Augmented Reality as an Interactive Learning and Communication Medium: Examining Learner Satisfaction and Loyalty in Educational Contexts

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Abstract. This study investigates the role of augmented reality (AR) as an interactive learning and communication medium in shaping learner satisfaction and loyalty in educational contexts. A cross-sectional survey of 384 young adult learners in Malaysia with prior AR learning experience was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings show that system quality and content quality significantly enhance learner satisfaction, while interactivity does not. Learner satisfaction strongly predicts loyalty and mediates the relationship between AR characteristics and loyalty. These results highlight the importance of technical reliability and high-quality content in sustaining learner engagement with AR applications and contribute empirical evidence to the post-adoption evaluation of educational technologies.

Keywords: Augmented Reality; Learner Satisfaction; Learner Loyalty; System Quality; Content Quality; Interactivity; PLS-SEM.

1 Introduction

Augmented Reality (AR) is transforming digital education by integrating virtual elements into physical learning environments, creating immersive experiences that enhance engagement and understanding [1]. With the rise of mobile technologies and accessible AR-enabled devices, its adoption has expanded across higher education, professional training, and skills-based learning.

AR's distinctive strength lies in its ability to facilitate visual and contextualized communication. Features such as visual augmentation, interactive simulations, and real-time feedback allow learners to visualize complex concepts, manipulate virtual objects, and receive immediate guidance, leading to improved motivation and comprehension [2, 3].

Despite growing interest, most research has focused on adoption and usability, with limited attention to post-adoption outcomes such as satisfaction [4] and loyalty [5].

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These factors are critical, as satisfaction drives continued usage and loyalty reflects long-term commitment to AR-based learning systems.
This study examines how system quality, content quality, and interactivity influence learner satisfaction and loyalty among young adult learners in Malaysia [6]. By focusing on these determinants, it provides empirical evidence on the post-adoption evaluation of AR in education and highlights satisfaction's mediating role in sustaining learner engagement.

2 Literature Review

2.1 Augmented Reality in Education

Augmented Reality (AR) has gained increasing attention in educational technology due to its ability to integrate digital information with real-world environments. Unlike traditional digital learning technologies, AR overlays virtual elements such as images, animations, and data onto physical environments, enabling learners to interact simultaneously with both real and virtual objects. According to Azuma [7], AR systems combine real and virtual environments, provide real-time interaction, and support three-dimensional visualization, making them particularly suitable for educational applications.

The integration of AR technologies in education has increased significantly with the advancement of mobile devices and digital learning platforms. AR applications have been widely used in fields such as science, engineering, medical education, and technical training to enhance learners' engagement and conceptual understanding. Studies indicate that AR-based learning environments can support experiential learning by enabling learners to explore interactive simulations and visualize complex concepts more effectively [8, 9].

Despite its potential benefits, the implementation of AR in education also presents several challenges. Previous research has highlighted issues related to usability, technological readiness, and instructional design, which may influence the effectiveness of AR-based learning systems. For instance, poorly designed AR applications may create cognitive overload or technical difficulties that hinder the learning process [10]. Therefore, understanding how AR characteristics influence learners' experiences and perceptions remains an important research focus in educational technology.

2.2 AR as Interactive Learning Medium

Augmented reality is increasingly recognized as an effective medium for interactive learning due to its ability to create immersive and engaging learning environments. Unlike conventional e-learning platforms that rely primarily on static text and images, AR enables learners to interact directly with three-dimensional digital objects embedded within their physical surroundings[11]. This interactive capability allows learners to manipulate virtual elements, observe processes dynamically, and explore learning materials in a more engaging manner.

Research suggests that AR-based learning environments support experiential and exploratory learning processes. By integrating virtual elements with real-world contexts, AR allows learners to visualize abstract concepts and interact with digital simulations that enhance conceptual understanding. Studies conducted in STEM education have shown that AR technologies can significantly improve learners' motivation, engagement, and learning outcomes [12, 13].

In addition, AR technologies facilitate student-centered and collaborative learning experiences. Interactive AR environments allow learners to participate in collaborative tasks, shared problem-solving activities, and group-based exploration of digital content. These features contribute to more dynamic learning experiences and encourage active participation in the learning process, thereby enhancing the overall effectiveness of digital learning environments [14].

