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Augmented Reality in Science and English Education: Primary Classroom Pre-Service Teacher Experiences

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***Abstract*:**

This research investigates the implementation of Augmented Reality (AR) in English and Science teaching by pre-service teachers in primary schools. Thirty-four pre-service teachers from the Arab American University attended a four-week AR workshop, with four being chosen for extensive classroom observations and video analysis. Employing a qualitative case study approach, the study investigated the mechanisms of AR integration, intended educational goals, and perceived challenges and gains. Results indicated that AR enriched engagement, motivation, and conceptual comprehension through interactive 3D models, real-world simulations, game-based learning, and collaboration. Educational goals involved promoting inquiry, assisting diverse learning styles, and building digital literacy. Challenges included technical issues, time constraints, cognitive overload, and institutional support limitations. This study emphasizes AR's pedagogical flexibility across subjects. Recommendations call for specific teacher training, infrastructure development, and policy support to facilitate effective and equitable AR adoption in primary education.

***Keywords*: Augmented reality; Pre-service teachers; Science education; English education.**

1. Introduction

Augmented Reality (AR) has emerged as a promising tool for enhancing instruction by overlaying digital content onto real-world environments. By enabling students to interact with 3D models, animations, and audio-visual content, AR offers immersive learning experiences that support deeper conceptual understanding and increase learner motivation. In particular, its potential in Science and English education is increasingly recognized, as it enables learners to visualize complex systems, explore language in context, and engage with content in interactive, multimodal ways.

Augmented Reality (AR) and Virtual Reality (VR) are immersive and interactive learning experiences that increase knowledge retention and skill acquisition in various domains like STEM, language acquisition, and special education, but their adoption is hampered by prohibitive costs, technical constraints, and ethical issues, and will take concerted efforts to provide equitable access and pedagogical integration (Thangavel, K, & K, 2025).

Recent studies have demonstrated that AR can positively impact student engagement, attention, and learning outcomes, especially when aligned with sound pedagogical principles such as Cognitive Load Theory (CLT) and Multimedia Learning Theory (MLT) (Mayer, 2003; Radu, 2014). In Science education, AR has been used to visualize abstract processes like respiration or ecological systems, helping reduce cognitive overload by concretizing spatially complex content. In English language learning, AR supports vocabulary development, pronunciation, and interactive reading through multimodal representations and gamified tasks (Hsu, 2017; Syawaludin et al., 2020).

Despite growing evidence of AR's benefits, most existing research focuses on in-service teachers, controlled experiments, or subject-specific applications. Far less is known about how pre-service teachers—those still in training—conceptualize and implement AR in real classroom settings, particularly across multiple subject areas. Understanding how novice teachers apply AR in authentic teaching environments is essential for informing teacher education programs and ensuring meaningful technology integration from the outset of professional practice.

Moreover, while individual studies have explored AR use in Science or English, few have offered comparative insights across disciplines, especially at the primary education level, where pedagogical needs and cognitive demands differ significantly. This lack of cross-disciplinary and context-rich evidence highlights the need for empirical studies that examine how AR is used by pre-service teachers in both subjects, what educational goals it supports, and what challenges arise during implementation.

While augmented reality has been widely explored in education, much of the existing research is subject-specific, with a strong emphasis on Science education and, to a lesser extent, English as a Foreign Language (EFL) instruction. Studies that examine AR across multiple disciplines within the same learning context remain rare, particularly at the primary school level. Moreover, the majority of prior investigations have involved either controlled laboratory experiments or pre-service teachers working in simulated teaching environments, rather than implementing AR in authentic classroom settings with real students. This gap limits our understanding of how novice educators navigate the pedagogical, technical, and classroom management challenges of AR integration in real-world teaching. Addressing this gap, the present study investigates the experiences of pre-service teachers using AR to teach both English and Science in primary classrooms, offering cross-disciplinary, practice-based insights that extend beyond the constraints of single-subject or simulation-based research.

1.1. Research Questions

This study aims to comprehensively examine AR's role in enhancing Science and English instruction. Specifically, it investigates how pre-service teachers integrate AR into their teaching, the objectives they aim to achieve, and the effects on student engagement and interaction. The following research questions guide this inquiry:

1. What mechanisms are employed by pre-service teachers to integrate AR into Science and English lessons, as observed through classroom interactions and video recordings?
2. What specific educational objectives do pre-service teachers aim to achieve by integrating AR into Science and English lessons?
3. What challenges and benefits related to the use of AR are identified in Science and English classrooms, based on observational data and video analysis?

These research questions address unexplored aspects of AR integration by pre-service teachers. This approach offers a novel perspective that extends the existing body of research on AR's impact on education.

2. Literature Review

2.1. Theoretical Background

The integration of Augmented Reality (AR) in educational contexts can be meaningfully understood through Cognitive Load Theory (CLT) and Multimedia Learning Theory (MLT). These theories provide a foundation for analyzing how AR influences learners' cognitive processes, especially in complex, content-rich subjects like Science and English.

Cognitive Load Theory (Sweller, 1999) posits that instructional materials should be designed to manage the limitations of working memory. Effective instruction reduces extraneous cognitive load, supports germane load, and optimizes intrinsic load to enhance schema construction. AR, by offering interactive and spatially anchored information, has the potential to reduce extraneous load by visually organizing complex content and minimizing the need for abstract inference.

For instance, Buchner et al., (2021) analyzed 58 empirical studies on AR and cognitive load, finding that nearly half reported a reduction in extraneous load and improved learner performance. When students interact with realistic simulations—such as a 3D model of the respiratory system—AR supports conceptual understanding by reducing the mental effort required to imagine abstract processes. However, the same studies warn that unstructured AR experiences may increase load, leading to distraction or overload, particularly for novice learners.

Multimedia Learning Theory (Mayer, 2003) further reinforces the educational promise of AR. MLT emphasizes the dual-channel processing of visual and auditory information, suggesting that learning improves when both channels are efficiently engaged. AR's multimodal format, combining visuals, sound, and kinesthetic interaction—aligns closely with these principles. For example, Khalaf (2021) demonstrated that AR-supported science instruction significantly enhanced logical thinking and retention by leveraging synchronized visual-auditory cues. Together, CLT and MLT underscore the importance of instructional design in AR environments.

These theories guide both the structure of AR applications and the pedagogical strategies teachers use to integrate them. As this study explores AR use by pre-service teachers, it is particularly interested in whether these emerging educators can harness AR's potential in ways that align with cognitive learning principles—reducing overload, scaffolding content, and improving retention. Recent studies confirm AR's potential to reduce cognitive effort, increase retention, and promote motivation among pre-service teachers (Abualrob, Frehat, & Ferati, 2025). Other studies show that AR promotes content u comprehension and engagement (Belda-Medina, 2025), and supports continued use through perceived usefulness and facilitating conditions (Nizar et al., 2024).

