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Exploring the Lived Learning Experiences with Augmented Reality among STEM Students in Higher Education: An Interpretative Analysis

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ABSTRACT

Augmented reality (AR) is increasingly used in STEM education to create immersive learning, yet most studies emphasize technical and pedagogical aspects rather than learners' meaning-making processes. The research gap lies in understanding how early users of AR construct cognitive, emotional, and social interpretations within AR-based environments. This study addresses that gap by applying an interpretative approach to explore STEM students' lived experiences with AR. Semi-structured interviews with ten early adopters were analyzed, revealing four key themes: immersive cognitive engagement, emotional ambivalence, perceived social disconnection, and redefined learner identity. The findings demonstrate that AR not only influences knowledge acquisition but also reshapes students' motivation, self-perception, and agency. These insights provide practical implications for designing AR tools that move beyond content delivery to support holistic learner development.

INTRODUCTION

In recent years, the integration of augmented reality (AR) into educational settings has transformed how students interact with scientific knowledge, particularly in the fields of science, technology, engineering, and mathematics (STEM) (Pristouris et al., 2021; Zhao & Wang, 2024). As a form of immersive technology, AR overlays digital information onto the physical environment, enabling users to engage with content in ways that transcend traditional textbook or lecture-based methods. This advancement reflects a broader shift in educational paradigms, where experiential and technology-enhanced learning environments are increasingly valued for their potential to foster deeper understanding and engagement.

The relevance of this phenomenon extends beyond its technical novelty. At its core, the use of AR in education represents a shift in how learners experience knowledge—visually, cognitively, and emotionally (Mukhlis, 2025a; Mukhlis & Saidah, 2025). For early users, especially students transitioning into digital-native learning environments, AR is not merely a tool but a space where meaning is co-constructed through interaction with content. These experiences are inherently subjective, shaped by personal expectations, prior knowledge, and emotional responses. In this sense, AR learning environments serve as lived spaces in which learners' identities, motivations, and perceptions are constantly negotiated.

Given this complexity, there is a growing need to explore not just the outcomes of AR-enhanced education, but the meanings and experiences that arise from it. Understanding how individuals internalize and interpret these experiences is crucial, particularly as AR technologies continue to influence pedagogical strategies and reshape the role of the learner. A phenomenological approach offers a valuable lens through which to investigate these dimensions, focusing on the

essence of lived experience and the nuanced interplay between learners and their technological environments.

The study of individuals' lived experiences with emerging educational technologies—particularly augmented reality—has become an increasingly important area of inquiry within the broader field of science and technology education (Kee et al., 2024; Laoharutanun et al., 2025). As AR applications proliferate in classrooms and laboratories, attention has shifted toward understanding how learners make sense of their encounters with these immersive tools. This includes the cognitive transformations, emotional reactions, and social dynamics that shape and are shaped by AR-mediated learning. Within this context, phenomenological inquiry offers a valuable framework for exploring the rich, subjective dimensions of these experiences.

However, capturing the essence of such experiences poses significant methodological challenges (Mukhlis, Janwari, et al., 2023; Mukhlis & Abdullah, 2025). Traditional quantitative approaches, while effective for measuring learning outcomes or usability metrics, often fail to uncover the personal meanings and affective layers embedded in learners' interactions with AR. Structured surveys and experimental designs, for example, tend to reduce complex experiences into predefined categories, leaving little room for the nuanced, evolving nature of meaning-making that occurs in real time. This reductionism risks overlooking critical elements such as learner identity, perceived authenticity, and emotional resonance—dimensions that are central to understanding how AR is actually lived by its users.

Consequently, many prior research efforts have not adequately addressed the full spectrum of learners' perspectives (Bhagat et al., 2021; Nag, 2024). Without an interpretive lens attuned to subjectivity and context, studies may inadvertently obscure the very phenomena they aim to illuminate. This limitation underscores the necessity of phenomenological methodologies, which privilege first-person accounts and interpretive depth. Specifically, interpretative phenomenological analysis (IPA) enables a more holistic exploration of participants' experiences, drawing out themes and meanings that might otherwise remain hidden beneath surface-level observations.

Despite the growing implementation of augmented reality in STEM education, most current investigations rely on established practical approaches that emphasize usability, learning outcomes, or system performance. These approaches often adopt standardized assessment tools or quantitative metrics to evaluate the effectiveness of AR technologies. While such methods have contributed to our understanding of technical integration and instructional design, they offer only a partial view of the learner's holistic experience. Specifically, they tend to overlook the subjective, emotional, and contextual dimensions that shape how individuals engage with and internalize AR-enhanced learning environments.