2.3 Educational Communication in AR Learning

Educational communication refers to the process through which knowledge and learning content are effectively delivered and interpreted within educational environments. In digital learning contexts, communication occurs through various channels, including text, visuals, audio, and interactive media. AR enhances educational communication by integrating visual augmentation, contextual information, and real-time interaction into the learning process, enabling learners to understand complex information more effectively [14].

Through features such as visual overlays, contextual annotations, and real-time feedback, AR applications allow learners to receive immediate guidance and interactive cues while engaging with educational content. These communication mechanisms enable learners to connect theoretical knowledge with practical visualization, thereby improving comprehension and knowledge retention [8]. As a result, AR-based learning systems are increasingly used to support interactive communication between learners and digital learning environments.

Furthermore, AR technologies support multimodal communication by combining visual, auditory, and interactive elements within a single learning environment. Multimodal communication allows learners to process information through multiple sensory channels, which can improve engagement and facilitate deeper learning. Consequently, AR is considered a powerful communication medium that enhances the effectiveness of technology-supported learning environments [9]

2.4 Learner Satisfaction in Digital Learning

Learner satisfaction is widely recognized as an important indicator of the effectiveness of digital learning systems. It represents learners' overall evaluation of their experiences when interacting with learning technologies. In educational technology research, satisfaction often reflects learners' perceptions of system usability, content quality, and the effectiveness of instructional delivery [15].

In AR-based learning environments, learner satisfaction may be influenced by various technological and experiential factors. When AR applications provide reliable system performance, engaging visual content, and meaningful interactive experiences, learners are more likely to develop positive evaluations of the learning environment. Research suggests that immersive learning technologies such as AR can enhance learner engagement and satisfaction by providing more dynamic and interactive learning experiences [16].

Moreover, learner satisfaction has been widely associated with positive behavioral outcomes in digital learning environments. Satisfied learners are more likely to develop favorable attitudes toward learning technologies and demonstrate stronger intentions to continue using the system. Therefore, understanding the determinants of learner satisfaction is essential for improving the design and effectiveness of AR-based educational applications [15].

2.5 Learner Loyalty and Continued Usage

Learner loyalty refers to users' long-term commitment and continued engagement with a particular technological system or learning platform. In digital learning environments, loyalty is often reflected through behaviors such as repeated usage, continued interaction with learning applications, and sustained commitment to technology-supported learning experiences [17].

Previous studies in information systems research indicate that satisfaction plays a critical role in influencing users' continued usage intentions. According to Bhattacherjee [18], users who are satisfied with their experiences using a technological system are more likely to continue using the system and develop long-term loyalty toward the platform.

In the context of AR-based educational technologies, learner loyalty may be expressed through learners' intention to continue using AR applications, their repeated engagement with AR-supported learning environments, and their willingness to recommend AR technologies to others. Consequently, examining the relationship between learner satisfaction and loyalty provides valuable insights into the sustainability and long-term adoption of AR-based learning systems.

Based on the literature, this study focuses on three core AR characteristics system quality, content quality, and interactivity as primary determinants of learner's satisfaction. Satisfaction is further conceptualized as a key predictor of learner's loyalty, reflecting continued usage intention and commitment. This approach allows for a more focused and empirically testable framework.

3 Conceptual Framework and Hypothesis Development

This study adopts a refined conceptual framework that focuses on three core Augmented Reality (AR) characteristics such as system quality, content quality, and interactivity as predictors of learner satisfaction, which subsequently drives learner loyalty. While broader frameworks such as UTAUT3 and the Information Systems Success Model (ISSM) provide comprehensive perspectives, the present study narrows its scope to constructs most relevant to AR-supported learning environments. This refinement ensures consistency between theory, hypotheses, and empirical testing, while maintaining explanatory strength.

The framework integrates insights from three established theories. The Information Systems Success Model [17] emphasizes the importance of system quality and information quality in shaping user satisfaction and continued usage. Expectation–Confirmation Theory [5] explains satisfaction as a post-adoption response that occurs when system performance meets or exceeds user expectations. The Unified Theory of Acceptance and Use of Technology [19] highlight post-adoption behavior, including continued usage intention, which aligns closely with the concept of learner loyalty. Together, these perspectives provide a robust foundation for understanding how AR characteristics influence satisfaction and loyalty.