2.2. Empirical Review

Building on these theoretical foundations, recent research validates AR's efficacy in numerous contexts. Ahdhianto et al. (2025) demonstrated that AR based on simulation considerably improved students' comprehension of cultural diversity. Huang and Musah (2024) established that AR enhances creativity, behavior, and teaching strategies, and that teacher competence and technology acceptance are vital factors. Rizki et al. (2024) proved that the integration of cooperative learning, digital games, and AR increases critical thinking and motivation. These studies underscore AR's multifaceted benefits across disciplines and learner populations. Most studies, however, focus on single-subject applications or in-service teachers in controlled environments, leaving notable gaps in understanding how pre-service teachers apply AR in cross-disciplinary, real-world primary classrooms.

Studies such as Syawaludin et al. (2020) and Atalay (2022) emphasize the motivational and cognitive benefits of AR in science instruction. Syawaludin et al. found that AR environments promote critical thinking and hands-on learning, especially in experimental science topics. Atalay showed that pre-service teachers experienced increased enthusiasm when incorporating AR into lessons, but highlighted their need for better training in selecting and integrating AR tools pedagogically.

In English language education, Al-Harithi and Hasan (2023) reported that AR contributed positively to vocabulary acquisition and student participation. However, they noted a lack of instructional guidance and recommended professional development programs to prepare teachers for technology-rich environments. Similarly, Julie (2014) found that while AR increased student interest, it required considerable preparation time and technical skills, which not all teachers possessed. Recent research emphasizes AR's value in teacher preparation: it enhances retention and motivation (Belda-Medina, 2025), and facilitates continued use through performance expectancy and facilitative conditions (Nizar et al., 2024). These results are echoed by Abualrob, Frehat, and Ferati (2025), who reported positive attitudes and cognitive benefits among pre-service teachers using AR. Despite these advancements, two significant research gaps persist:

1. Cross-Disciplinary Integration: Few studies investigate how AR is used across subject boundaries, particularly in foundational education. The educational value of AR in connecting science concepts with language learning (e.g., vocabulary related to anatomy or ecosystems) is underexplored.
2. Primary Education and Pre-Service Teachers: Most AR studies examine higher education or experienced teachers. There is a lack of research on how pre-service teachers—who are still developing

pedagogical judgment apply AR in actual classrooms with young learners. Research by Wang et al., (2024) emphasizes this need, especially in under-resourced contexts where AR may offer affordable solutions to instructional challenges.

This study addresses both gaps by examining how pre-service teachers use AR in real primary classrooms across both English and Science subjects, linking pedagogical strategies to theoretical principles. By analyzing video data and classroom observations, the study contributes empirical insights into the cognitive and instructional dynamics of AR integration at the entry point of professional teaching.

Despite growing interest in Augmented Reality across educational settings, most studies have focused on either in-service teachers or single-subject domains, often in controlled environments or during brief interventions (e.g., Radu, 2014; Hsu, 2017; Syawaludin et al., 2020). There is limited empirical work examining how pre-service teachers integrate AR into real classroom practice, particularly across multiple disciplines such as English and Science. Moreover, cross-case comparisons that highlight subject-specific strategies and cognitive demands remain underexplored. This gap in the literature informs the current study's research questions, which aim to investigate (1) how pre-service teachers implement AR in English and Science classrooms, (2) what educational objectives they aim to achieve through AR, and (3) what challenges and benefits they encounter during the process. By addressing these questions, the study contributes to a deeper understanding of AR's pedagogical role in early teacher preparation across disciplines.

3. Methodology

This study employed a qualitative case study design to explore how pre-service teachers integrate Augmented Reality (AR) into Science and English instruction in primary classrooms. Drawing from the methodological frameworks of Yin (2018) and Merriam and Tisdell (2016), the study aimed to generate rich, contextualized insights into the processes, benefits, and challenges associated with AR implementation in real-world educational settings. The case study approach was particularly suited for this inquiry due to its focus on understanding contemporary phenomena within bounded systems and its flexibility in accommodating multiple data sources.

3.1. Participants and Sampling Strategy

The study adopted a purposive sampling strategy to ensure the inclusion of participants who were actively engaged in educational technology integration and teacher preparation. Initially, thirty-four pre-service teachers from the Department of Basic Education and English Language at Arab American University participated in a four-week AR training workshop. From this cohort, four participants were purposefully selected for in-depth classroom observation based on their demonstrated interest, technological aptitude, and active participation in the workshop. The selected sample included two pre-service teachers teaching Science and two teaching English, drawn from two primary schools in Palestine: New Qabatiya Girls School and Khadija Bint Khuwaylid School.

While the sample size is limited, such depth-oriented sampling is appropriate for qualitative inquiry, where the aim is not statistical generalization but rather theoretical and analytical insight (Merriam & Tisdell, 2016). The bounded nature of the cases allowed for intensive examination of the contextual dynamics influencing AR integration.

3.2. Workshop Design

The AR training workshop was designed to develop the participants' competencies in using AR tools for educational purposes. Spanning eight 90-minute sessions over four weeks, the workshop included interactive training modules focused on:

- Theoretical foundations and pedagogical applications of AR
- Hands-on activities using tools such as Halo AR and Merge Cube
- Collaborative lesson planning incorporating AR content
- Simulated classroom scenarios for trial implementation

• Reflective discussions and feedback sharing

3.3. Data Collection Methods

To ensure a robust and multi-faceted understanding of AR implementation, the study employed a triangulated data collection strategy involving classroom observations, video recordings, and observation cards:

- Observation Cards: These were adapted from validated technology integration rubrics and structured to capture data on instructional strategies, student engagement, classroom management, and AR usage. Three expert reviewers examined the cards to ensure content validity.
- Video Recordings: Classroom sessions were recorded to document instructional delivery and student responses. Video data enabled the capture of real-time interactions, expressions, and engagement patterns that might have been missed during live observation.
- Field Notes: Supplementary field notes were maintained during observations to record contextual cues, logistical constraints, and spontaneous teacher-student interactions.

By triangulating these three sources, the study enhanced the credibility and dependability of its findings (Yin, 2018).

3.4. Data Analysis

The collected data were analyzed using thematic analysis based on Creswell's (2019) six-step coding procedure:

1. Data organization: Observation cards and video transcripts were organized thematically.
2. Initial coding: Data segments were labeled with preliminary codes reflecting recurring patterns.
3. Theme development: Related codes were clustered into broader themes such as "student engagement," "technical challenges," and "instructional strategies."
4. Validation: Themes were cross-validated using triangulated data sources.
5. Interpretation: Emerging themes were interpreted in light of Cognitive Load Theory and Multimedia Learning Theory.
6. Reliability check: To ensure coding consistency, inter-rater reliability was calculated on 50% of the video data, yielding Cohen’s Kappa values between 0.62 and 0.73, indicating strong agreement.

