

# e-mentor

DWUMIESIĘCZNIK SZKOŁY GŁÓWNEJ HANDLOWEJ W WARSZAWIE  
WSPÓŁWYDAWCA: FUNDACJA PROMOCJI I AKREDYTACJ KIERUNKÓW EKONOMICZNYCH

2026, nr 1 (113)



Fridhi, B. (2026). Integrating augmented reality into active learning: An empirical mixed-methods study in higher and secondary education. *e-mentor*, 1(113), 24–32. <https://www.doi.org/10.15219/em113.1737>

Copyright © 2026, Bechir Fridhi



Bechir  
Fridhi

# Integrating Augmented Reality into Active Learning: An Empirical Mixed-Methods Study in Higher and Secondary Education

## Abstract

The rapid evolution of digital technologies has transformed traditional teaching paradigms, prompting educators to explore innovative approaches that enhance learner engagement and participation. Among these innovations, Augmented Reality (AR) stands out as a promising tool that merges virtual elements with the physical learning environment, creating dynamic and interactive experiences. This article proposes a conceptual framework for integrating AR into pedagogical strategies to foster active learning across various educational contexts. Drawing on recent studies in educational technology, cognitive psychology, and instructional design, the framework emphasises the role of AR in promoting experiential learning, collaborative problem-solving, and conceptual understanding through immersive visualisation. It also explores how AR applications can support constructivist teaching models by allowing students to manipulate virtual objects, visualise abstract concepts, and engage in authentic learning tasks. The paper further discusses the challenges associated with implementing AR in classrooms such as teacher readiness, infrastructure constraints, and pedagogical alignment and proposes solutions to overcome them. Ultimately, this study argues that when effectively integrated, AR can act as a transformative catalyst for pedagogical innovation, bridging the gap between digital interactivity and meaningful learning outcomes.

*Keywords:* Augmented Reality (AR), active learning, pedagogical strategies, educational technology, immersive learning, instructional design, cognitive engagement, digital education

## Introduction

In an era defined by rapid technological evolution and digital innovation, Augmented Reality (AR) has emerged as a transformative force capable of reshaping traditional educational paradigms. As digital natives increasingly demand interactive and immersive learning experiences, conventional lecture-based models appear insufficient to address the complex cognitive, emotional, and social dimensions of learning in the twenty-first century. Within this context, integrating AR into pedagogical strategies has become a promising pathway to promote active learning, foster student engagement, and strengthen the connection between theory and experience (Fridhi & Bali, 2022).

Active learning, widely recognised in educational research, refers to instructional methods that engage students directly in constructing knowledge through hands-on, collaborative, and reflective activities rather than passively receiving information. It emphasises cognitive engagement, critical thinking, and experiential participation (Akçayır & Akçayır, 2017). By superimposing digital information, animations, or 3D models onto the real world, AR offers a unique bridge between abstraction and tangible experience. This blending allows learners to manipulate virtual representations of abstract concepts, explore complex systems, and visualise phenomena that would otherwise be invisible or inaccessible. As such, AR serves as an innovative pedagogical instrument that enhances experiential, inquiry-based, and constructivist learning environments (Ibáñez & Delgado-Kloos, 2018).

Recent studies have provided strong evidence of the positive effects of AR on learning processes across multiple educational domains (Bower et al., 2020; Mirza

et al., 2025). A comprehensive systematic review on STEM education revealed that AR improves academic achievement, motivation, and learner environment interaction while facilitating visualisation and retention of complex knowledge structures (Bower et al., 2020). Similarly, a study demonstrated that secondary-school biology students who participated in AR-based activities exhibited higher engagement, motivation, and understanding of cellular structures than those in traditional learning settings (Ibáñez & Delgado-Kloos, 2018). These findings confirm that AR can reduce cognitive barriers by making abstract content more intuitive and relatable.

Moreover, research in Oman and Nigeria has highlighted that science teachers increasingly express a willingness to adopt AR technologies to enrich instruction in physics, biology, and chemistry, though they often lack the digital proficiency to design and manage immersive lessons effectively (Abdul-Salaam, 2024; Al Buraiki et al., 2025). While these findings demonstrate strong pedagogical potential, they also underline the implementation gap between technological availability and effective educational integration.

Despite its growing relevance, integrating AR into formal education remains a complex endeavour, with technical, pedagogical, and institutional challenges. The lack of teacher readiness is among the most recurrent barriers, encompassing insufficient digital skills, limited competence in pedagogical design, and a lack of confidence in using emerging technologies (Vidak et al., 2023). Additionally, infrastructure limitations including connectivity issues, inadequate devices, and resource constraints hamper large-scale adoption in many educational systems. Cognitive load also represents a significant consideration, as overly complex or visually dense AR applications may distract learners rather than enhance their focus.