In AR-supported learning environments, technological and communication-related features play a central role in shaping learner experiences. System quality refers to the reliability, usability, and technical performance of AR applications. When systems are stable, responsive, and easy to use, learners are more likely to perceive them as effective tools for learning [16]. Content quality encompasses the relevance, accuracy, and clarity of educational materials delivered through AR. High-quality content enhances learners' ability to connect theoretical knowledge with practical visualization, thereby improving comprehension and satisfaction [12]. Interactivity captures the extent to which learners can manipulate digital objects, engage in simulations, and receive real-time feedback. Interactive features are often associated with higher engagement and motivation, though their impact on satisfaction may depend on how well they are integrated into instructional design [2].

Learner satisfaction is widely recognized as a critical determinant of post-adoption behavior in digital learning environments [17]. From an expectation–confirmation perspective, satisfaction arises when learners perceive that AR applications deliver meaningful interaction, immersive communication, and effective learning support. Positive evaluations of system quality, content quality, and interactivity enhance satisfaction, which in turn encourages learners to continue using AR technologies for future learning activities. Satisfaction therefore functions both as an outcome of AR characteristics and as a mediator linking these characteristics to loyalty.

Learner loyalty reflects long-term commitment and sustained engagement with AR-based learning systems. It is expressed through behaviors such as repeated usage, continued interaction, and willingness to recommend AR applications to peers [14, 5]. Loyalty is particularly important in educational contexts, as it determines whether learners integrate AR into their ongoing learning practices rather than treating it as a one-time novelty. When satisfaction is high, learners are more likely to develop loyalty, ensuring the sustainability of AR adoption in education.

3.1 Hypothesis Development

Based on the proposed conceptual framework, the following hypotheses are formulated:

H1: System quality positively influences learner satisfaction in AR-based learning environments.
H2: Content quality positively influences learner satisfaction in AR-based learning environments.
H3: Interactivity positively influences learner satisfaction in AR-based learning environments.
H4: Learner satisfaction positively influences learner loyalty toward AR-based learning applications

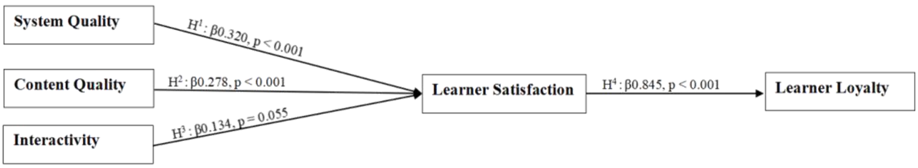

Fig. 1. Conceptual framework illustrating the relationships between augmented reality characteristics, learner satisfaction, and learner loyalty.

Figure 1 presents the conceptual framework of the study, which explains how AR characteristics influence learner satisfaction and loyalty in educational contexts. The framework proposes that system quality, content quality, and interactivity influence learner satisfaction, which subsequently leads to learner loyalty.

Within the framework, AR is represented by three core characteristics: system quality, content quality, and interactivity. System quality reflects the technical performance, reliability, and usability of AR applications. A system that functions smoothly and consistently enhances learners' confidence in the technology and reduces frustration during use. Content quality refers to the relevance, accuracy, and clarity of educational materials delivered through AR. High-quality content ensures that learners can connect theoretical knowledge with practical visualization, thereby improving comprehension and perceived usefulness. Interactivity captures the extent to which learners can manipulate digital objects, engage in simulations, and receive real-time feedback. While interactivity is often associated with engagement and motivation, its impact on satisfaction depends on how effectively it is integrated into instructional design.

Learner satisfaction is conceptualized as the evaluative response to these AR characteristics. Satisfaction arises when learners perceive that the system meets or exceeds their expectations, providing reliable performance, meaningful content, and engaging interactive features. Satisfaction is not only an outcome of AR characteristics but also a mediating construct that transforms positive experiences into long-term behavioral outcomes. In this framework, satisfaction plays a pivotal role in linking technological features to loyalty.

Learner loyalty represents sustained commitment to AR-based learning environments. It is expressed through behaviors such as repeated usage, continued engagement, and willingness to recommend AR applications to peers. Loyalty is particularly important in educational contexts because it reflects whether learners integrate AR into their ongoing learning practices rather than treating it as a novelty. When satisfaction is high, learners are more likely to develop loyalty, ensuring the sustainability of AR adoption in education.

