STEM Education

STEM Education, 5(6): 1000–1021
DOI: 10.3934/steme.2025044
Received: 23 January 2025
Revised: 31 July 2025
Accepted: 07 August 2025
Published: 01 September 2025

https://www.aimspress.com/journal/steme

Research article

Augmented Reality (AR) technology: Exploring Omani post-basic school teachers' readiness to use in teaching science subjects

Adnan Al Buraiki, Sharifah Intan Sharina Syed Abdullah* and Mas Nida Md Khambari

Faculty of Educational Studies, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; gs56746@student.upm.edu.my, sharifahintansharina@upm.edu.my, khamasnida@upm.edu.my

*** Correspondence:** Email: sharifahintansharina@upm.edu.my; Tel: +60397697909.

Academic Editor: William Guo

Abstract: The incorporation of emerging technologies in educational environments is an undeniable phenomenon. The successful adoption of these technologies is heavily influenced by teachers' perceptions and understanding of them. In this study, we aimed to investigate the readiness of science teachers in post-basic schools to effectively integrate Augmented Reality (AR) into their instructional practices, taking into account their educational backgrounds. A semi-structured interview approach was used to collect data from a sample of 10 science teachers in two post-basic schools in the Al-Batinah North governorate of the Sultanate of Oman. The results suggested that science teachers show a propensity to use AR; however, not all possess prior familiarity with the technology. Subjects such as physics, chemistry, and biology were identified as areas where AR could significantly enhance learning outcomes. Participants recommended the introduction of instructional programs focused on the application of AR. Additionally, some teachers expressed caution regarding potential adverse effects of AR on humans, a scepticism likely stemming from limited exposure to tangible technological devices. This study contributes to the theoretical understanding by providing empirical evidence that validates the AR Readiness Index as a useful framework for exploring teachers' preparedness to effectively employ emerging technologies.

Keywords: Augmented Reality (AR), post basic schools, Sultanate of Oman, readiness, science subjects, technology

1. Introduction

The 21st century has witnessed rapid technological advancements that are transforming nearly every sector, including education. Among these innovations, augmented reality (AR) has emerged as a promising tool capable of enhancing educational engagement and comprehension through immersive, interactive learning environments [1,2].

The rapid growth of smartphone technology has profoundly transformed daily life. Just fifteen years ago, the current capabilities of mobile phones would have been unimaginable. Technological advancements continue to render previous tools and methods obsolete, and this trend is expected to persist in the coming years. The 21st century has seen numerous innovations that are too extensive to fully detail in this context. However, our central argument is that nearly every aspect of the global environment is undergoing rapid change, leaving few domains untouched by technological progress [2].

While traditional pedagogical methods offer recognized benefits, there is a growing consensus that targeted improvements are necessary to meet evolving educational needs. These improvements can be facilitated through the use of appropriate technologies. Mobile devices, for instance, support the integration of AR, allowing students to remain actively engaged with educational content inside and outside the classroom [3].

Research suggests that students demonstrate enhanced levels of understanding and engagement when concepts are conveyed through concrete examples, videos, and other practical modalities. This is attributed to the human cognitive capacity to process inputs that are visual and auditory being more effective compared to exclusively auditory information [4]. In this context, the integration of AR enables students to visually and physically experience virtual representations in real time, fostering a deeper comprehension of the subject matter [5].

Under such circumstances, students' ability to comprehend the subject matter mentioned above in a prompt manner might be greatly improved. AR has demonstrated educational benefits across domains, including primary and secondary education, museums, architecture, and clinical psychology [6]. Despite its proven potential, its adoption in post-basic education in Oman remains limited, particularly among science teachers who continue to rely on traditional instructional technologies. It is crucial to advance the implementation of AR inside the realm of post-basic school education. It is noticed that science teachers in Oman are committed to using conventional technologies that cannot meet the advancement of teaching strategies and approaches. Therefore, it is important to explore science teachers' readiness for using this technology.

2. Literature review

AR has gained increasing attention in education and training due to its ability to create interactive, immersive learning experiences. Research highlights AR's potential across disciplines, particularly in science, mathematics, and spatial skills development.