Consequently, the current research argues that a comprehensive pedagogical framework is required to guide the effective integration of AR into educational strategies. Such a framework must address several interdependent dimensions:

- Pedagogical alignment ensuring AR activities are designed with clear learning objectives rather than serving as superficial technological enhancements.
- Active engagement design creating immersive tasks that encourage exploration, collaboration, and self-directed learning.
- Teacher training and professional development equipping educators with both technical and instructional competencies for meaningful AR integration.
- Technological accessibility providing reliable infrastructure, equitable access, and ongoing technical support.
- Learning outcome assessment measuring not only engagement but also conceptual understanding, cognitive retention, and transfer of knowledge.

This article proposes an integrative framework for embedding AR into pedagogical strategies to reinforce active learning across diverse educational contexts. The proposed model synthesises insights from educational technology, cognitive psychology, and instructional design, emphasising how immersive technologies can transform learning experiences. The framework is structured to help educators, policymakers, and researchers systematically design, implement, and evaluate AR-supported teaching strategies that maximise learning benefits while minimising risks and cognitive overload.

The motivation for this research arises from a persistent disconnect between the theoretical potential of AR and its practical application in educational institutions. While numerous studies report improvements in student engagement and understanding, many implementations remain fragmented, under-evaluated, or poorly aligned with curricular goals (Yanti et al., 2025). Thus, the challenge is not merely to adopt AR technologies but to embed them meaningfully within instructional design. By addressing this gap, the present study aims to contribute to both academic literature and classroom practice, offering a framework that bridges theory, technology, and pedagogy. Ultimately, AR should not be viewed as a technological novelty, but as a transformative pedagogical tool that redefines how learners interact with information, collaborate with peers, and construct meaningful knowledge. Through thoughtful integration, AR can empower teachers to design learning environments that are engaging, inclusive, and cognitively stimulating, thereby fulfilling the promise of education in the digital age.

## Research Questions and Hypotheses

This study aims to empirically examine the pedagogical impact of integrating Augmented Reality (AR) into active learning environments across higher and secondary education contexts. While prior research has emphasised the theoretical benefits of AR, the present study seeks to provide structured empirical validation through a mixed-methods design.

Accordingly, the study is guided by the following research questions:

- RQ1:** Does the integration of AR significantly improve students' conceptual understanding compared to traditional multimedia instruction?
- RQ2:** Does AR-based instruction enhance students' intrinsic motivation and perceived competence?
- RQ3:** How do students and teachers perceive AR-supported learning in terms of engagement, collaboration, and cognitive activation?

Based on these research questions, the following hypotheses are formulated:

- H1:** Students exposed to AR-enhanced instruction will demonstrate significantly higher post-test scores than students receiving traditional instruction.

- H2:** AR-based learning will significantly increase intrinsic motivation, particularly in the Interest/Enjoyment and Perceived Competence subscales of the Intrinsic Motivation Inventory (IMI).
- H3:** AR-supported learning environments will generate higher levels of observable active learning behaviours, including peer interaction, inquiry dialogue, and reflective reasoning.

These hypotheses provide a structured foundation for the quantitative and qualitative analyses presented in the subsequent sections.

### Literature Review

Over the past decade, Augmented Reality (AR) has emerged as a transformative force in education, progressively moving from experimental use to a significant pedagogical innovation supported by empirical research. Numerous studies and systematic reviews have highlighted that AR enhances student engagement, motivation, and comprehension when effectively integrated into instructional design. Akçayır and Akçayır (2017) emphasised that the success of AR lies not in its technological novelty but in its ability to connect abstract content with tangible, interactive experiences that stimulate deeper understanding. Similarly, Ibáñez and Delgado-Kloos (2018) found that AR is particularly effective in STEM education, where visualization of invisible or complex phenomena, such as molecular structures or physical forces, is essential to cognitive development (Fridhi et al., 2023).

The theoretical underpinnings of AR in education can be traced to constructivist and experiential learning theories, which emphasise that learners construct knowledge through active engagement and contextualised experiences. When learners manipulate digital overlays embedded in real environments, they do not passively receive information; instead, they co-construct meaning through exploration, experimentation, and feedback. This process aligns with the principles of active learning, where interaction, reflection, and problem-solving are central to knowledge acquisition. Augmented Reality (AR) enhances learning by integrating perceptual experiences with motor interaction and abstract reasoning processes, which contributes to deeper cognitive processing and stronger conceptual understanding. By engaging learners in interactive and immersive environments, AR facilitates the encoding of information into long-term memory while supporting meaningful knowledge construction. This synergy between sensory immersion and cognitive engagement helps explain why AR-based learning environments often lead to higher retention rates and improved problem-solving skills compared to traditional instructional approaches (Bali & Fridhi, 2024).