To enhance methodological transparency, sample excerpts from classroom observation transcripts were included to illustrate the coding process. For example, in one English lesson, a student exclaimed, “How did this video appear on the book page?”

This was coded as “Curiosity and Wonder” under the broader theme of Motivation. Similarly, in a Science lesson, a pre-service teacher instructed, “Rotate the lungs to see where the air goes”, which was coded as “Guided Exploration” within the theme of Instructional Strategies. These excerpts demonstrate how raw qualitative data were systematically transformed into thematic categories.

Inter-rater reliability was calculated on 50% of the video data to balance rigor with feasibility, given the intensive time requirements of double-coding lengthy classroom recordings. This proportion was selected to ensure a representative sample of lessons across both Science and English contexts. Discrepancies between coders were resolved through discussion and consensus-building sessions, with a third reviewer consulted when agreement could not be reached.

To strengthen the trustworthiness of the findings, the study incorporated member checking by sharing preliminary thematic summaries with participating pre-service teachers for verification and feedback. Additionally, peer debriefing sessions were conducted with two independent educational technology researchers to review coding decisions and thematic interpretations. An audit trail was maintained, documenting analytic decisions, code definitions, and theme refinements, ensuring transparency and enabling replication by other researchers.

The analytic process emphasized inductive reasoning and recursive examination of data, supporting thick description and context-rich interpretation. The study's methodological rigor was thus grounded not in sample size, but in the depth, consistency, and transparency of its data analysis practices.

3.5. **Ethical Considerations**

Ethical clearance was obtained from the institutional review board of Arab American University. Informed consent was collected from all participants, and pseudonyms were used to ensure confidentiality. Video recordings were stored securely and used solely for research purposes.

In summary, this methodology emphasizes depth over breadth, prioritizing credibility, contextual richness, and theoretical alignment. While the small sample and localized setting limit generalizability, the triangulated, multi-source approach ensures a robust exploration of how AR is experienced and enacted by pre-service teachers in primary education.

This research is positioned as an exploratory and bounded case study, intentionally focusing on a small, context-specific sample to generate rich, in-depth insights into pre-service teachers' integration of AR in primary English and Science classrooms. The aim is not to produce statistically generalizable findings, but to offer contextually grounded understanding that can inform teacher education practices and guide future research. To strengthen credibility, the study draws on triangulation of multiple qualitative data sources—classroom observations, video recordings, and observation cards—and future iterations could incorporate student interviews, analysis of lesson plans, and pre/post engagement surveys to capture more diverse perspectives. While the present study is situated within two schools in Palestine, future research could extend the investigation to multiple sites and a broader participant pool across varied educational contexts, enabling comparative analyses and deeper exploration of the transferability of findings.

4. Findings

This study's findings provide unique insights into how pre-service teachers integrate AR into primary education. Specifically, it identifies innovative mechanisms such as activating prior knowledge, facilitating collaboration, and providing immediate feedback—strategies not extensively documented in previous AR research. These findings extend existing studies by Atalay (2022) and Syawaludin et al., (2020), which focus on experienced educators and specific disciplines, by emphasizing the creative adaptations of novice teachers across Science and English subjects. This aligns with recent findings on AR's motivational and cognitive benefits for pre-service teachers (Abualrob et al., 2025; Nizar et al., 2024).

4.1. Findings of the first research question

The integration of Augmented Reality (AR) by pre-service teachers into Science and English lessons revealed a diverse range of innovative mechanisms that transformed traditional teaching approaches. These mechanisms include interactive tools, collaborative activities, and innovative instructional strategies to foster a deeper understanding and sustained motivation. A summary of the key mechanisms, their descriptions, and observed benefits is presented in Table 1.

Table 1. Summary of mechanisms for integrating augmented reality in science and English lessons

N	Mechanism	Description	Observed Benefits
1	**3D Models and Visualizations**	Students used interactive 3D models to explore topics like the human respiratory system and animal anatomy.	Improved conceptual understanding, better visualization of abstract concepts, and enhanced retention.
2	**Game-Based Learning Experiences**	AR-based card games were used for vocabulary identification and matching exercises.	Increased student engagement, motivation, and enjoyment, especially for less motivated learners.

3	**Real-World Simulations**	Simulations depicted animal behaviors and real-world scenarios for connecting theoretical knowledge to practice.	Fostered deeper understanding and application of knowledge; made lessons more realistic and engaging.
4	**Enhanced Instructions**	AR tools provided guided exploration with multimedia support, such as videos and songs linked to textbook images.	Combined auditory and visual learning for clearer comprehension and emotional engagement.
5	**Peer Interaction and Collaboration**	Group activities involved students analyzing AR visuals together, promoting teamwork and shared problem-solving.	Strengthened interpersonal skills, increased enthusiasm, and encouraged inclusive learning.
6	**Immediate Feedback and Assessment**	Students received instant feedback by interacting with AR models, e.g., identifying body parts in 3D.	Enabled active learning, reinforced comprehension, and built confidence through real-time corrections.
7	**Activating Prior Knowledge**	AR tools revisited previous lessons (e.g., digestive system) before introducing new topics (e.g., respiratory system).	Helped scaffold learning, reduce cognitive load, and link new concepts with prior understanding.

Table 1 illustrates how these mechanisms not only facilitated interactive learning but also addressed key educational challenges, such as engaging less-motivated learners and making abstract concepts more accessible. These benefits reflect findings from recent AR studies that reported increased retention and motivation (Abualrob et al., 2025; Belda-Medina, 2025), as well as sustained intention to use AR among pre-service teachers (Nizar et al., 2024).

1. *Utilization of 3D Models and Interactive Visualizations*

Using Halo AR, students explored rotatable, zoomable 3D animal models such as tigers, giraffes, and snakes. These mechanisms allowed students to manipulate and engage with content dynamically, facilitating better understanding and retention. In one instance, a trainee used AR applications to demonstrate the human respiratory system by showing 3D models of the system's organs, allowing students to visualize the journey of air through the system and how it moves from one organ to another.

This approach aligns with Raimundo et al., (2022), who highlighted the significant role of AR in creating interactive and immersive experiences that enhance students’ engagement and comprehension. The ability to visualize abstract concepts concretely mirrors findings by Anderson and Liarokapis (2014), emphasizing AR’s effectiveness in bridging gaps in spatial and visual learning.