2.1. Types of AR technology

A wide range of AR is available, including projection-based, recognition-based, location-based, outlining-based, and superimposition-based systems [7]. Projection-based AR relies on advanced projectors to assist with complex tasks, particularly in manufacturing and training contexts [8].

Recognition-based AR detects objects using a device's camera and provides additional information, such as when users scan QR codes or barcodes to access product details.

This method enables mobile devices to identify signs or objects and retrieve related data from the internet. Location-based AR delivers content within specific geographic areas, such as schools or museums [9]. Incorporating such contextually relevant content has been shown to improve learning outcomes [10]. Outlining-based AR uses cameras to detect object edges, functioning similarly to projection-based systems [11].

Although the human eye is highly developed, it cannot detect infrared light or function well in low-light conditions. Specialized AR-compatible cameras have been developed to address these limitations [12]. For example, some vehicles now include heads-up displays (HUDs) that project information directly onto the windshield.

Superimposition-based AR replaces or enhances real-world objects with digital overlays. In education, this approach can enhance visual understanding, such as when studying anatomical structures through 3D skeletal models [13].

While different AR types share certain features, each field requires tailored technological solutions. Education, engineering, healthcare, and training present distinct challenges that demand customized AR applications. In education, recognition-based and location-based AR are most commonly used [14,15].

Studies support the use of AR in educational settings, particularly when integrated with mobile technologies and appropriate software [16,17]. Mobile platforms, especially smartphones, are more widely adopted in classrooms due to their accessibility and ease of use compared to non-mobile devices.

2.2. AR and its application in education

AR continues to evolve as a transformative technology in education by blending digital and physical worlds to enhance interactivity and conceptual understanding. The researchers in [18] describe AR as a technical advancement that overlays virtual objects onto real-world views in real time, thereby enhancing the user's perception of reality. Similarly, the researchers in [19] emphasize that AR facilitates simultaneous interaction with both physical and virtual environments, making abstract concepts more tangible. This is especially pertinent in STEM fields, where complex spatial or invisible phenomena are central to learning [20,21].

Cheng et al. [21] outlined three core characteristics of AR: It blends real and virtual content, enables real-time interaction, and offers accurate 3D spatial alignment. [22] and [23] highlight the importance of hardware readiness, including real-time video input, GPS, sound systems, and intuitive user interfaces, which collectively enhance the learner's immersive experience.

Researcher has shifted from technical capabilities to measuring AR's pedagogical impact using effectiveness indices. For example, Hou et al. [24] reported a significant increase in student engagement and conceptual retention in engineering design courses using AR-assisted simulations. Wen et al. [25] measured cognitive load, retention scores, and skill acquisition in control systems courses, showing AR to be significantly more effective than traditional labs. These results validate earlier assumptions about AR's motivational appeal [23], now backed by quantifiable educational gains.

The pedagogical potential of AR is strongly aligned with constructivist and inquiry-based learning theories. Constructivism posits that learners actively construct knowledge through experience and interaction with their environment [26,27]. In AR-enhanced classrooms, students engage directly with dynamic, multimodal representations of content, encouraging exploration, experimentation, and concept-building core features of a constructivist approach [22].

Similarly, inquiry-based learning emphasizes learner-driven investigation and problem-solving. AR supports this model by enabling students to visualize abstract scientific phenomena, test hypotheses in virtual environments, and receive immediate feedback, which fosters deeper conceptual understanding [28,29]. Therefore, AR serves not only as a technological enhancement but also as a pedagogically grounded tool that complements and operationalizes key educational theories.

Particularly in engineering education, AR has shown strong outcomes. Ragab et al. [30] examined the integration of AR in fluid dynamics and found students demonstrated better spatial understanding and reduced misconceptions compared to conventional teaching. Likewise, the researchers in [31] used effectiveness indices such as time-on-task and error rates in electronics labs, concluding that AR not only increased accuracy but also improved learners' confidence.

Moreover, AR textbooks and interactive applications continue to offer hands-on learning through 3D models, enhancing spatial reasoning and interactivity [32,33]. As the results in [34] suggest, AR offers pedagogical advantages by combining teacher-led instruction with independent, student-driven exploration, an essential factor in developing 21st-century skills like problem-solving, collaboration, and technological fluency.