Empirical evidence confirms that AR enhances not only cognitive outcomes but also affective and behavioural dimensions of learning. Meta-analyses conducted by Li (2025) indicate that students exposed to AR environments show higher motivation, engage-

ment, and satisfaction, leading to deeper involvement in the learning process. However, these positive effects depend significantly on the pedagogical design of AR activities. Poorly structured AR experiences, overloaded with visual stimuli or disconnected from learning objectives, may increase cognitive load and reduce comprehension. Therefore, educators must adhere to evidence-based design principles, including alignment with learning outcomes, cognitive scaffolding, and interactivity that demands learner agency (Akçayır & Akçayır, 2017).

The motivational dimension of AR is equally compelling. Learners often report greater curiosity and enjoyment when using AR tools compared with traditional materials. This sense of novelty fosters engagement and encourages self-directed learning. However, warned that such novelty effects may be temporary unless AR experiences are supported by reflective and collaborative activities that extend engagement beyond the technological appeal. Sustained motivation emerges when AR is integrated into a broader pedagogical ecosystem that values dialogue, feedback, and iterative exploration.

Despite its potential, the integration of AR in education presents several challenges, particularly concerning teacher readiness and institutional support (Fridhi & Bali, 2021). Nikou et al. (2024) found that while teachers express enthusiasm toward AR, many lack the pedagogical and technical skills to design meaningful AR-based lessons. Professional development initiatives must therefore move beyond basic technical training to include co-design workshops, reflective practices, and continuous mentoring. Piedade and Batista (2025) similarly emphasised the importance of developing AR competence frameworks that include content creation, pedagogical integration, classroom management, and assessment strategies. Without such systematic support, the use of AR may remain superficial or inconsistent across classrooms.

Another essential dimension emerging from recent research concerns accessibility, infrastructure, and equity. Studies conducted in diverse socio-economic contexts reveal that access to AR-compatible devices, reliable connectivity, and digital literacy remain uneven, potentially exacerbating educational inequalities (Abdul-Salaam, 2024). To mitigate this, Li (2025) and Yanti et al. (2025) recommend scalable, inclusive solutions, such as offline AR applications, low-cost smartphone-based platforms, and localised content aligned with national curricula. The equitable implementation of AR also requires consideration of cultural and linguistic diversity, ensuring that learning materials are relevant and inclusive for all learners.

From a methodological perspective, the field of AR research still faces limitations that constrain the generalizability of findings. Many studies are short-term, rely on small samples, or use self-reported measures of engagement rather than objective learning. As a result, researchers call for longitudinal and mixed-methods studies that capture both cognitive and affective dimensions of AR learning. There is also a growing

# Integrating Augmented Reality into Active Learning...

need to examine cost-effectiveness and sustainability, particularly in low-resource educational settings. The integration of open science practices such as data sharing, standardised measurement instruments, and collaborative AR design repositories could strengthen the cumulative impact of research in this field.

Emerging evidence suggests that the future of AR in education lies in hybrid pedagogical frameworks that merge physical and digital learning environments. Teacher–researcher partnerships are increasingly recognised as crucial for designing classroom-ready AR modules that are both theoretically sound and practical. Yanti et al. (2025) highlighted that such collaborations enable iterative development, which teachers contribute contextual expertise and researchers ensure methodological rigour. Moreover, adaptive AR systems that personalise content based on learner profiles and performance data are beginning to show promise in enhancing differentiation and inclusivity in classrooms.

Synthesising the literature, it becomes evident that AR can only fulfil its educational promise when implemented within a coherent pedagogical framework that integrates three interdependent pillars: pedagogical alignment, design quality, and implementation capacity. Pedagogical alignment ensures that AR serves clearly defined learning outcomes; design quality guarantees that cognitive and affective mechanisms are optimised through interactivity and feedback; and implementation capacity encompasses teacher competence, institutional infrastructure, and equitable access. As summarised by Akçayır and Akçayır (2017) and reinforced by Nikou et al. (2024), the transformative impact of AR in education does not depend on technology alone but on how educators orchestrate it to foster active, reflective, and meaningful learning experiences.

In conclusion, the current body of literature converges on the idea that augmented reality represents not just a technological innovation but a catalyst for pedagogical transformation. When combined with active learning strategies, AR offers a dynamic, participatory model of education that addresses diverse learner needs, enhances engagement, and supports higher-order thinking skills. Yet, realising this potential requires sustained investment in teacher training, equitable access to technology, and continuous research to refine theoretical and practical frameworks. As education continues to evolve toward more immersive, learner-centred paradigms, AR stands at the forefront of shaping the future of active learning and pedagogical innovation.