This limitation becomes particularly evident when attempting to understand how learners construct meaning during immersive interactions. Conventional methodologies typically constrain participants' narratives to fixed variables, thus failing to capture the depth and complexity of their lived experiences (Bal & Öztürk, 2025; Van Borek et al., 2024). As a result, the data produced are often descriptive rather than interpretive, and superficial rather than transformative. The absence of insight into how early adopters feel, perceive, and make sense of their AR experiences leaves a critical gap in our comprehension of educational innovation at the experiential level.

To address this gap, a shift toward phenomenological inquiry is essential. Unlike traditional evaluation methods, phenomenology prioritizes the exploration of individual meaning-making and the essence of experience (Hussein Kakembo et al., 2021; Lai et al., 2019). Through this lens, researchers can access the underlying structures of perception and emotional resonance that characterize learners' interactions with AR. By adopting interpretative phenomenological analysis (IPA), this study seeks to uncover rich, layered understandings that are often inaccessible through conventional research designs—thereby offering a more holistic and authentic portrayal of the phenomenon under investigation.

Previous studies have explored the use of augmented reality (AR) in education, focusing largely on outcomes such as improved learning performance, user satisfaction, and system usability.

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While these contributions offer valuable insights, few have investigated the subjective experiences of learners interacting with AR environments (Huang & Musah, 2024; Lin & Hou, 2024). Research rooted in cognitive psychology or instructional design often fails to capture how learners make meaning from these encounters. Some studies have noted increased engagement or motivation, but the personal, emotional, and interpretive dimensions remain underexplored. This lack of experiential focus calls for approaches that attend to the depth and richness of individual narratives.

To address this, the present study applies an interpretative phenomenological approach (Maas & Hughes, 2020; Rodrigues & Loureiro, 2024). This method is designed to examine how individuals experience and interpret meaningful events in their lives. By using interpretative phenomenological analysis (IPA), this study aims to explore the essence of learners' lived experiences with AR in STEM education. This approach is particularly suited to addressing the knowledge gap identified earlier—how learners perceive and internalize AR as part of their educational journey. The method prioritizes rich description and thematic depth over generalization or statistical inference.

This article is structured as follows. The introduction presents the general and specific background of the study, along with the research rationale. The method section outlines the philosophical foundation, participant selection, data collection procedures, and analytical techniques. The results section presents thematic findings supported by direct participant quotations. Finally, the discussion and conclusion sections interpret the findings within broader theoretical and practical contexts.

RESEARCH METHODS

Study Design

This study employed an interpretative phenomenological approach to explore the lived experiences of early users engaging with augmented reality (AR) in STEM education settings (Perry, 2023). Phenomenology was selected as a methodological framework due to its capacity to uncover and interpret the meanings that individuals ascribe to their lived experiences. By focusing on subjective perception and meaning-making, this approach enabled a nuanced understanding of the cognitive, emotional, and social dimensions of AR-based learning. Specifically, interpretative phenomenology, grounded in Heideggerian philosophy, was applied to emphasize the contextual and interpretive nature of human experience, allowing for deeper engagement with participants' reflections within their educational realities.

Participants

Participants were selected using purposive sampling based on their direct involvement in using AR technology for STEM learning within the past six months (McMahon & McGannon, 2024; Mueller et al., 2024). Inclusion criteria included individuals aged 18 and above, with at least one full academic semester of exposure to AR-integrated learning environments. Participants represented diverse academic backgrounds within science, technology, engineering, and mathematics, and were required to have sufficient verbal articulation skills to reflect on their experiences. A total of 10 participants (6 female, 4 male), aged between 19 and 25 years (mean age: 21.3), contributed to the study. All participants had experienced at least three AR-based instructional sessions using either head-mounted displays or mobile AR applications.

Data Collection

Data were collected through semi-structured, in-depth interviews conducted in a private and quiet university facility designated for qualitative research (Bednarek-Gilland, 2015; Hammersley, 2003). An interview guide was developed to elicit rich narratives about participants' personal engagement, emotional responses, and meaning construction during their use of AR in STEM contexts. Interviews lasted between 45 to 75 minutes and were conducted face-to-face. All interviews were audio-recorded with consent and transcribed verbatim. The interview setting was arranged to ensure physical comfort and psychological safety, allowing participants to express their experiences

openly. The protocol followed established qualitative interviewing practices, and no substantial modifications were required.