The framework therefore proposes that system quality, content quality, and interactivity positively influence learner satisfaction, which subsequently leads to learner loyalty. By highlighting satisfaction as the central mechanism, the model underscores its importance in sustaining long-term learner engagement with AR technologies. This mediating role of satisfaction emphasizes that technological features alone are insufficient; it is the learners' positive evaluations of these features that ultimately drive loyalty and continued usage.

4 Research Methodology

4.1 Research Design

This study adopts a quantitative research design to examine the relationships between augmented reality (AR) characteristics, learner satisfaction, and learner loyalty in educational contexts. A cross-sectional survey approach was employed to collect empirical data from respondents with prior experience using AR-based educational applications. The quantitative design is appropriate because it enables the testing of hypothesized relationships among multiple constructs and facilitates the validation of the proposed conceptual framework through statistical analysis. By focusing on measurable variables and applying Partial Least Squares Structural Equation Modeling (PLS-SEM), the study ensures methodological rigor and provides empirical evidence to support theoretical claims.

4.2 Population and Sample

The target population for this research comprises young adult learners in Malaysia, aged 18 to 34, a demographic estimated at approximately 2.5 million individuals currently enrolled in tertiary education. This cohort was selected due to their high degree of digital literacy and frequent exposure to interactive pedagogical platforms, making them an ideal focal point for post-adoption Augmented Reality (AR) research. To ensure data integrity and theoretical relevance, a non-probability purposive sampling technique was executed to isolate 'information-rich' cases, such as individuals possessing the specific technical competencies and lived experience necessary to evaluate AR interfaces accurately.

Participants were subjected to a mandatory screening protocol to verify they had used AR-based pedagogical tools, such as marker-based or location-based AR, within a formal or informal learning environment in the preceding six months. This selection process helped ensure that respondents had sufficient experience with AR applications, allowing the study to capture more stable evaluations rather than temporary reactions toward new technology.

The study yielded a final sample of 384 valid responses. This sample size significantly exceeds the minimum threshold of 200 recommended by Hair et al. (21) for robust Partial Least Squares Structural Equation Modeling (PLS-SEM). Consequently, the sample size provides sufficient statistical power to test complex hypothesized relationships and ensures a high degree of generalizability within the specified demographic context.

4.3 Data Collection Procedure

Data for this study were collected using a structured online questionnaire, which was distributed through academic networks, social media platforms, and professional learning communities. The online survey method was chosen because it offers efficiency in reaching a large and geographically dispersed population, while also being well-suited for research on technology-related topics. Online distribution allowed the study to target learners who are actively engaged in digital learning environments and therefore more likely to have prior experience with AR-based educational applications.

The questionnaire was carefully designed to ensure clarity, relevance, and alignment with the research objectives. It consisted of two main sections. The first section gathered demographic information, including age, gender, and educational background, to provide descriptive insights into the sample profile. The second section contained measurement items related to the constructs of interest: system quality, content quality, interactivity, learner satisfaction, and learner loyalty. To ensure that responses were relevant, a screening question was placed at the beginning of the survey, requiring participants to confirm that they had prior experience using AR applications for learning purposes. This step helped eliminate respondents without the necessary background and strengthened the validity of the data.

Participation in the survey was voluntary, and respondents were assured of anonymity and confidentiality to encourage honest and unbiased responses. Ethical considerations were observed throughout the data collection process, including informed consent and the protection of participants' privacy. The use of an online questionnaire also minimized logistical challenges and allowed for efficient data management, ensuring that the study could obtain a sufficient number of valid responses for statistical analysis

4.4 Measurement of Variables

The constructs in this study were measured using multi-item scales adapted from established instruments in prior literature, with minor contextual modifications to suit the augmented reality educational setting. This approach ensured that the measures were both theoretically grounded and practically relevant.

System quality was assessed through items that captured the technical reliability, usability, and responsiveness of AR applications. These items reflected learners' perceptions of whether the system functioned smoothly, was easy to navigate, and provided a stable learning environment. Content quality was measured through items evaluating the accuracy, relevance, and clarity of the learning materials delivered via AR. High-quality content was expected to enhance learners' ability to connect theoretical knowledge with practical visualization, thereby improving comprehension and satisfaction. Interactivity was measured through items that assessed the extent to which learners could manipulate digital objects, engage in simulations, and receive real-time feedback. These items reflected the degree of active engagement and immersion provided by the AR environment.