Despite growing global research, there remains a significant lack of empirical studies focused on the Sultanate of Oman and the broader GCC governorate. This regional gap is particularly important given the distinctive educational policies, cultural values, and infrastructural contexts that influence technology adoption in these countries. While researchers in the GCC have explored aspects of e-learning and general ICT integration [35,36], research targeting AR in science education remains limited. In Oman, most researchers have focused on teacher readiness for digital transformation and challenges in integrating ICT into classroom practice [37]. Similarly, research in the UAE and Saudi Arabia has documented progress in smart learning initiatives, but with minimal focus on immersive technologies like AR [38]. This highlights a pressing need for in-depth, context-specific investigations into how AR can be effectively implemented in science classrooms across Oman and the wider GCC. Thus, emphasizing regional studies would provide more relevant guidance for policymakers and educators, ensuring that technological strategies align with local educational needs and capabilities.

2.2.1. AR in science education

Studies highlight AR's significant role in enhancing students' comprehension of abstract and complex scientific concepts. AR's interactive and immersive nature helps bridge the gap between theoretical knowledge and tangible understanding, particularly for phenomena that are otherwise invisible or intangible. For example, the researchers in [39] demonstrated that AR applications could effectively improve learners' grasp of natural physical forces, such as magnetic fields and fluid dynamics, by enabling students to visualize and manipulate virtual models superimposed onto real-world environments. Similarly, the researchers in [29] demonstrated that AR-supported collaborative environments improved students' engagement and understanding of scientific processes, especially when abstract content was visualized through interactive simulations.

In the domain of health sciences, AR has been leveraged to enhance dental education through clinical simulations that enable students to practice procedures in a risk-free environment, increasing skill acquisition and confidence [40]. These AR-based simulations improve spatial understanding of anatomical structures and procedural workflows, leading to better clinical outcomes.

Moreover, AR is applied in primary and secondary education, particularly in teaching astronomy. Huerta-Cancino and Alé-Silva [41] reported that AR tools enabled students to interact with 3D models of celestial bodies and visualize cosmic phenomena, resulting in heightened engagement and improved conceptual retention. Recent studies extend this further; for instance, the researchers in [42] emphasize that AR fosters experiential learning in science education by facilitating active exploration, which enhances motivation and long-term retention.

Despite these promising outcomes, current research identifies a notable gap in regionally focused studies, especially in developing countries or contexts with distinct curricular frameworks. Tailoring AR applications to local educational standards, languages, and cultural contexts remains a critical area for further development to ensure equitable access and pedagogical effectiveness [43,44]. Moreover, addressing these needs could maximize AR's impact by creating more relevant and accessible learning experiences for diverse student populations.

2.2.2. AR in mathematics and spatial skills

AR has increasingly been recognized as a powerful tool for enhancing mathematics education by facilitating the learning of abstract concepts and improving problem-solving skills. The researchers in [45] demonstrate that AR applications could significantly improve students' comprehension of complex mathematical ideas, such as geometry and algebra, by enabling learners to visualize and interact with 3D representations of abstract concepts, which traditional methods often struggle to convey effectively.

Interactive AR-based educational games, like [46] "Skills Arena," are also effective in increasing student engagement and academic performance. This AR math game offers dynamic and adaptive problem-solving tasks that encourage active learning, resulting in improved motivation and classroom behavior. Lee's study with second-grade students found that those using the game solved significantly more problems and exhibited greater classroom discipline compared to peers in conventional learning environments.

Furthermore, AR tools such as AR-Dehaes employ 3D virtual models to enhance spatial reasoning skills, which are fundamental in STEM fields. Pang and Cai [47] reported that students using AR-Dehaes showed improved ability to mentally manipulate geometric shapes and understand spatial relationships, outcomes that are critical in disciplines like engineering, architecture, and physical sciences. These immersive experiences support cognitive processes that traditional 2D learning materials may not adequately stimulate.

Recent advances emphasize AR's potential to bridge the gap between abstract mathematical theory and concrete understanding through multisensory engagement. Studies also indicate that AR applications can be particularly beneficial for learners with diverse needs, offering personalized pacing and multiple modes of representation [48,49]. [50] and [51] further highlight the foundational role of spatial reasoning in science and math problem-solving, an area where AR shows promise by enhancing mental rotation and spatial visualization skills.