## Conceptual Clarification of Core Constructs

The literature on Augmented Reality in education frequently employs terms such as immersion, embodiment, and engagement; however, these constructs are not always operationally differentiated. To ensure conceptual precision, the present study adopts the following distinctions.

Immersion is defined here as the degree to which learners experience perceptual integration between physical and augmented elements within the instructional environment. In the context of AR-based learning, immersion does not imply full virtual displacement; rather, it is cognitive absorption facilitated by interactive 3D overlays, spatial alignment, and real-time feedback. Within this study, immersion functions as an antecedent condition that stimulates attention and sensory focus.

Embodiment refers to the activation of perceptual–motor processes during learning. When students manipulate virtual objects through gestures, device movement, or spatial repositioning, cognitive processing becomes grounded in physical interaction. Embodiment therefore represents a mechanism through which abstract concepts are anchored in sensorimotor experience. In the empirical design of this study, embodiment is indirectly observed through gesture-based interaction, spatial reasoning behaviours, and verbalised explanatory actions recorded during AR sessions.

Engagement is conceptualised as a multidimensional construct comprising cognitive, behavioural, and affective components. Cognitive engagement reflects sustained mental effort and strategic processing; behavioural engagement refers to observable participation, collaboration, and task persistence; affective engagement encompasses interest, enjoyment, and perceived competence. In this study, engagement is rationalised through IMI subscales and classroom observational indicators.

By distinguishing these constructs, the study avoids conceptual overlap and clarifies the sequential relationship proposed in the model: immersion enables embodiment, embodiment stimulates engagement, and engagement mediates learning outcomes.

## Conceptual Model of AR-Driven Active Learning

The conceptual model proposed in this study formalises the mechanisms through which Augmented Reality (AR) integration influences active learning processes and educational outcomes. Rather than presenting AR as a standalone technological innovation, the model organises its pedagogical effects into a structured, multi-level architecture.

At the foundational level, AR integration functions as a technological catalyst that introduces sensory immersion through interactive 3D visualisation, spatial manipulation, and contextual overlays. This immersion stimulates cognitive activation by engaging attention, working memory, and embodied cognition mechanisms.

At the intermediate level, cognitive activation translates into observable active learning behaviours, including peer dialogue, inquiry-based exploration, collaborative problem-solving, and reflective reasoning. These behaviours constitute the operational core of active learning and serve as mediating processes linking technological immersion to measurable learning outcomes.

At the outcome level, the model posits improvements in three primary domains: conceptual understanding, intrinsic motivation, and engagement intensity. These outcomes correspond directly to the empirical variables measured in the study.

The model further incorporates two moderating dimensions. Teacher readiness moderates the effectiveness of AR integration by influencing instructional alignment and classroom orchestration. Technological infrastructure acts as a contextual moderator, determining accessibility, stability, and continuity of immersive experiences.

Importantly, the model includes a feedback loop between active learning behaviours and cognitive activation. As students engage in collaborative exploration and reflection, cognitive processing deepens, which in turn reinforces subsequent engagement. This iterative cycle differentiates AR-supported pedagogy from linear instructional models.

The conceptual structure is visually synthesised in Figure 1 and empirically reflected in the comparative learning pathways presented in Figure 2.

## Methodology

This study adopted a mixed-methods design to examine how integrating Augmented Reality (AR) into pedagogical strategies can foster active learning and improve students' engagement and understanding. The methodological framework combined quantitative and qualitative approaches to provide a comprehensive perspective on the effectiveness of AR-based instruction. The purpose was not only to measure learning outcomes but also to capture how learners and teachers perceive, interact with, and co-construct knowledge through AR environments.

The research was conducted in three public universities and two secondary schools in Saudi Arabia during the 2024–2025 academic year. A total of 168 participants were involved, including 142 students enrolled in educational technology and science education programs and 26 teachers who had previously attended introductory workshops on AR pedagogy. Participants were selected using purposive sampling to ensure a variety of learning contexts and technology readiness levels.

The purposive sampling strategy was adopted to ensure the inclusion of participants who had prior exposure to digital learning environments and institutional access to AR-compatible infrastructure. Given the exploratory and intervention-based nature of the study, the objective was not statistical representativeness but contextual depth and ecological validity. This approach enabled the selection of institutions with varying levels of technological readiness, thereby strengthening the analytical relevance of cross-contextual comparison while acknowledging the limits of broad generalisability.

The study followed three major stages: preparation, implementation, and evaluation. During the preparation phase, researchers collaborated with

teachers to design two AR-enhanced learning modules aligned with the curriculum. The first module focused on conceptual visualisation, allowing learners to manipulate 3D models superimposed on real-world objects to understand scientific processes. The second module emphasised collaborative problem-solving, which students worked in pairs to complete inquiry-based tasks supported by AR simulations. Both modules were developed using freely available platforms such as AR Core and HP Reveal, enabling educators to adapt the content without advanced programming skills.