Learner satisfaction was measured through items capturing respondents' overall evaluation of their AR learning experience. This included perceptions of usefulness, enjoyment, and learning effectiveness, which together reflect the affective and cognitive dimensions of satisfaction. Learner loyalty was measured using indicators related to continued usage intention, repeated engagement with AR applications, and commitment to AR-supported learning environments. These items captured the behavioral outcomes associated with satisfaction and reflected the sustainability of AR adoption in education.

All responses were recorded on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Reliability and validity of the measurement model were established prior to hypothesis testing. Cronbach's alpha and composite reliability values for all constructs exceeded the recommended threshold of 0.70, confirming internal consistency. Average Variance Extracted (AVE) values were above 0.50, indicating convergent validity. Discriminant validity was established using the heterotrait–monotrait (HTMT) criterion, with all values below 0.85, thereby confirming that the constructs were distinct from one another.

4.5 Data Analysis Technique

The collected data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 4.0 software. PLS-SEM was selected because it is particularly suitable for analyzing complex relationships among latent constructs, especially when the research model includes mediating effects and multiple predictors. Unlike covariance-based SEM, PLS-SEM is more flexible with sample size requirements and distributional assumptions, making it appropriate for exploratory studies in educational technology where constructs are measured through multi-item scales. Its ability to simultaneously assess measurement and structural models ensures methodological rigor and provides robust insights into both the reliability of constructs and the strength of hypothesized relationships.

The analysis followed a two-stage procedure. In the first stage, the measurement model was assessed to ensure that the constructs were reliable and valid. Internal consistency reliability was evaluated using Cronbach's alpha and composite reliability, both of which exceeded the recommended threshold of 0.70. Convergent validity was assessed through Average Variance Extracted (AVE), with all values above 0.50, confirming that the items adequately represented their respective constructs. Discriminant validity was established using the heterotrait–monotrait (HTMT) ratio, with all values below 0.85, indicating that the constructs were distinct from one another. This rigorous assessment ensured that the measurement model was sound before proceeding to hypothesis testing.

In the second stage, the structural model was evaluated to test the hypothesized relationships among AR characteristics, learner satisfaction, and learner loyalty. Path coefficients were estimated to determine the strength of the relationships, while t-values and p-values were obtained through a bootstrapping procedure with 5,000 resamples to assess statistical significance. Bootstrapping was chosen because it provides robust estimates of standard errors and confidence intervals, even in non-normal data distributions. The analysis also examined the coefficient of determination (R^2) to evaluate the explanatory power of the model, as well as effect sizes (f^2) and predictive relevance (Q^2) to provide additional insights into the strength and utility of the proposed framework.

This comprehensive analytical approach ensured that the study not only tested the direct effects of system quality, content quality, and interactivity on satisfaction, but also examined the mediating role of satisfaction in influencing loyalty. By employing PLS-SEM, the study was able to validate the conceptual framework and provide empirical evidence on the post-adoption evaluation of AR-based educational technologies.

5 Results and Findings

5.1 Normality Assessment

Prior to conducting structural equation modeling analysis, the normality of the data was assessed using skewness and kurtosis values. According to Hair et al. (2011) and Pallant (2020), skewness values within the range of −2 to +2 and kurtosis values within the range of −7 to +7 indicate acceptable normality.

The results indicate that the skewness values ranged from −1.422 to −0.166, while kurtosis values ranged from −0.750 to 3.320. These values fall within the recommended thresholds, suggesting that the data are approximately normally distributed. Although PLS-SEM does not require strict normality assumptions, assessing normality helps ensure the robustness of the statistical analysis.

5.2 Measurement Model Assessment

All constructs demonstrated satisfactory reliability and validity. Cronbach's alpha and composite reliability values exceeded 0.70. AVE values were above 0.50, confirming convergent validity. HTMT ratios were below 0.85, supporting discriminant validity.

Internal Consistency Reliability
Internal consistency reliability was assessed using Cronbach's alpha and composite reliability (CR). The results indicate that all constructs exceeded the recommended threshold value of 0.70, confirming that the measurement items demonstrate satisfactory reliability.