2.3. Technological developments and implementation

Significant advances in AR hardware and software have driven the evolution of educational tools from complex, specialized systems to more accessible and scalable solutions. Early implementations, such as the Multimedia AR Interface for E-Learning (MARIE) developed in 2002, focused on engineering education by employing head-mounted displays (HMDs), cameras, and computer systems to deliver interactive content, such as flow charts for Moore Machines [52]. While innovative, these early systems were often limited by hardware bulkiness, high costs, and technical complexity, restricting their widespread use in classrooms.

In recent years, technological improvements have prioritized user-friendliness, portability, and affordability, which are crucial factors for broader educational adoption. Modern AR applications frequently rely on standard personal computers, webcams, and mobile devices, minimizing the need for specialized equipment and thus reducing implementation barriers [53]. For instance, many AR platforms now operate seamlessly on smartphones and tablets, leveraging built-in cameras and sensors to deliver immersive experiences without additional hardware investment [54].

Moreover, software developments have enhanced AR systems' flexibility and adaptability, enabling easy content updates and customization to suit diverse curricular demands and learner needs [55]. Cloud-based AR platforms and web AR technologies further simplify deployment by enabling real-time content delivery and collaboration across devices and locations [56].

These technological advances not only improve the practicality of AR in educational settings but also promote inclusivity by expanding access to immersive learning experiences across socio-economic and geographic boundaries. Continued innovation in AR hardware miniaturization, improved tracking accuracy, and intuitive user interfaces is expected to further facilitate its integration into mainstream education [57].

2.4. Challenges and opportunities

Despite significant advances in AR technology and its educational applications, several challenges continue to impede its widespread and effective integration into teaching and learning environments. A primary concern is the need for comprehensive teacher training programs that equip educators with the skills to effectively incorporate AR tools into their pedagogical practices without increasing instructional time or workload [58,59]. Many teachers report lacking confidence or adequate support to fully leverage AR's capabilities, which can limit its educational impact.

Curriculum integration poses another major challenge. AR content must be flexible and adaptable to align with diverse regional curricula and subject-specific learning objectives. This flexibility ensures relevance and facilitates seamless inclusion within existing teaching frameworks [60]. Moreover, current AR applications often prioritize novelty over sustained pedagogical effectiveness, highlighting the need for content development grounded in educational theory and learning sciences.

On the opportunity side, AR's immersive and interactive features offer unique potential to transform learning experiences, especially in STEM disciplines, by enabling visualization of complex concepts and fostering active learner engagement [30]. Researchers should prioritize the creation of context-specific AR applications tailored to local educational contexts, cultural norms, and resource availability. Additionally, rigorous longitudinal studies are essential to evaluate the sustained impact of AR on student learning outcomes, motivation, and skills development [61]. Although AR is widely promoted as a transformative educational tool, its effectiveness is often amplified when combined with interdisciplinary, project-based learning strategies. However, there remains a scarcity of empirical studies documenting how such interdisciplinary approaches are being adopted in contexts like Turkey or the broader Middle East. Countries with similar centralized education systems often face shared barriers such as rigid curricula, teacher preparedness gaps, and limited flexibility in assessment structures, yet empirical data on interdisciplinary PBL models within these systems remains limited [62,63]. Including such perspectives could provide a more grounded basis for developing implementation frameworks that resonate with local educational policies.

Addressing these challenges through collaborative efforts among educators, developers, and policymakers can unlock AR's full pedagogical potential, leading to more inclusive, engaging, and effective education systems worldwide.

3. Theoretical framework

In this study, we aim to explore the readiness of science teachers to integrate AR technology into their teaching practices. To obtain a deep understanding of science teachers' perception, Technology Readiness Index (TRI) is adopted as a lens for this research. According to [64], readiness can be described as the inclination of learners to modify their reactions in the face of technological difficulties, collaborative training, and both synchronous and asynchronous self-paced training. The Technology Readiness Index (TRI) serves as the theoretical framework for exploring readiness. According to [65], the term "technology readiness" refers to individuals' inclination to adopt and utilize novel technologies to achieve objectives both in their personal lives and professional endeavors. Larasati [66] argues that the TRI model emerged as the more advantageous option due to its consideration of user characteristics, such as technology usage and attitudes toward technology. The researchers in [67] also emphasize TRI's focus on the inclination toward utilizing technology than proficiency in its utilization.