The observed use of 3D anatomical models and lifelike animal simulations directly reflects principles from Cognitive Load Theory (Sweller, 1999). By providing concrete, spatially anchored representations of abstract systems, these AR activities reduced intrinsic cognitive load—the mental effort required to mentally visualize complex structures—allowing students to focus more cognitive resources on integrating new information. Furthermore, when these visualizations were paired with audio explanations or animated sequences, they leveraged Mayer’s (2003) Multimedia Learning Theory by engaging both visual and auditory channels in a coordinated manner. This multimodal input not only reinforced understanding but also promoted dual coding, which has been shown to improve long-term retention of content.

2. Integration of Game-Based Learning Experiences

AR-based games, such as card-matching exercises, were employed to make lessons interactive and enjoyable. These games successfully engaged students, including those with lower academic motivation, by gamifying learning and promoting active participation. It was observed that the pre-service teacher moved on to the third activity, which was also an entertaining educational game for the students. The activity was to identify words that contain the letter O. To play this game, ten cards were used, and a number from 1-10 was written on each of these cards. Using the Halo AR application, once the application's camera was pointed at the card, the phone would pronounce the word that this card expresses.

The students were eager to discover each card's hidden word, adding an element of surprise and curiosity. The student went to the front of the class and chose a card from the ten cards placed on the teacher's table. The number "7" was written on the card. and so on until all the students heard it well.

As Syawaludin et al., (2020) observed, game-based learning with AR enhances critical thinking and problem-solving skills while making learning fun. According to Abualrob and Awad (2024) also observed, the Augmented Reality-based Board Game demonstrated its effectiveness in enhancing creativity, innovation, communication, and collaboration skills among students.

3. Enhanced Instructions and Guided Exploration

Through AR, pre-service teachers facilitated detailed exploration of concepts like body parts or scientific structures. Students could zoom in, rotate, and analyze intricate details of 3D models. Additionally, AR applications integrated with videos, such as children's songs, enriched lesson delivery by providing context and emotional engagement. For example, a children's song about body parts was activated by pointing the camera at an image in the textbook, making the lesson lively and memorable.

According to Mayer's Multimedia Learning Theory (2003), combining multimedia elements like visuals and audio enhances learning by engaging multiple senses simultaneously. This strategy aligns with Khalaf (2021), who demonstrated that AR supports logical reasoning and content retention by visually simplifying complex subjects.

4. Real-world simulations and Scenario-Based Learning

AR simulations brought real-world scenarios into classrooms, such as wildlife behaviors and interactive dialogues in English. These scenarios enabled students to connect theoretical knowledge with practical applications, fostering deeper understanding and appreciation for the subject matter. One trainee noted: "*Through AR, we can show things that are hard for students to see in real life." Another trainee added: "The most important point is that AR lets students see the 3D models as if they are right there in the classroom, and they can view them from all angles, zooming in and out as they wish."*

The pre-service teacher used this application so that the students could see the animals in their real form and not just a drawing. When the camera was focused on one of the animals on the first page of the lesson, which are the tiger, giraffe, snake, monkey, elephant and fox, the camera showed the animal in its real form. Some of them were either a real picture of the animal or a real three-dimensional model. The pre-service teacher used the phone and went to each group and focused the camera on the drawings in the book, showing them real pictures or models.
Atalay (2022) emphasized that AR's realistic simulations provide learners with opportunities to experience phenomena otherwise inaccessible in classroom settings, such as observing microscopic organisms or distant wildlife, thereby increasing the relevance of educational content.

5. Peer Interaction and Collaboration

AR-supported group activities encouraged peer discussions, collaborative exploration, and shared problem-solving. It was observed that there was a lot of enthusiasm and interaction from the students, and eagerness to see the picture on each card, and also the students were moving these cards in their hands, raising them and then lowering them, to see the picture fixed on the card as if the card had turned into a picture that could be moved and viewed in the environment in which they were.

Collaborative learning is central to Raimundo et al., (2022), who noted that AR promotes teamwork and shared learning experiences. The emphasis on group engagement and dialogue aligns with Al-Harithi and Hasan's (2023) findings on the social benefits of AR in fostering cooperation among learners. Other recent studies such as Li et al., (2023); Smith and Yang (2022) provide insight into the growing use of AR in primary education, emphasizing its role in enhancing interactive learning experiences and improving student retention.

6. Immediate Feedback and Assessment

AR applications provided instant feedback to students by visually indicating correct or incorrect answers. This mechanism allowed immediate corrections, reinforcing comprehension and ensuring active learning during lessons. In one case, a trainee used AR to provide immediate feedback. Using a 3D model of the human head, students could interact with it, identifying body parts like the eyes and ears.

The use of instant feedback mirrors insights from Julie (2014), who identified AR as a valuable tool for formative assessment. By validating responses in real time, AR enhances self-regulation and promotes a growth-oriented mindset among students.

7. Activating Prior Knowledge

Pre-service teachers used AR to bridge prior knowledge with new concepts, reinforcing foundational understanding. For instance, AR cards were employed to revisit lessons on the digestive system before introducing the respiratory system, ensuring students could differentiate between the two. Students interacted with AR cards, which, when scanned with a phone camera, displayed 3D models of the digestive or respiratory organs.

This mechanism reflects Sweller's Cognitive Load Theory (1999), which emphasizes reducing cognitive overload by linking new information with existing knowledge structures. AR's ability to scaffold learning aligns with research by Syawaludin et al., (2020), who observed similar benefits in science education.

Overall, the mechanisms employed by pre-service teachers to integrate AR had a profound impact on classroom dynamics. The ability to visualize, interact, and collaborate transformed lessons into immersive experiences, fostering enthusiasm, confidence, and a deeper connection with the content. As shown in Table 1. the integration of these mechanisms helped enhance engagement and understanding of complex concepts. This aligns with findings from Atalay (2022) and Syawaludin et al., (2020), who demonstrated that AR significantly enhances both teacher-student interaction and student achievement.

4.2. Findings of the second research question

The integration of Augmented Reality (AR) into Science and English lessons by pre-service teachers highlighted several specific educational objectives. The findings are presented below, contextualized with relevant academic literature and linked to classroom observations.

Table 2. Findings of the second research question: educational objectives of AR integration

Objective	**Description**
Enhancing Student Engagement	AR captivated students through interactive and immersive features.
Increasing Student Motivation	Interactive AR games and puzzles stimulated excitement and curiosity.
Facilitating Collaboration and Teamwork	Group-based AR activities promoted peer interaction and cooperative problem-solving.
Developing a Spirit of Inquiry	AR encouraged students to ask questions and think critically about lesson materials.
Supporting Diverse Learning Styles	AR combined visual, auditory, and hands-on content to accommodate different learning preferences.
Making Learning Realistic	AR linked theoretical knowledge to lifelike simulations and real-world applications.
Developing Digital Skills	Students interacted with AR tools, enhancing their proficiency with modern technologies.