Convergent Validity
Convergent validity was assessed using Average Variance Extracted (AVE). All constructs achieved AVE values above the recommended threshold of 0.50, indicating that the constructs explain more than half of the variance of their respective indicators.

Discriminant Validity
Discriminant validity was evaluated using the Heterotrait–Monotrait ratio (HTMT). The HTMT values were below the recommended threshold of 0.90, confirming that each construct is empirically distinct from the others. These results indicate that the measurement model demonstrates adequate reliability and validity for further structural model analysis.

5.3 Structural Model Assessment

The structural model was assessed using a bootstrapping procedure with 5,000 resamples to examine the significance of the hypothesized relationships. The explanatory power of the model was evaluated using the coefficient of determination (R^2) and effect size (f^2). The results indicate that the model explained 54.2% of the variance in learner satisfaction ($R^2 = 0.542$) and 71.4% of the variance in learner loyalty ($R^2 = 0.714$), demonstrating substantial predictive power.

The findings reveal that system quality and content quality significantly influence learner satisfaction. System quality showed a significant positive effect on learner satisfaction ($\beta = 0.320$, $p < 0.001$, $f^2 = 0.18$), indicating that reliable system performance and usability are important determinants of positive learner experiences. Similarly, content quality also demonstrated a significant positive relationship with learner satisfaction ($\beta = 0.278$, $p < 0.001$, $f^2 = 0.15$), highlighting the importance of accurate, relevant, and meaningful educational content in AR-based learning environments. Therefore, H1 and H2 were supported.

However, interactivity did not significantly influence learner satisfaction ($\beta = 0.134$, $p = 0.055$, $f^2 = 0.012$). As a result, H3 was not supported. This finding suggests that although interactive features are present in AR applications, learners may place greater importance on system reliability and content quality compared to interactive engagement alone. One possible explanation is that excessive interactive elements may increase cognitive load and distract learners from the main learning objectives. Furthermore, as AR technologies become more common in educational settings, interactivity may be perceived as a standard feature rather than a factor that strongly enhances satisfaction.

In addition, learner satisfaction showed a strong positive effect on learner loyalty ($\beta = 0.845$, $p < 0.001$), supporting H4. This result indicates that satisfied learners are more likely to continue using AR-based learning applications and remain committed to AR-supported educational environments

Table 1. Hypothesis Testing Results

Hypotheses	Relationship	Beta	p-value	Result
H1	System Quality →Learner Satisfaction	0.320	<0.001	Supported
H2	Content Quality →Learner Satisfaction	0.278	<0.001	Supported
H3	Interactivity → Learner Satisfaction	0.134	0.055	Not Supported
H4	Learner Satisfaction → Learner Loyalty	0.845	<0.001	Supported

5.4 Mediation Analysis

A mediation analysis was conducted to examine whether learner satisfaction serves as a mechanism through which augmented reality (AR) characteristics influence learner loyalty. The results indicate that learner satisfaction significantly mediates the relationship between system quality and loyalty, as well as content quality and loyalty ($\beta = 0.618$, $t = 12.879$, $p < 0.001$). This means that while system quality and content quality contribute directly to satisfaction, their ultimate impact on loyalty occurs primarily through satisfaction. In other words, learners remain loyal to AR applications not simply because the system is reliable or the content is high-quality, but because these factors enhance their satisfaction, which then drives loyalty behaviors such as continued usage and recommendation.

This finding highlight satisfaction as a critical psychological bridge between positive AR experiences and long-term commitment to AR-based learning environments. It reinforces the idea that satisfaction is not just an outcome but a mediating construct that transforms technical and content-related strengths into sustained learner engagement. Practically, this suggests that developers and educators should focus on strategies that maximize satisfaction, since it is the key pathway through which AR characteristics translate into loyalty. By ensuring reliable system performance and delivering meaningful content, institutions can foster satisfaction that, in turn, secures learners' loyalty to AR-supported educational technologies.

6 Discussion

The empirical findings of this study offer a significant departure from traditional technology acceptance reports by situating Augmented Reality (AR) within a robust post-consumption theoretical framework. The results underscore that system quality and content quality serve as the primary determinants of satisfaction in AR-supported pedagogy. This confirms that functional reliability and epistemic value are fundamental prerequisites for a positive learner experience.