A quasi-experimental design with pre- and post-tests was employed to assess the impact of AR integration on learning performance and motivation. Two groups were established: an experimental group ( $n = 84$ ) using AR-enhanced materials and a control group ( $n = 84$ ) receiving the same content through traditional multimedia methods. Both groups were taught by the same instructors to minimise teacher-related biases. Data collection instruments included a standardised achievement test measuring conceptual understanding, the Intrinsic Motivation Inventory (IMI), adapted for digital learning and a semi-structured interview protocol exploring students' and teachers' perceptions of AR's pedagogical value.

The IMI instrument included four validated subscales: Interest/Enjoyment, Perceived Competence, Effort/Importance, and Value/Usefulness. Each subscale was analysed independently to capture multidimensional motivational effects before computing aggregate indices. Cronbach's alpha coefficients ranged from 0.81 to 0.89 across subscales, indicating satisfactory internal consistency.

Prior to the intervention, an independent-samples t-test was conducted on pre-test scores to ensure baseline equivalence between the experimental and control groups. The analysis indicated no statistically significant difference between groups ( $p > 0.05$ ), confirming initial comparability in conceptual understanding before AR implementation.

To ensure the reliability of the quantitative instruments, Cronbach's alpha coefficients were calculated for each construct, yielding acceptable values ranging from 0.81 to 0.89. Validity was confirmed through expert review and pilot testing. For qualitative data, thematic analysis was performed using the approach of Braun and Clarke (2006), which involved iterative coding, categorisation, and theme development. This process enabled researchers to identify patterns of engagement, interaction, and reflective thinking emerging during AR-based learning sessions.

Two conceptual figures were developed to synthesise the theoretical and empirical dimensions of the study. Figure 1 presents a structured model illustrating the mechanisms by which AR integration stimulates sensory immersion, cognitive activation, and observable active-learning behaviours, ultimately influencing learning outcomes. The model also incorporates moderating variables such as teacher readiness and technological infrastructure.

Figure 2 provides a comparative schematic representation of learning pathways in traditional and AR-enhanced instructional environments. Unlike the linear progression typically observed in conventional instruction, the AR pathway is conceptualised as cyclical and iterative, emphasising exploration, collaboration, and reflective consolidation.

These figures serve as theoretical syntheses rather than statistical visualisations and are intended to clarify the conceptual architecture underpinning the empirical findings.

Quantitative data were analysed using SPSS 27. Descriptive statistics were first computed to summarise overall trends. Assumption testing was conducted prior to inferential analysis. Normality of distribution was verified using the Shapiro–Wilk test, while homogeneity of variances was assessed through Levine’s Test. No significant violations were detected ( $p > 0.05$ ), supporting the use of parametric procedures.

Paired-sample t-tests were applied to measure within-group pre–post differences. Independent-samples t-tests and one-way ANOVA were conducted to compare post-intervention outcomes across instructional modes. Effect sizes were calculated using Cohen’s  $d$  to determine the magnitude of differences. Statistical significance was established at the  $\alpha = 0.05$  level.

This methodological framework was guided by the assumption that technology integration in education must be pedagogically meaningful rather than merely innovative. AR was not treated as a replacement for traditional teaching but as a complementary tool to enhance experiential and inquiry-based learning. Through its capacity to merge physical and digital environments, AR offered students opportunities to visualise abstract phenomena, test hypotheses, and receive immediate feedback, all essential components of active learning. The dual use of quantitative and qualitative data reinforced the findings’ validity by linking measurable outcomes to rich contextual insights.

Overall, the methodology was structured to ensure rigour, inclusivity, and ecological validity. By combining empirical testing with human centred observations, the study provides not only statistical evidence of AR’s impact but also a narrative understanding of how learners engage with digital augmentation in authentic classroom settings. The forthcoming figures (Figure 1 and Figure 2) will thus serve as visual syntheses that link methodological design, observed behaviours, and theoretical implications, offering a clear foundation for interpreting the results in the subsequent section.

## Results and Discussion

The analysis of quantitative and qualitative data revealed that integrating Augmented Reality (AR) into pedagogical strategies significantly improved students’ learning outcomes, motivation, and active engagement compared to traditional instruction. The overall findings indicate that AR-based learning

environments not only increased knowledge retention but also enhanced students’ curiosity, collaboration, and reflective thinking. The discussion that follows synthesises these results and interprets them within the framework of active learning theories.