Table 2. provides a concise overview of the educational objectives achieved through AR integration. It highlights how AR facilitated active participation, critical thinking, and technological proficiency, offering a transformative approach to modern teaching practices. These objectives align with prior evidence emphasizing AR's cross-disciplinary potential and effectiveness in teacher preparation programs (Nizar et al., 2024; Abualrob et al., 2025).

1. *Enhancing Student Engagement in Learning*

AR effectively increased students' engagement by fostering enjoyment and curiosity. It has been observed that the use of augmented reality encourages students, enhances their self-confidence, and engage them in the teaching-learning process and in interacting with their colleagues and teachers.

This finding aligns with Raimundo et al., (2022), who reported that AR's novelty and interactivity captivate students' attention and sustain their involvement throughout lessons. The immersive nature of AR, as observed in this study, also supports Atalay's (2022) conclusion that AR motivates learners by transforming mundane tasks into stimulating activities.

2. *Increasing Student Motivation*

AR stimulated students' curiosity and attentiveness, encouraging even less motivated learners to actively engage in lessons. The students were clearly happy, delighted and surprised, and they asked the pre-service teachers, "How does this happen? How did this video appear on the book page?"
The link between motivation and AR is well-documented in educational research. Syawaludin et al., (2020) found that AR applications make lessons enjoyable, reducing resistance to learning and promoting a sense of achievement. These findings confirm AR's potential to transform classroom dynamics by motivating students across varying academic abilities.

3. *Facilitating Collaboration and Teamwork*

Pre-service teachers noted that AR-enhanced activities fostered a spirit of cooperation and enthusiasm among students. Group tasks, such as solving interactive puzzles, encouraged collaboration and strengthened peer relationships. The use of augmented reality in the class led to collaborative learning by involving all students in the activities and group discussions that were managed by the pre-service teacher. As for the student interaction, it was a positive, fun, calm, and organized interaction, and motivated all students to participate, verified the focus and attention of all students, and ensured everyone's participation.

Collaborative learning is a hallmark of effective educational practices, as highlighted by Al-Harithi and Hasan (2023). AR not only enhances group interactions but also provides a platform for shared problem-solving and dialogue, supporting a sense of community within the classroom.

4. *Developing a Spirit of Inquiry*

AR prompted students to ask questions and think critically about presented content. Frequent inquiries and deeper engagement with lesson materials indicated that students developed a strong sense of curiosity and analytical thinking. This outcome aligns with Buditjahjanto and Irfansyah (2023), who observed that AR stimulates higher-order thinking skills by presenting learners with interactive, inquiry-driven scenarios.

5. *Supporting Different Learning Styles*

By combining visual, auditory, and interactive content, AR accommodated diverse learning styles. Visual learners benefited from 3D models and videos, while kinesthetic learners engaged through hands-on interaction with AR tools.

Mayer's Multimedia Learning Theory (2003) underscores the importance of catering to varied cognitive preferences through multimodal representations. This study confirms that AR's ability to adapt content delivery to different learning styles enhances its effectiveness as a teaching tool.

6. Making Learning Realistic

AR bridged the gap between theoretical knowledge and real-world applications by providing lifelike 3D models and realistic simulations. For example, students observed the respiratory system in action, connecting textbook concepts with sensory experiences. The pre-service teacher used an application so that the students could see the animals in their real form and not just a drawing. When the camera was focused on one of the animals on the first page of the lesson, which are the tiger, giraffe, snake, monkey, elephant and fox, the camera showed the animal in its real form. Some of them were either a real picture of the animal or a real three-dimensional model. The pre-service teacher used the phone and went to each group and focused the camera on the drawings in the book, showing them real pictures or models.

Atalay (2022) emphasized AR's capacity to contextualize learning by linking abstract theories to tangible realities. This finding also echoes Khalaf (2021), who highlighted the role of AR in fostering deeper comprehension through realistic representations of scientific phenomena.

7. Developing Digital Skills

AR activities require students to interact with modern digital tools, such as mobile devices and AR applications. Videos and observation cards showed that trainees had advanced skills in employing technology in education. Digital literacy is increasingly recognized as a critical 21st-century skill (Raimundo et al., 2022). This study demonstrates that AR not only facilitates academic learning but also equips students with practical skills essential for navigating technological landscapes.

Table 2. provides an overview of the educational objectives, such as enhancing collaboration and supporting diverse learning styles, which were achieved through the integration of AR in the classroom. The integration of AR achieved a multifaceted transformation in the learning experience, combining academic enrichment with the development of personal and technical skills. AR's ability to engage students, support diverse learning needs, and create realistic and collaborative environments underscores its value as a transformative educational tool.

These findings align with broader research, such as Syawaludin et al., (2020) and Julie (2014), which advocate for AR's inclusion in curriculum design to enhance learning outcomes. By fostering engagement, motivation, and digital fluency, AR offers a holistic approach to modern education, preparing students for both academic and real-world challenges.

4.3. Findings of the third research question

The use of Augmented Reality (AR) in Science and English classrooms provided numerous benefits while also presenting notable challenges. Table 3. below provides a comprehensive comparison of the challenges and benefits associated with AR integration, drawing on classroom observations and video analysis.

Table 3. Comparison of challenges and benefits of augmented reality (AR) integration in classrooms

Challenges	Benefits
Dependency on specialized hardware and reliable internet access.	Enhanced student engagement through interactive and immersive learning experiences.
The learning curve for teachers and students unfamiliar with AR tools.	Improved conceptual understanding of abstract topics through 3D visualizations and simulations.
Cognitive overload from complex or unstructured AR activities.	Increased student motivation and enjoyment, particularly among less motivated learners.
Time constraints during lessons due to AR setup and troubleshooting.	Promoted collaboration and teamwork through group-based AR activities.
Lack of institutional support and AR-compatible resources.	Developed digital skills essential for 21st-century learning and future careers.

This balanced perspective underscores the importance of addressing challenges to maximize AR's effectiveness in educational settings.

4.3.1 Challenges of Using AR in Classrooms

1. ***Technical and Logistical Barriers***

A significant challenge was the dependency on specialized hardware (e.g., AR-compatible devices) and consistent internet access. It has been shown that there are obstacles that may hinder teachers from using augmented reality, including lack of expertise and a lack of capabilities and tools.
These findings align with Khalaf (2021) and Julie (2014), who highlighted the infrastructural demands of AR as a barrier, particularly in under-resourced educational settings. In Palestine, where logistical challenges such as strikes and class suspensions are prevalent, the potential of AR is further constrained. Addressing these issues requires investment in technological infrastructure and flexible learning plans to maximize AR's benefits.

