structured narrative flow, multimodal presentation, and guided progression cues within the ASER environment may have reduced extraneous cognitive demands, allowing learners to allocate cognitive resources more efficiently toward meaningful learning processes.

The findings related to learning engagement and motivation further highlight the strengths of the ASER Framework. Participants exposed to the ASER-based experience reported significantly higher levels of engagement and motivation than those in the traditional learning condition. These results are consistent with prior research demonstrating that gamification and interactive AR environments can enhance learner involvement. However, the present study extends this literature by showing that engagement and motivation were embedded within a coherent pedagogical framework rather than driven solely by novelty or entertainment. The integration of storytelling, feedback mechanisms, and emotionally aligned cues likely contributed to sustained attention and intrinsic motivation, supporting learners' willingness to persist with the learning task.

Emotional engagement emerged as the most strongly affected outcome, underscoring its central role within the ASER Framework. Participants in the ASER condition reported substantially higher emotional engagement, suggesting that the deliberate use of affective design elements such as background music, narrative progression, and meaningful feedback successfully elicited emotional responses that enhanced the learning experience. From the authors' perspective, this finding reinforces the argument that emotional engagement functions as a cognitive facilitator rather than a distraction. When carefully aligned with instructional goals, emotional elements can enhance meaning-making, relevance, and memory consolidation, thereby improving overall learning effectiveness.

The multivariate analysis further supports the holistic impact of the ASER Framework. The significant MANOVA results indicate that instructional condition exerted a combined effect across emotional engagement, motivation, learning engagement, and cognitive load. Although these outcomes are measured on bounded 5-point Likert scales, which naturally constrain score dispersion, the consistent and substantial group separation across all measures reflects a theoretically coherent pattern. Engagement, motivation, emotional engagement, and cognitive load represent interrelated dimensions of the learning

experience and were intentionally influenced together by the ASER Framework. Their convergence reflects a system-level experiential shift rather than redundancy among measures. This multivariate perspective demonstrates that the benefits of the ASER Framework are not isolated to a single outcome but operate across interconnected cognitive and affective dimensions of learning.

Taken together, these findings suggest that the ASER Framework offers a promising design model for AR-based learning environments that aim to move beyond surface-level engagement toward deeper, long-lasting educational impact. The stronger long-term retention effect reinforces the framework's central premise: emotionally enriched, narrative-driven, and gamified AR instruction can support durable learning rather than transient performance gains. The strength of the framework lies in its integrative approach, which coordinates emotional memory, narrative structure, and gamification to reduce cognitive strain while enhancing engagement and retention. Importantly, the present study evaluates the ASER Framework as an integrated instructional system in which augmented reality interaction, emotional memory cues, interactive storytelling, and gamification operate together. Accordingly, the findings should be interpreted as evidence for the combined effect of the framework rather than the isolated contribution of any single design component. These results have important implications for educators, instructional designers, and developers seeking to leverage AR technologies for meaningful learning. Future research may explore how individual components of the ASER Framework contribute to learning outcomes across different subject domains and learner populations, further refining the framework and expanding its applicability.

VIII. FUTURE WORK AND LIMITATIONS

Several limitations should be considered when interpreting the findings of this study. First, the experimental sample size was ($N = 30$), which may limit the generalizability of the results despite the statistically significant effects observed.

Future studies with larger and more diverse samples would help strengthen the empirical validation of the ASER Framework. Second, several experiential variables in this study, including engagement, motivation, emotional involvement, and cognitive load, were measured using self-reported survey instruments. Although validated scales were used, self-report measures may be influenced by response biases such as social desirability or novelty effects. Future studies could complement these measures with objective behavioral metrics derived from interaction logs or physiological indicators. Finally, long-term retention was assessed after a three-week delay. While this interval provides meaningful evidence of delayed learning outcomes, longer follow-up periods would provide stronger insight into the durability of ASER-based learning effects.

Future research should extend the ASER Framework beyond the chemistry-focused context of the present study to examine its applicability across a wider range of subject domains and learner populations. Investigating ASER-based learning experiences in fields such as physics, biology, mathematics, history, and language learning would help

determine whether the observed benefits for engagement and long-term knowledge retention generalize across content areas. Such studies could also clarify how subject-specific cognitive structures and representational demands influence the effectiveness of emotional memory, storytelling, and gamification within augmented reality environments.

Future studies should further explore the ASER Framework with larger and more diverse participant groups to support broader implementation across varied educational settings. Expanding participant diversity would enable more detailed analyses, including subgroup comparisons and component-level investigations, helping to refine the framework and better understand how its integrated elements contribute to learning outcomes.

Additional research should examine the impact of the ASER Framework across different age groups, including children, adolescents, and older adult learners. Learners at different developmental stages may respond differently to emotional cues, narrative complexity, and gamified interactions, influencing engagement, cognitive load, and retention. Examining age-related variations would provide insight into how ASER-based designs can be tailored to developmental needs and learning preferences.

Finally, future work should investigate the role of cultural context in ASER-based storytelling. Narrative structures, characters, symbols, and emotional cues may be interpreted differently across cultures, potentially shaping emotional engagement and learning effectiveness. Comparative studies that adapt ASER storytelling elements to diverse cultural contexts could identify culturally responsive narrative strategies and clarify how cultural alignment influences emotional memory and long-term knowledge retention, strengthening the framework's global applicability.

IX. CONCLUSION

The findings of this study empirically validated the ASER Framework as an instructional model for AR learning environments, with a specific focus on enhancing long-term knowledge retention. By integrating emotional memory cues, interactive storytelling, and gamification within a cohesive AR learning experience, the ASER Framework was shown to produce meaningful improvements across both cognitive and affective learning outcomes.

The results demonstrated that learners who engaged with the ASER-based AR experience achieved significantly higher short-term learning performance and substantially greater long-term knowledge retention compared to learners who received traditional, non-AR instruction. Importantly, these gains were observed several weeks after the learning intervention, providing evidence that emotionally enriched and narrative-driven AR experiences can support durable learning rather than only immediate performance improvements.

Beyond knowledge outcomes, the ASER Framework also exerted a strong positive influence on experiential and psychological dimensions of learning. Participants in the ASER condition reported significantly higher levels of emotional engagement, motivation, and learning engagement, alongside more favorable cognitive load. The multivariate

analysis confirmed that these outcomes did not operate in isolation but reflected a coherent, system-level shift in the overall learning experience. This pattern aligns with the theoretical foundations of the ASER Framework, which intentionally coordinates emotional, narrative, and motivational elements to support deeper cognitive processing while reducing extraneous mental effort.

Collectively, these findings suggest that AR learning environments designed with a strong pedagogical structure, rather than relying solely on visual novelty or interactivity, can yield deeper, more sustained educational benefits. The ASER Framework provides a theoretically grounded and empirically supported design model that demonstrates how emotional memory, storytelling, and gamification can be systematically integrated to enhance both learner experience and long-term retention.

By moving beyond short-term engagement metrics and providing empirical evidence of lasting learning effects, this study contributes to the growing body of research on pedagogically grounded AR learning design. The ASER Framework offers practical guidance for educators, instructional designers, and developers seeking to leverage AR technologies to achieve meaningful and enduring learning outcomes across diverse educational contexts.

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