Larasati [66] has posited that the components comprising the TRI construct encompass innovativeness, discomfort, optimism, and insecurity. In this particular context, the term "insecurity" pertains to a deficiency in confidence or trust towards technology. Similarly, "discomfort" denotes a prevailing emotional state triggered by technology that is characterized by a sense of unease or distress. "Innovation" signifies the act of introducing novel technologies into the technological landscape, while optimism is commonly understood as a favorable disposition or mindset specifically directed toward technology. The driving forces behind human behavior can be attributed to optimism and innovation, whereas the impediments might be associated with discomfort and insecurity. The results in [68] suggest that the TRI exerts a positive influence on both technology adoption rates and individuals' views of its usefulness. The aforementioned conceptual framework was utilized as the foundation for the development of the interview questions pertaining to each of the TRI factors.

It is important to clarify that we do not assess the readiness or maturity of AR technology for classroom use, a capability that has already been widely validated across educational contexts [69,70]. Instead, we investigate the readiness of science teachers to adopt and implement AR in their teaching practice. By applying the TRI framework, we focus on teachers' perceptions, attitudes, and psychological preparedness such as their optimism, innovativeness, discomfort, and insecurity regarding the use of AR. This distinction is crucial, as understanding teacher readiness is essential for effective technology integration and for addressing the human and pedagogical dimensions that influence implementation in real-world classrooms.

The research encompasses the administration of interviews with science educators in post-basic educational institutions in Oman, intending to explore their preparedness to utilize AR as a pedagogical instrument for instructing science disciplines. [71] and [69] assert that the perceptions held by teachers exert a substantial influence on the process of learning and play a pivotal role in shaping the overall organizational structure of educational institutions. The primary emphasis of academic research has predominantly centered on the examination of teachers as opposed to students. We aim to contribute to this domain by analyzing how teacher readiness influences the integration of AR in science education.

While global studies have shown the educational benefits of AR, there remains limited research on its integration in Omani schools, particularly regarding the readiness of science teachers to adopt such technology within the post-basic education framework.

Building on this foundation, we aim to investigate the readiness of science teachers to integrate AR technology into their teaching practices. Specifically, we explore their perceptions asking four questions:

1. How do science teachers consider their readiness to use AR in teaching science subjects in terms of optimism?
2. How do science teachers consider their readiness to use AR in teaching science subjects in terms of innovativeness?
3. How do science teachers consider their readiness to use AR in teaching science subjects in terms of discomfort?
4. How do science teachers consider their readiness to use AR in teaching science subjects in terms of insecurity?

These research questions aim to provide a comprehensive understanding of the factors influencing teachers' readiness to adopt AR, and the potential barriers and enablers that could shape its integration into science education.

4. Methodology

We aim to explore the readiness of science teachers to utilize AR technology in their teaching practices. To achieve this, an interpretive philosophical framework was adopted, focusing on understanding the responses and behaviors of science teachers concerning AR. The interpretivist approach was deemed appropriate, as it aligns with the researchers' goal of gaining insights into teachers' experiences and practices, thereby contributing to the broader understanding of preparedness in technology integration [72].

A qualitative research design was employed, following the logical approach outlined by [73]. We used a deductive research strategy, applying the Technology Readiness Index (TRI) framework [74] as an analytical lens to investigate teachers' attitudes toward AR. The TRI examines four key dimensions: Optimism, innovativeness, discomfort, and insecurity regarding technology use.

4.1. Case study and participant selection

A case study strategy was used to investigate the readiness of science teachers at post-basic schools (grades 10–12) in the Al-Batinah North governorate of the Sultanate of Oman. Schools were purposively selected based on the following criteria:

Classification as post-basic schools (grades 10–12).
Location within Al-Batinah North governorate.
Offering science education across subjects such as physics, chemistry, and biology.
Willingness of school administration to support the research process.

Participants were purposefully chosen according to these criteria:

Currently employed as science teachers in post-basic schools in Al-Batinah North.
Having a minimum of two years' teaching experience.
Willingness to participate in the study.
Ability to clearly express their views in interviews.
Representation across science disciplines (physics, chemistry, and biology).