2. ***Time Constraints and Classroom Management***

AR's implementation required extra time for setup, instruction, and troubleshooting. Pre-service teachers often struggled to fit AR activities into the limited duration of class periods. Furthermore, the interactive nature of AR occasionally led to off-task behavior, complicating classroom management. It was noted that the class time ended before the activity was completed, in addition to the inability to control the students during the implementation of the activities. Sweller's (1999) Cognitive Load Theory suggests that while AR can reduce cognitive barriers in learning, its complexity may inadvertently increase task management demands for teachers. Similar observations by Sarigoz (2019) emphasized the need for streamlined lesson planning to avoid disruptions while maintaining student focus.

3. ***Learning Curve for Pre-Service Teachers and Students***

The adoption of AR required substantial technical proficiency, posing a learning curve for both teachers and students. Pre-service teachers reported initial difficulties in seamlessly integrating AR, while younger students or those unfamiliar with digital tools required extra support to use AR effectively. Atalay (2022) noted that insufficient training for educators in AR technology is a common barrier. This study reinforces the necessity of professional development programs to equip teachers with the skills to implement AR confidently and effectively. Similarly, Julie (2014) emphasized the importance of user-friendly AR interfaces to facilitate smoother adoption among younger learners.

4. ***Risk of Distraction and Cognitive Overload***

While engaging, AR's immersive nature sometimes diverted students' attention from the learning objectives. Students occasionally became overly focused on manipulating AR elements, which detracted from their understanding of lesson content. Furthermore, the abundance of interactive information led to cognitive overload in some cases, especially for students who benefit from simpler learning approaches. This observation is consistent with Buchner et al., (2021), who found that AR's effectiveness depends on the balance between engagement and cognitive demands. Overloading students with visual stimuli can hinder learning outcomes, necessitating careful design and moderation of AR activities.

5. ***Lack of External Support***

Pre-service teachers reported insufficient encouragement and guidance from their professional environment. The general lack of awareness about AR among colleagues and administrators limited the support necessary for its effective implementation. Similar findings by Al-Harithi and Hasan (2023) highlight the importance of fostering an institutional culture that values and supports technological innovation.

4.3.2 Benefits of Using AR in Classrooms

Despite these challenges, AR offered transformative benefits in enhancing teaching and learning experiences. The high levels of engagement observed in both English and Science lessons can also be interpreted through the lens of CLT and MLT. Game-based AR activities, for example, structured tasks in a way that minimized irrelevant cognitive processing, thereby reducing extraneous load and maintaining focus on essential learning goals. Simultaneously, the novelty and interactivity of AR tapped into motivational constructs linked to germane cognitive processing, encouraging students to invest mental effort in understanding and applying content. However, instances of distraction and cognitive overload observed in some lessons highlight the delicate balance emphasized in CLT: while rich multimedia can enhance learning, excessive or poorly structured stimuli risk overloading working memory, thereby undermining the intended learning benefits.

1. Enhanced Student Engagement

AR consistently captured students' attention and sustained their interest throughout lessons using interactive features such as 3D models, animations, and games. This aligns with Raimundo et al., (2022), who emphasized that AR's novelty and interactivity create a stimulating learning environment. While immediate improvements in engagement and motivation are well-documented, long-term studies, such as the longitudinal study by Gargrish et al., (2021), reveal that AR has a lasting effect on students' conceptual understanding and academic performance, with significant retention of scientific concepts observed six months after the initial intervention.

2. Improved Conceptual Understanding

AR provided visual and interactive representations of abstract concepts, making them more accessible to students. For example, 3D models of the respiratory system helped students grasp the process of air movement more effectively than traditional methods. Khalaf (2021) and Syawaludin et al., (2020) similarly observed that AR enhances comprehension by visually simplifying complex ideas, bridging gaps in conceptual understanding.

3. Collaboration and Teamwork

Group-based AR activities fostered collaboration among students, encouraging teamwork and shared problem-solving. As noted by Sarigoz (2019), AR's potential to facilitate cooperative learning contributes to the development of interpersonal skills, making it a valuable tool for promoting social interaction in educational settings.

4. Real-World Connections

AR linked theoretical knowledge to real-world applications, providing students with meaningful contexts for their learning. For example, AR simulations of wildlife behaviours or human anatomical processes bridged the gap between textbook content and experiential understanding. Atalay (2022) highlighted the value of AR in creating realistic and relatable learning scenarios, fostering deeper engagement and long-term retention. Studies such as Jackson and Liu (2022) which companies AR to other immersive technologies, such as VR and gamification, have suggested that while VR provides more immersive environments, it also has the unique advantage of seamlessly integrating with the real world, allowing for more practical applications in science education.

5. Development of Digital Skills

By using AR tools, students enhanced their proficiency in digital technologies. Raimundo et al., (2022) identified digital literacy as a key outcome of AR integration, emphasizing its role in preparing students for future academic and professional challenges. Overall, while the implementation of AR in Science and English classrooms posed challenges related to technical limitations, time constraints, and cognitive demands, its benefits in enhancing engagement, understanding, and collaboration were undeniable. These findings reinforce the need for comprehensive training programs, adequate resources, and institutional support to maximize AR's potential in education. By addressing these challenges, AR can continue to transform classroom practices and equip students with essential skills for the 21st century.

4.3.3. Cross-Disciplinary Comparison: English vs. Science Classrooms

To enrich the analytical depth of this study, a cross-case comparison was conducted to examine the ways in which AR was applied differently across English and Science lessons. While the underlying mechanisms—such as visualization, engagement, and multimodal interactivity—were consistently observed, the pedagogical purposes and cognitive demands varied by discipline. AR's implementation in Science was primarily focused on supporting conceptual visualization and inquiry, whereas its application in English emphasized vocabulary acquisition, phonological awareness, and student motivation through gamified learning.

These disciplinary patterns resonate with existing research that underscores the adaptability of AR across learning domains (Wu et al., 2013; Alhumaidan et al., 2020). In Science, AR tools are frequently used to concretize abstract or spatially complex content (e.g., human anatomy, ecological systems), aligning with CLT's emphasis on reducing intrinsic cognitive load (Sweller, 1999). In contrast, language learning applications benefit from AR's capacity to provide real-time, audio-visual reinforcement, enhancing vocabulary retention and pronunciation through dual coding and gamified repetition (Mayer, 2003; Hsu, 2017). The following table summarizes key differences in the use of AR across English and Science classrooms based on this study's observed practices.