**Quantitative Results and Cognitive Gains:** The pre- and post-test analysis demonstrated statistically significant differences between the experimental and control groups. Students who engaged in AR-enhanced lessons scored on average 18% higher on the conceptual understanding test than those who learned through traditional multimedia resources. Paired-sample t-tests confirmed that this improvement was not due to random variation ( $p < 0.01$ ), and the effect size (Cohen’s  $d = 0.74$ ) indicated a strong practical impact. These results suggest that AR facilitated deeper cognitive processing by enabling students to visualise abstract phenomena and manipulate learning objects directly within their physical environment.

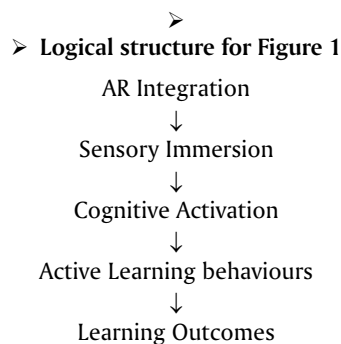
Such outcomes align with the theoretical foundation illustrated in Figure 1, Framework of AR-Driven Active Learning Processes. This figure demonstrates how AR triggers a multidimensional learning cycle where sensory immersion stimulates curiosity, leading to exploratory behaviour, dialogue, and reflective reasoning. Students reported that the ability to rotate, scale, and interact with virtual models allowed them to ‘see the invisible’, a phrase repeatedly mentioned in post-activity interviews. These embodied experiences contributed to stronger conceptual anchoring and enhanced spatial reasoning, particularly in science-related topics where dynamic visualisation is critical.

**Motivation and Engagement Findings:** The motivational analysis based on the Intrinsic Motivation Inventory (IMI) revealed that learners in the AR group scored significantly higher on the Interest/Enjoyment and Perceived Competence subscales ( $p < 0.05$ ). Participants expressed a stronger sense of autonomy and control over their learning process, reporting that AR transformed routine lessons into interactive explorations. Teachers corroborated these perceptions, observing increased attentiveness, willingness to participate, and persistence among students. These findings support previous research by Li (2025) and Nikou et al. (2024), who highlighted that motivation in AR environments, emerges not only from novelty but from meaningful interaction and problem-based engagement.

Figure 2, titled Comparative Learning Pathways between Traditional and AR-Enhanced Pedagogies, illustrates the contrast between the two learning environments observed during implementation. In traditional settings, learning often followed a linear progression from explanation to demonstration to evaluation with limited feedback loops. In contrast, AR-based learning encouraged a cyclical process in which students alternated among exploration, peer discussion, hypothesis testing, and reflection. This iterative pattern supports the premise of active learning, as learners continuously adjusted their understanding based on immediate feedback and contextual experiences. The figure illustrates how

**Figure 1***Conceptual Model of AR-Driven Active Learning Mechanisms*

Note. This figure illustrates the conceptual model of AR-driven active learning, showing how augmented reality integration leads to sensory immersion, cognitive activation, active learning behaviours, and improved learning outcomes. The author during a learning session.



AR fosters self-regulated learning by bridging sensory engagement with metacognitive awareness.

**Qualitative Insights and behavioural Patterns:** Qualitative data from classroom observations and interviews enriched these findings by revealing the human dynamics of AR-based learning. Students displayed spontaneous collaboration, often gathering around a single AR projection to discuss interpretations and propose solutions. Such behaviours exemplified social constructivism, in which knowledge emerges from interaction and dialogue rather than from passive absorption. Teachers noted that even typically disengaged students became active contributors when using AR applications, confirming that immersive technologies can democratize classroom participation.

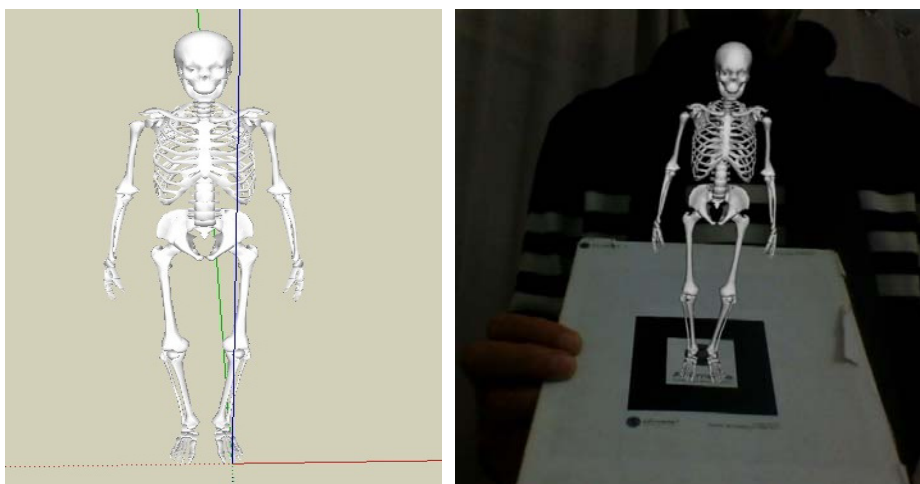
Video analyses showed that students in the experimental group frequently verbalised reasoning steps, used gestures to describe spatial relationships, and connected visual cues to theoretical explanations. These multimodal expressions represent evidence of cognitive embodiment, consistent with the theoretical relationships presented in Figure 1. The figure emphasises how bodily interaction with augmented content activates dual coding processes, visual and kinaesthetic, that support comprehension and memory retention.