Notably, the rejection of H3 (Interactivity) suggests a critical 'maturity shift' in learner expectations. As AR transitions from a technical novelty to a stabilized communication medium, users increasingly prioritize technical stability and the accuracy of information over mere tactile or sensory engagement. This aligns with the Information Systems Success Model (7), yet extends it by demonstrating that in high-stakes educational contexts, the 'wow factor' of interactivity is secondary to the reliability of the delivered content.

Furthermore, learner satisfaction emerged as the most potent predictor of learner loyalty, with mediation analysis identifying it as the central mechanism through which AR characteristics translate into long-term commitment. This reinforces the principle that loyalty is not a direct consequence of isolated technology features, but rather an emergent property of a confirmed positive cognitive evaluation. These findings provide a theoretical bridge between system design and sustained adoption, suggesting that educators and developers must prioritize systemic stability and content integrity to secure the satisfaction necessary for long-term learner engagement.

7 Implications

7.1 Theoretical Implications

This study contributes to the growing body of literature on educational technology by integrating perspectives from the Information Systems Success Model, Expectation–Confirmation Theory, and the Unified Theory of Acceptance and Use of Technology. By combining these frameworks, the study offers a more holistic understanding of how technological features of AR applications influence post-adoption behaviors in digital learning environments.

The findings highlight learner satisfaction as a mediating construct that connects AR characteristics with loyalty. This extends post-adoption research by demonstrating that satisfaction is not merely an outcome but a mechanism that transforms technological experiences into sustained engagement. In doing so, the study advances theoretical discussions on technology adoption by emphasizing the importance of satisfaction in bridging system performance and long-term behavioral outcomes.

7.2 Practical Implications

From a practical perspective, the results provide actionable insights for educators, instructional designers, and AR developers. To enhance satisfaction and foster loyalty, AR applications must prioritize system reliability, high-quality educational content, and meaningful interactive features. Developers should design AR systems that are user-friendly, visually engaging, and capable of delivering accurate and contextually relevant materials.

Educators can leverage AR technologies by embedding them into teaching strategies that encourage active learning, collaborative exploration, and problem-solving. Institutions that invest in improving the usability and instructional quality of AR applications are more likely to secure sustained learner engagement and loyalty, thereby maximizing the return on technological investments in education

8 Limitations and Future Research

Despite its contributions, this study has several limitations. First, the focus on young adult learners aged 18–34 restricts generalizability to other demographic groups, such as younger students or mature learners. Future research could broaden the sample to capture diverse age groups and educational contexts.

Second, the cross-sectional design limits the ability to examine how satisfaction and loyalty evolve over time. Longitudinal studies would provide deeper insights into the dynamics of AR adoption and sustained engagement. Third, reliance on self-reported survey data introduces potential response bias. Future studies could incorporate objective measures such as system usage logs, performance outcomes, or observational data to triangulate findings.

Finally, the study focused on system quality, content quality, and interactivity. Future research could explore additional variables such as emotional engagement, cognitive load, or motivation, which may further explain how AR fosters satisfaction and loyalty. Expanding the model to include these factors would enrich understanding of the mechanisms driving sustained adoption of AR in education

9 Conclusion

This study examined how augmented reality (AR) characteristics influence learner satisfaction and loyalty in educational contexts. The findings reveal that system quality and content quality are the strongest predictors of satisfaction, while interactivity does not exert a significant effect. Satisfaction emerged as the key driver of loyalty and mediates the relationship between AR features and long-term engagement, underscoring its central role in sustaining adoption.

By integrating perspectives from the Information Systems Success Model, Expectation–Confirmation Theory, and the Unified Theory of Acceptance and Use of Technology, the study advances theoretical understanding of post-adoption behavior in digital learning environments. Methodologically, it contributes by employing a robust quantitative design and Partial Least Squares Structural Equation Modeling (PLS-SEM) to validate the framework with empirical data from young adult learners. Practically, the results provide clear guidance for educators, instructional designers, and developers by identifying system reliability and content quality as critical drivers of satisfaction and loyalty, while clarifying the limited role of interactivity.

Overall, this study highlights that the sustainability of AR in education depends not only on technological innovation, but also on learners' satisfaction with the quality, reliability, and relevance of AR learning experiences. By positioning satisfaction as the bridge between system design and long-term loyalty, the research offers both theoretical clarity and practical direction for advancing AR as a transformative force in digital learning.

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