4.2. Data collection

Semi-structured interviews served as the primary data collection method. Ten science teachers participated in interviews guided by a protocol developed from the TRI framework. Questions addressed themes such as optimism, innovativeness, discomfort, and insecurity related to technology use. Sample questions included:

- How do you currently use technology, including mobile devices, in your teaching?
- What are your perceptions of the usefulness and reliability of AR in science education?
- What challenges do you anticipate when integrating AR technology into your classroom?

The interview questions were piloted with two science teachers outside the study sample to ensure clarity and relevance. This standardized structure enhanced the reliability and comparability of responses.

To complement the interviews, participants were shown two pre-recorded videos demonstrating AR applications aligned with relevant science topics, such as plant cell structure, photosynthesis, and electromagnetic fields. The choice of pre-recorded videos ensured consistent exposure for all participants and addressed limitations related to access to AR devices and curriculum-specific AR content.

4.3. Data saturation and sample size justification

Data collection ceased after ten interviews when thematic saturation was achieved and no new themes or insights emerged. This aligns with researchers' [73] definition of saturation as the point when further data collection yields no additional information relevant to the research questions. Guest et al. [75] similarly suggest that saturation often occurs within six to twelve interviews in homogeneous populations, such as this group of science teachers within a specific geographic and institutional context.

The decision to interview ten participants was consistent with qualitative research principles that prioritize depth and richness over breadth. The use of a standardized interview protocol grounded in the TRI framework further ensured data quality and analytic value despite the modest sample size.

4.4. Data analysis

Thematic analysis, following [76] with a six-phase approach, was used for data analysis. Interview recordings were transcribed using Microsoft Word, then translated from Arabic to English. Coding was conducted with reference to the TRI constructs. Codes were then organized into themes and sub-themes aligned with TRI dimensions. An independent second coder reviewed the coding to enhance reliability and minimize bias.

4.5. Ethical considerations

We adhered to ethical standards for research involving human participants. Ethical approval was obtained from the affiliated institution. Informed consent was secured from all participants, and confidentiality and anonymity were maintained throughout the research process.

4.6. Trustworthiness and validity

Several strategies were employed to ensure trustworthiness and validity. Content validity was addressed by aligning interview questions with TRI constructs and consulting two experts in educational technology for feedback. The forward- and backward-translation process ensured semantic accuracy of transcripts translated from Arabic to English. Thematic validity was supported through the rigorous application of the methodology in [76] and independent review by a second coder.

To ensure the trustworthiness and validity of the instruments used, several strategies were employed. Content validity was addressed through the alignment of interview questions with the TRI constructs and by obtaining feedback from two experts in educational technology. The interview transcripts, initially conducted in Arabic, were translated into English using a forward- and backward-translation process to preserve semantic accuracy. Thematic validity was reinforced using Braun and Clarke's [76] six-phase thematic analysis, where codes and themes were reviewed by an independent second coder to ensure consistency and minimize bias.

5. Findings

We investigated the readiness of science teachers in post-basic schools in Oman to adopt AR in their science teaching practices. Using the Technology Readiness Index (TRI) as a framework, four key themes emerged: Optimism, Innovativeness, Discomfort, and Insecurity.

Theme 1: Optimism

Participants generally expressed positive attitudes and high expectations regarding the use of AR in science education. Their comments reflect an eagerness to integrate new technologies to improve engagement and comprehension.

"I like to use AR technology. I want to try it. I think this technology will help me in my teaching. I heard a lot about it. It can facilitate my teaching science concepts." (P3)

This quote reflects general enthusiasm, suggesting that teachers view AR as a practical aid for improving the clarity of science concepts.

"I can conduct my science lessons in the school garden. I am a biology teacher, and I want to show my students more information about flowers. I think my students will understand more because

they change their places." (P10)

Here, the teacher links AR with flexibility and contextual learning, highlighting its potential to support outdoor, experiential education.

Theme 2: Innovativeness

Many participants demonstrated a willingness to explore new pedagogical approaches and viewed AR as a means to engage students more creatively.

"I teach chemistry in the science lab. I can divide my students into groups to encourage them to share ideas... using AR can make them active." (P10)

This quote illustrates a recognition of AR's capacity to support collaborative learning and peer engagement in traditionally individual-oriented subjects like chemistry.