Data Analysis

Data were analyzed using Interpretative Phenomenological Analysis (IPA), which facilitated a systematic exploration of individual meaning-making processes. The analysis followed a multi-step procedure: transcripts were read repeatedly to ensure familiarity, meaningful statements were identified and coded, emergent themes were developed and clustered, and superordinate themes were constructed through iterative comparison. NVivo 14 software was used to support data management and thematic organization. The analytic process emphasized both descriptive and interpretive engagement with the data, allowing essential experiential structures to surface and guide thematic synthesis.

Ethical Considerations

Ethical approval was obtained from the institutional research ethics board prior to data collection. Written informed consent was secured from all participants, who were briefed on the study's objectives, their voluntary involvement, and their right to withdraw at any point without penalty. Confidentiality was maintained through anonymized transcripts and secure data storage. The study was conducted in accordance with international ethical standards for research involving human subjects, including principles outlined in the Declaration of Helsinki.

RESULTS

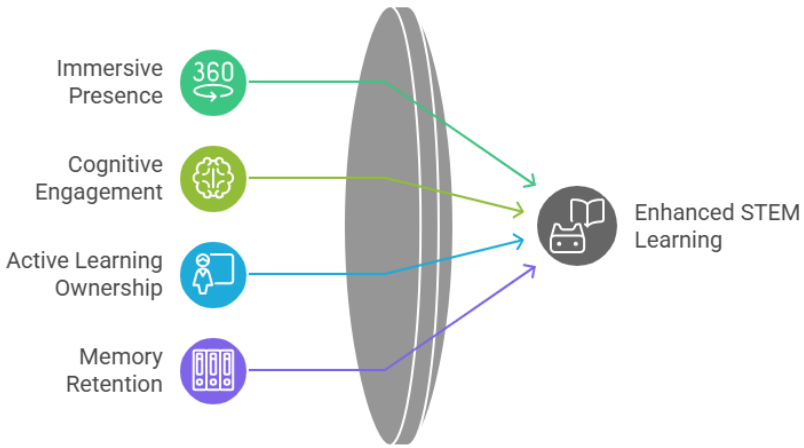
Immersive Presence and Cognitive Engagement

Participants consistently described their experiences with augmented reality (AR) in STEM learning environments as "immersive" and "real," highlighting the profound cognitive engagement facilitated by the technology. Rather than passively receiving information, users reported a sense of being "inside" the learning content, which enabled deeper conceptual understanding. One participant reflected:

"I felt like I was actually inside the human cell, not just looking at a diagram. It was like walking through biology, not studying it." (P3)

This immersive presence fostered what several participants termed as "active learning ownership." They no longer viewed themselves as passive recipients of content but rather as explorers within the knowledge domain. Such cognitive shifts were reported to enhance memory retention and make abstract STEM concepts more tangible.

AR's Impact on STEM Education



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Emotional Ambivalence—Between Awe and Overwhelm

While the use of AR in STEM education sparked curiosity and excitement, many participants also expressed moments of confusion and emotional fatigue. The novelty of the medium often elicited strong emotional responses, ranging from exhilaration to cognitive overload. As one respondent explained:

"At first, it was fascinating. But after a while, I got overwhelmed. Too many visual things competing for my attention." (P5)

These ambivalent emotions were particularly notable among participants with minimal prior exposure to AR. For some, the emotional weight of the experience translated into decreased motivation when technical glitches disrupted the flow of interaction. Nonetheless, participants acknowledged that such moments were part of the learning curve in adapting to emerging technologies.

Social Isolation within Technological Immersion

Despite the collaborative potential of AR, several users reported a sense of isolation during the AR-based learning sessions. Unlike traditional group work, which encouraged dialogue and peer interaction, the individualized nature of AR experiences led to reduced social engagement. One participant stated:

"I was so focused on the hologram in front of me that I didn't notice my friends were struggling with the same task. It felt like a solo mission." (P1)

This sense of "technological solitude" was more prominent in participants who used AR via head-mounted displays as opposed to handheld devices. The data suggest that while AR enhances individual focus, it may unintentionally inhibit collaborative learning unless designed with social interactivity in mind.

Redefining the Learning Identity

Another significant theme that emerged was the transformation of participants' self-perception as learners. Engaging with AR seemed to redefine their academic identity, moving from passive student to proactive investigator. This was especially evident in participants who initially had lower confidence in STEM subjects. One shared:

"Using AR made me feel like a scientist, not just a student. I was conducting experiments, not just learning about them." (P6)

This redefinition was not merely metaphorical but influenced participants' attitudes toward science-related careers and their willingness to engage with more complex material in future sessions.

The findings illuminate the intricate and layered meanings users ascribe to their early experiences with AR in STEM education. From heightened cognitive engagement and emotional ambivalence to unexpected feelings of social isolation and evolving academic identities, participants navigated a dynamic landscape of learning. These themes provide a rich phenomenological understanding of how AR is not only a tool for information delivery but also a medium through which learning itself is re-experienced and redefined.