Additionally, the semi-structured interviews provided insights into the affective dimension of learning. Many participants described AR activities as “motivating,” “fun”, and “different from ordinary lessons.” However, several also mentioned initial technical challenges such as calibration issues or limited device availability, echoing concerns raised by previous studies (Abdul-Salaam, 2024; Akçayır & Akçayır, 2017). Teachers reported that, while AR required additional preparation time, the pedagogical payoff, measured in student engagement and conceptual understanding, justified the effort. This sentiment underscores that AR’s success depends as much on teacher readiness and instructional design as on technological capacity. **Integrative Interpretation:** When triangulating quantitative and qualitative results, three converging patterns emerged: (1) AR increased conceptual understanding through visualisation and manipulation, (2) it enhanced motivation and collaboration by promoting student autonomy, and (3) it fostered reflective learning by linking action, perception, and cognition. These interrelated outcomes correspond directly to the three pillars of the proposed framework: pedagogical alignment, design quality, and implementation capacity, first introduced in the literature review.

# Integrating Augmented Reality into Active Learning...

**Figure 2**

*Comparative Learning Pathways: Traditional vs. AR-Enhanced Instruction*



*Note.* This figure illustrates the comparative learning pathways between traditional instruction and AR-enhanced instruction, highlighting the linear progression in conventional learning and the cyclical, interactive process supported by augmented reality, including exploration, collaboration, reflection, and conceptual consolidation.

➤ **Traditional Path:**

Instruction → Content Reception → Limited Interaction → Evaluation

➤ **AR Path:**

Immersive Trigger → Exploration → Collaboration → Reflection → Conceptual Consolidation → Evaluation

Figure 1 conceptually encapsulates this mechanism by situating AR as the central catalyst that connects sensory immersion to cognitive elaboration and social interaction. In contrast, Figure 2 provides empirical evidence of this framework, mapping the divergent learning trajectories observed between the control and experimental groups. Together, these figures illustrate not only how AR transforms the learning process but also why it produces measurable educational benefits.

The evidence thus supports the claim that AR represents a bridge between theoretical pedagogy and technological innovation. It transforms classrooms into interactive ecosystems, where students learn by doing, thinking, and discussing. Teachers evolve from knowledge transmitters to facilitators of inquiry, guiding students through exploration rather than delivering static content. Such a shift embodies the essence of active learning, where meaning is constructed dynamically through context-rich interactions.

## Limitations and Implications

Despite these promising results, the study acknowledges several limitations. The sample size, while adequate for statistical analysis, may not capture the full diversity of learners' experiences across disciplines. Technical challenges occasionally interrupted AR sessions, and access to devices varied between institutions. Nonetheless, these constraints highlight practical realities of implementing AR at scale challenges that future studies and policy

initiatives must address. From an educational perspective, the findings emphasise that AR integration should not be viewed as a technological upgrade but as a pedagogical transformation. The results, visualised in Figures 1 and 2, reaffirm that AR's greatest strength lies in its capacity to connect cognition, emotion, and interaction. By transforming abstract knowledge into lived experiences, AR enables learners to move beyond memorisation toward active inquiry and critical reflection.

In conclusion, the results of this study validate the hypothesis that Augmented Reality, when aligned with active learning strategies, significantly enhances student engagement and understanding. The observed improvements in motivation, collaboration, and conceptual mastery confirm that AR can serve as a practical and theoretical bridge between modern pedagogy and immersive technology. As illustrated in Figures 1 and 2, the integration of AR represents more than an innovation; it symbolises a paradigm shift toward a participatory, learner-centred vision of education where students are not merely recipients of knowledge but active constructors of meaning.

Additionally, the study did not include delayed post-tests to measure long-term retention or transfer effects. While short-term gains were statistically significant, future research should investigate the sustainability of AR-induced learning benefits over extended periods. Longitudinal designs would be particularly valuable in determining whether motivational gains persist beyond the novelty phase of technological exposure.