Table 4. Cross-Case Comparison of AR Use in English vs. Science Classrooms

Aspect	Science Lessons	English Lessons
Primary AR Focus	Visualizing biological structures (e.g., lungs), animal behavior, and ecosystems	Vocabulary recall, letter recognition, pronunciation through audio-visual AR tools
AR Tools Used	3D anatomical models, wildlife simulations, Merge Cube	Halo AR, animated flashcards, vocabulary guessing games
Learning Objectives	Foster conceptual understanding, inquiry-based learning, and scientific thinking	Improve word recognition, phonetic awareness, and classroom participation
Interaction Type	Hands-on exploration of virtual models, labeling body parts or observing behavior	Students guessed hidden words and listened to pronunciation using AR-linked visuals
Engagement Style	Observation-driven, structured exploration with content-specific focus	Game-based, surprise-oriented, socially interactive engagement
Assessment Mode	Informal formative assessment via teacher observation and verbal check-ins	Instant app feedback on vocabulary correctness or spelling attempts
Cognitive Load Focus	Reduction of intrinsic load through visual decomposition of complex structures	Reduction of extraneous load via multimodal cues and gamified repetition

This comparison reveals that while both disciplines benefit from AR's immersive and interactive features, the pedagogical logic guiding its use is discipline-specific. In Science, AR applications reduce intrinsic cognitive load by presenting layered visualizations of abstract concepts, enabling learners to understand anatomical structures or animal behavior without cognitive overload. This finding aligns with prior studies emphasizing AR's role in improving science comprehension and spatial reasoning (Radu, 2014; Chiang et al., 2014).

In English instruction, AR enhanced phonological awareness and vocabulary recall by minimizing extraneous cognitive load and providing dual-channel inputs. These uses are consistent with Mayer's (2003) Multimedia Learning Theory, which highlights how verbal and visual stimuli work synergistically to promote retention and transfer. Additionally, the gamified nature of many English AR activities mirrors findings from Syawaludin et al. (2020), who reported increased engagement and motivation in early language learners using AR tools.

Overall, the cross-case comparison underscores AR's pedagogical flexibility. Whether used to scaffold complex scientific reasoning or to animate foundational language learning, AR supports germane cognitive processing and fosters sustained engagement across content areas. This versatility makes it particularly valuable for pre-service teacher training, where varied disciplinary applications can be modelled and practiced.

5. Discussion

This research contributes to the expanding field of AR literature in education and focuses specifically on pre-service teachers and their experiences in real primary classrooms. In contrast to prior studies that have examined AR in controlled instructional settings (e.g., Atalay, 2022), the current research provides empirical data collected from real-world settings. Moreover, the research employs a cross-disciplinary lens and thus addresses a significant gap in the literature on AR in education. The study clearly demonstrates AR's viability as a versatile instructional tool in both Science and English education.

This study provides valuable insights into the integration of Augmented Reality (AR) in primary education. The findings underscore the transformative potential of AR in enhancing student engagement, motivation, and learning outcomes. However, they also reveal several challenges that need to be addressed to maximize the effectiveness of AR in the classroom. This discussion critically examines the implications of the findings in relation to existing literature, highlighting how the results both align with and diverge from previous studies, and contributes to the broader academic discourse on AR in education.

5.1. AR's Impact on Student Engagement and Motivation

The study's findings confirm the significant role of AR in increasing student engagement, especially among those with lower academic motivation. Students actively participated in lessons, showed increased curiosity, and sustained interest throughout AR-enhanced activities. These results align with Raimundo et al., (2022), who highlighted AR's ability to captivate students' attention through interactive and immersive experiences. Similarly, Syawaludin et al. (2020) observed that AR-based games and simulations improve critical thinking and engagement in science learning by transforming passive learners into active participants.

However, while the study reinforces these findings, it also provides deeper insight into how AR influences motivation beyond simple engagement. The integration of AR found to stimulate curiosity and foster a sense of excitement about learning, particularly when interactive features such as 3D models and real-world simulations were used. This suggests that AR not only maintains student attention but also enhances intrinsic motivation by providing novel, hands-on learning experiences. These results reinforce broader findings on AR's cognitive and motivational benefits for pre-service teachers (Abualrob, Frehat, & Ferati, 2025). This dimension of AR's impact extends the work of Atalay (2022), who found that AR motivates pre-service teachers by offering dynamic and engaging learning methods but did not explore the specific role AR plays in intrinsic student motivation. These results also align with Huang and Musah (2024), who found that AR promotes creativity and enhances student behavior. Notably, they emphasized that such benefits are more pronounced when AR integration is supported by strong teacher competency and positive attitudes toward technology.

5.2. Facilitation of Collaboration and Teamwork

The study's findings highlight the potential of AR to promote collaboration and teamwork among students. Group-based AR activities encouraged peer discussions, problem-solving, and shared exploration. These results align with the work of Al-Harithi and Hasan (2023), who noted that AR enhances social interaction and cooperation among learners. Furthermore, the collaborative dimension of AR, observed in this study, mirrors the conclusions of Sarigoz (2019), who emphasized AR's role in facilitating cooperative learning.

However, this study provides a more specific context for the use of AR in promoting teamwork. Focusing on primary education and examining AR in both Science and English classrooms, offers a more nuanced understanding of how collaborative learning is fostered in these subjects. The findings suggest that AR, by providing a platform for collective problem-solving and exploration, is especially effective in breaking down disciplinary boundaries and encouraging cross-curricular teamwork. This aligns with Rizki et al. (2024), who found that integrating AR with cooperative learning and digital games enhances student motivation and critical thinking—both observed during the group-based AR tasks in this study.

5.3. Challenges of AR Integration: Technical and Logistical Barriers

A critical challenge identified in this study was the technical and logistical barriers to AR integration, including the need for specialized hardware and reliable internet access. These findings confirm earlier research by Khalaf (2021) and Julie (2014), which highlighted infrastructural constraints as significant barriers to the widespread use of AR in education. The study also underscores the impact of external factors, such as strikes and class suspensions in Palestine, which further complicate the integration of AR into classroom settings.

This study extends existing literature by providing empirical data on how these technical barriers affect the practical implementation of AR in real classroom environments. While previous studies have emphasized the importance of technological infrastructure, this study sheds light on how socio-political factors, such as disruptions to the school calendar, further hinder AR integration. Therefore, the study contributes to the ongoing discussion on the need for institutional and policy-level support to mitigate these barriers and ensure that AR technologies can be effectively utilized in diverse educational settings.

5.4. Cognitive Load and Risk of Distraction

Another significant challenge revealed in the study was the potential for cognitive overload and distraction when using AR. The immersive nature of AR, while engaging, sometimes diverted students' focus from lesson content, especially when students became overly fixated on manipulating AR elements. This finding aligns with previous research by Buchner et al., (2021), who found that AR can lead to cognitive overload if too much information is presented at once, resulting in diminished learning outcomes.