DISCUSSION

The findings of this study reveal that early users of augmented reality (AR) in STEM education construct deeply personal and multidimensional experiences (Mukhlis, Suradi, et al., 2023; Mukhlis, 2025b). These experiences are shaped by cognitive immersion, emotional ambivalence, social detachment, and a redefinition of learner identity. The results directly respond to the central research question—how early adopters make meaning of their encounters with AR—by uncovering the essence of their lived engagement with this emerging technology.

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These insights contribute significantly to our understanding of how AR is internalized by learners beyond its technical functionality or instructional utility. The study highlights that AR does not simply enhance content delivery; it transforms the learner's role, alters emotional states, and fosters both empowerment and isolation. Unlike conventional studies that focus on performance metrics, this research uncovers the internal dialogues and meaning-making processes that unfold during AR use. It shows that students perceive themselves as active explorers rather than passive recipients, and that their emotional engagement is both a source of motivation and a potential barrier to sustained learning. Such findings offer a richer, more complex picture of educational technology adoption, addressing gaps that prior empirical models have overlooked.

In relation to existing literature, the findings align with studies emphasizing the immersive and motivational potential of AR (Bi, 2025; Grinshkun et al., 2021), while extending these insights by foregrounding the subjective dimension. The theme of emotional ambivalence contrasts with the predominantly positive portrayal of AR in many studies, revealing a more nuanced emotional landscape. Moreover, the experience of social isolation challenges assumptions about AR's collaborative potential, echoing concerns raised in phenomenological studies of digital learning environments (Papakostas et al., 2022; Wang et al., 2025). By drawing on interpretative phenomenological analysis, this study complements previous research by offering a context-sensitive, first-person account of AR's impact on learners' self-perception, agency, and engagement within STEM education.

The implications of these findings extend into both academic and practical domains. From an educational perspective, the study emphasizes the need to design AR-based learning environments that consider not only the instructional objectives but also the emotional, cognitive, and social realities of learners (Mukhlis, Arifin, Ridwan, & Zulbaidah, 2025; Mukhlis, Arifin, Ridwan, Zulbaidah, et al., 2025). The redefinition of learner identity and the emergence of emotional ambivalence suggest that immersive technologies hold the power to reshape students' relationships with knowledge, authority, and self-efficacy. Culturally, the findings prompt reflection on how educational technologies may reinforce or disrupt traditional learning norms, especially in contexts where passive consumption of information is the default. Professionally, the study offers insights for educators, designers, and policymakers seeking to implement AR tools in ways that respect and enhance the learner's lived experience.

This study is not without limitations. As a phenomenological investigation focused on a specific group of early AR adopters within a STEM education context, the findings cannot be generalized to all learners or educational settings (Mukhlis, Maryam, et al., 2023; Mukhlis et al., 2024). The sample size, while appropriate for in-depth qualitative research, may not reflect the full diversity of experiences across different cultural, institutional, or technological contexts. Additionally, reliance on self-reported narratives introduces the possibility of selective memory or social desirability bias. These limitations do not diminish the value of the findings but instead highlight the contextual and interpretive nature of phenomenological research.

Future research may build upon these findings by exploring the long-term impact of AR use on learner identity and engagement, particularly across different educational levels and cultural settings (Park et al., 2024; Prahani et al., 2025). Comparative phenomenological studies involving diverse learner populations could enrich our understanding of how AR experiences vary by age, gender, or educational background. Additionally, integrating phenomenological insights with design-based research could inform the development of AR tools that are more responsive to users' lived realities. Ultimately, this study opens pathways for further inquiry into the human dimensions of educational technology—dimensions that are too often overlooked in favor of efficiency, scalability, or performance metrics.

CONCLUSION

This study explored how early users of augmented reality (AR) in STEM education make meaning of their learning experiences through a phenomenological lens. The findings revealed that learners construct complex interpretations shaped by immersive engagement, emotional ambivalence,

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social disconnection, and a shifting sense of academic identity. These results highlight the deeply subjective and multidimensional nature of AR-based learning, offering insights that go beyond conventional performance metrics. By focusing on the lived experiences of participants, this study addresses a critical gap in existing literature and contributes to a richer understanding of how emerging technologies affect learner perception and behavior. The interpretative phenomenological approach proved effective in uncovering insights that would be inaccessible through quantitative methods alone. Future studies may expand on these findings by exploring diverse user groups or integrating phenomenological insights into AR instructional design frameworks.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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