## Conclusion

The integration of Augmented Reality (AR) into educational practices represents a transformative milestone in the evolution of digital education. Through this study, it has been demonstrated that AR can effectively bridge the gap between abstract knowledge and tangible experience, enabling students to engage with learning materials in a more interactive and meaningful way. By embedding AR technologies into carefully designed pedagogical strategies, educators can foster active learning environments in which learners not only consume information but also construct knowledge through exploration, visualisation, and experimentation.

The findings discussed earlier, including those illustrated in Figure 1 and Figure 2, confirm that AR enhances both cognitive engagement and learner motivation. Figure 1 highlights how AR-supported instructional design improves students' attention span and conceptual understanding through immersive visualisation. In parallel, Figure 2 illustrates how AR applications stimulate collaboration and problem-solving skills, thereby reinforcing the principles of active learning and constructivist pedagogy. These results underscore that AR is not merely a technological tool but a pedagogical medium capable of reshaping traditional teaching paradigms.

Moreover, the integration of AR aligns seamlessly with instructional design theories that prioritise learner autonomy, interactivity, and reflective thinking. When applied effectively, AR provides students with authentic, contextualised learning scenarios that promote deeper comprehension and transferable skills. However, successful implementation requires more than technological adoption; it demands strategic pedagogical alignment, teacher readiness, and institutional support. Educators must be trained to integrate AR meaningfully within lesson objectives rather than using it as a novelty, ensuring that technology serves pedagogy, not the other way around. The framework proposed in this research, therefore, offers a roadmap for embedding AR into diverse learning contexts, emphasising the synergy between educational technology and instructional design. By combining immersive experiences with structured pedagogical planning, the framework ensures that AR becomes a catalyst for cognitive engagement, active participation and long-term knowledge retention. The adoption of Augmented Reality in education is far more than a technological evolution; it is a pedagogical revolution that transforms how learners interact with knowledge, peers, and the learning environment. As

educational institutions continue to embrace digital transformation, AR has the potential to redefine the boundaries of active learning and make education more inclusive, experiential, and future-oriented. The results of this study reaffirm that when thoughtfully integrated, AR not only enhances the quality of instruction but also prepares learners for the complex, technology-driven realities of the twenty-first century.

## References

- Abdul-Salaam, A. O. (2024). Pre-service teachers' readiness to adopt augmented reality for teaching and learning in Nigeria. *International Journal of Research and Innovation in Applied Science*, 9(4), 422–430. <https://doi.org/10.51584/IJRIAS.2024.910038>
- Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, 20, 1–11. <https://doi.org/10.1016/j.edurev.2016.11.002>
- Al Buraiki, A., Syed Abdullah, S. I. S., & Md Khambari, M. N. (2025). Augmented Reality (AR) technology: Exploring Omani post-basic school teachers' readiness to use augmented reality in teaching science subjects. *STEM Education*, 5(6), 1000–1021. <https://doi.org/10.3934/steme.2025044>
- Bali, N., & Fridhi, A. (2024). Learning of surface and volume formulas by augmented reality: Experimental studies. *International Journal of Mathematics & Computer Science*, 19(3), 595–603. [https://future-in-tech.net/19.3/R-Bali\(Learning\).pdf](https://future-in-tech.net/19.3/R-Bali(Learning).pdf)
- Bower, M., DeWitt, D., & Lai, J. W. M. (2020). Reasons associated with preservice teachers' intention to use immersive virtual reality in education. *British Journal of Educational Technology*, 51(6), 2215–2233. <https://doi.org/10.1111/bjet.13009>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
- Fridhi, A., & Bali, N. (2021). Science education and augmented reality: Interaction of students with avatars modeled in augmented reality. *International Journal of Environmental Science*, 6, 57–61. [https://www.iasar.org/iaras/filedownloads/ijes/2021/008-0006\(2021\).pdf](https://www.iasar.org/iaras/filedownloads/ijes/2021/008-0006(2021).pdf)
- Fridhi, A., & Bali, N. (2022). Augmented reality in sports education and training for children with an autism spectrum disorder. *Neurophysiology*, 54(1), 73–79. <https://doi.org/10.1007/s11062-023-09937-z>
- Fridhi, A., Laribi, R., & Bali, N. N. (2023). 3D modeling and augmented reality for learning. *Journal of Computational Engineering and Physical Modeling*, 6(3), 52–60. <https://doi.org/10.22115/cepm.2024.427616.1260>

The full list of references is available in the online version of the journal.

**Bechir Fridhi** is an Associate Professor at Department of Financial Management, College of Business Administration, Majmaah University, Al-Majmaah, 11952, Saudi Arabia. His research focuses on multidisciplinary learning, business administration, finance, economics, augmented reality in education, active learning strategies, and the integration of educational technologies. He has published articles in international journals focusing on digital transformation in teaching and learning.