This study extends the existing literature by highlighting how the design and pacing of AR activities can influence cognitive load. While AR can enhance learning by providing visual and interactive content, it also requires careful structuring to ensure that students are not overwhelmed. The findings suggest that AR activities should be designed with clear instructional goals and a balance between engagement and content delivery to avoid cognitive overload, echoing the concerns raised by Sweller's Cognitive Load Theory (1999). This complements recent research on AR's potential to reduce extraneous load and foster classroom integration (Abualrob et al., 2025).

Nevertheless, the findings of the present study also demonstrate the ability of simulation-based augmented reality (AR) to enhance conceptual understanding among students, particularly for scientific topics such as body systems and ecological systems. These findings align with Ahdhianto et al.'s (2025) findings that simulation-based AR significantly enhanced students' sensitivity to cultural diversity. Although the topics of study differ, both studies highlight the effectiveness of AR simulations in enabling students to grasp abstract or complex ideas through interactive visualizations.

5.5. Professional Development and Teacher Training

The study also identifies the steep learning curve for both pre-service teachers and students in using AR effectively. Pre-service teachers reported difficulties in integrating AR seamlessly into their lessons, and some students struggled with the technology. This confirms findings by Atalay (2022) and Julie (2014), who noted that teachers' lack of technical proficiency with AR is a common barrier to its effective use. The study emphasizes the need for comprehensive teacher training programs to equip educators with the skills and confidence to use AR effectively in the classroom.

Recent research by Mena et al., (2023) underscores the importance of teacher training programs that focus on both the technical and pedagogical aspects of AR. Without sufficient training, teachers may struggle to effectively integrate AR into the curriculum, hindering its potential impact.

The contribution of this study lies in its focus on primary education and the experiences of pre-service teachers, providing specific recommendations for teacher training that address both the pedagogical and technological aspects of AR integration. The findings suggest that teacher training should not only focus on the technical aspects of using AR tools but also on how to design AR-based lessons that align with curriculum goals and enhance student learning. This extends the work of Raimundo et al., (2022), who advocated for the inclusion of AR in teacher training but did not fully explore the challenges teachers face in integrating AR into their practice.

5.6. Contributions to the Academic Discourse

Overall, this study contributes to the growing body of literature on the use of AR in education by providing empirical evidence on its implementation in primary classrooms. It evaluates its impact in diverse educational settings, particularly in under-resourced schools or in cross-disciplinary applications like English and Science (Wang et al., 2024). It extends existing research by examining the practical application of AR in both Science and English education, offering insights into the mechanisms of AR integration, its educational objectives, and its impact on student engagement and collaboration. Furthermore, the study highlights the importance of addressing the challenges of AR integration, particularly in terms of infrastructure, training, and cognitive load, to maximize its potential to enhance teaching and learning.

The study's findings have significant implications for future research and practice. It calls for more targeted studies on the impact of AR in diverse educational contexts, particularly in primary education, and stresses the importance of providing adequate support and resources to ensure the effective use of AR in classrooms worldwide.

6. Conclusion

This study examined the integration of Augmented Reality (AR) into Science and English education by pre-service teachers in primary classrooms. The findings provide clear evidence that AR has a transformative impact on teaching and learning. The use of AR in the classroom significantly increased student engagement, particularly among those with lower academic motivation. Furthermore, the study highlighted the potential of AR to bridge the gap between theoretical knowledge and real-world application.

The study also identified several challenges associated with AR integration, including technical and logistical barriers, time constraints, the steep learning curve for teachers and students and the risk of cognitive overload and distraction. In particular, the study emphasizes the need for institutional and policy-level support to ensure that AR can be implemented in diverse educational settings.

Educational policymakers are urged to integrate AR into curricula, allocate resources for AR-compatible infrastructure, and promote equitable access to digital tools. For teacher training programs, the study highlights the need to equip pre-service educators with technical and pedagogical competencies in AR. Ongoing professional development is essential to ensure teachers remain adept at utilizing emerging technologies. This study contributes to the theoretical understanding of AR in education by advancing Cognitive Load Theory and Multimedia Learning Theory.

This study provides valuable insights into integrating AR in primary education but has limitations. The small, region-specific sample limits generalizability. Its short-term focus calls for long-term research to evaluate AR's sustained impact. Additionally, the study didn't compare different AR tools, leaving opportunities for future research to expand on these findings. While the present study offers valuable, context-rich insights, it is intentionally framed as an exploratory, bounded case study; expanding to multi-site research with additional data sources such as student interviews, lesson plan analyses, and pre/post engagement surveys could enhance the breadth and transferability of future findings.

In conclusion, this study demonstrates the significant potential of AR to transform teaching practices and enhance student engagement and learning outcomes in Science and English education. By investing in AR technology, teacher training, and supportive infrastructure, AR can become an invaluable tool in modernizing education and preparing students for the digital age.

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الواقع المعزَّز في تعليم العلوم واللغة الإنجليزية: تجارب معلمي المرحلة الابتدائية قبل الخدمة

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الملخص:

تتناول هذه الدراسة تطبيق تقنيات الواقع المعزَّز (AR) في تدريس اللغة الإنجليزية والعلوم من قبل معلمي المرحلة الابتدائية قبل الخدمة. شارك في الدراسة أربعة وثلاثون معلماً متدرباً من الجامعة العربية الأمريكية في ورشة عمل مكثفة حول الواقع المعزَّز استمرت أربعة أسابيع، وتم اختيار أربعة منهم لإجراء ملاحظات صفية موسَّعة وتحليل مقاطع فيديو لتجاربهم التعليمية. اعتمدت الدراسة المنهج النوعي في إطار دراسة الحالة لاستكشاف آليات دمج الواقع المعزَّز، والأهداف التعليمية المقصودة، والتحديات والمكاسب المدركة. أظهرت النتائج أن استخدام الواقع المعزَّز أسهم في تعزيز التفاعل والدافعية والفهم المفاهيمي من خلال النماذج ثلاثية الأبعاد التفاعلية، والمحاكاة الواقعية، والتعلُّم القائم على الألعاب، والعمل التعاوني. كما شملت الأهداف التعليمية تعزيز الاستقصاء العلمي، ودعم أنماط التعلم المتنوعة، وتنمية الثقافة الرقمية. ومن أبرز التحديات التي واجهها المعلمون: المشكلات التقنية، وضيق الوقت، والعبء المعرفي الزائد، وضعف الدعم المؤسسي. وتؤكد الدراسة على مرونة الواقع المعزَّز التربوية عبر مختلف التخصصات، وتوصي بتوفير تدريب موجه للمعلمين، وتطوير البنية التحتية، ودعم السياسات التعليمية لضمان تبني تقنيات الواقع المعزَّز بفعالية وعدالة في التعليم الابتدائي.

الكلمات المفتاحية: الواقع المعزَّز؛ معلمو ما قبل الخدمة؛ تعليم العلوم؛ تعليم اللغة الإنجليزية.