"I don't expect that this technology can make a change in my teaching style. My students are lazy... AR can help me and make my students attentive." (P6)

Despite initial skepticism, the teacher acknowledges AR's potential to transform classroom dynamics, indicating that even hesitant educators may adopt it if it proves effective.

Theme 3: Discomfort

Some science teachers expressed unease or lack of confidence, often due to limited technical knowledge or fear of failure.

"I am afraid because I might not be able to use AR technology properly... I will be happy if provided with some training." (P1)

This quote reveals that discomfort is not due to resistance but a lack of preparedness, suggesting the need for targeted professional development.

"To overcome any difficult situation... I will ask for assistance. I am not shy." (P1)

Despite discomfort, this comment reflects growth mindset teachers are willing to seek help and learn, indicating that support structures can mitigate this barrier.

Theme 4: Insecurity

Concerns about data security, student privacy, and loss of information emerged as key barriers to AR adoption.

"When I work on AR application. I want to save my work because I don't want to lose my information." (P7)

This quote reflects practical concerns about data loss and system reliability, which can undermine confidence in using digital tools.

"I might not be happy if the use of AR application might make personal information of my students appear to other students." (P7)

This statement highlights privacy-related anxiety, especially when shared devices are involved pointing to the importance of ethical considerations in AR implementation.

6. Discussion

Our purpose of this study was to explore the readiness of science teachers in post-basic schools in the Al-Batinah North governorate of the Sultanate of Oman to adopt AR technology in their teaching practices. Using the Technology Readiness Index (TRI) as a conceptual framework, four major themes emerged from the data: Optimism, Innovativeness, Discomfort, and Insecurity. These are discussed in relation to the literature to contextualize the findings and illustrate this study's contribution to the broader field of educational technology integration.

Science Teachers' Readiness: Optimism

The findings indicated that science teachers were generally optimistic about adopting AR tools in their classrooms. Participants associated AR with enhanced student engagement, better conceptual understanding, and greater teaching flexibility especially for complex or abstract scientific topics. This aligns with findings by the researchers in [42]. In [41], the researchers report that AR positively influences motivation and conceptual retention by facilitating active, experiential learning. Teachers in this study also perceived AR as a means of enriching their teaching environments, citing potential applications in traditional classrooms and outdoor learning contexts. This reinforces the notion that optimism is rooted in the perceived pedagogical utility of AR than mere novelty.

In addition, participants expressed a strong desire for professional development, viewing training not as a barrier but as a pathway to competence. This finding supports the findings in [58] and [59], emphasizing that targeted support and institutional encouragement significantly influence educators' openness to adopting new technologies. A key contribution of this study is its identification of how a supportive school climate, including leadership encouragement and collaborative teacher culture, can bolster this optimism. While other studies, such as [61], have highlighted institutional factors in general terms, this study offers grounded, context-specific insights into how positive environments cultivate readiness among teachers.

Science Teachers' Readiness: Innovativeness

Many teachers demonstrated a strong disposition toward innovation, seeking creative ways to integrate AR into science instruction. They recognized AR as an opportunity to move beyond traditional textbook-based teaching toward more interactive, student-centered methods. This reflects the proactive mindset described by the researchers in [49] and [45], who found that educators often show a natural inclination to explore new tools that foster student participation and curiosity. Specifically, teachers discussed using AR to visualize abstract phenomena in subjects such as biology and chemistry, including systems like blood circulation or the structure of molecules. These applications align closely with the findings by the researchers in [39] and [29], who emphasize AR's value in making invisible or complex scientific processes more tangible for learners.

Crucially, the teachers' enthusiasm extended beyond the technology; it reflected a pedagogical drive to improve discipline-specific teaching outcomes. This distinction contributes a new layer to the literature: Innovativeness among educators is not just technological readiness, but also content-driven creativity aimed at transforming the way science is taught.

Science Teachers' Discomfort with AR

While optimistic and willing to innovate, some teachers expressed discomfort in using AR due to limited technical skills or previous exposure. This finding echoes the barriers identified in earlier research, particularly by the researchers in [58] and [60], who warn that lack of familiarity and confidence can hinder the practical adoption of educational technologies, even when attitudes are positive.

However, this study adds nuance to the conversation. Rather than resisting change, teachers framed their discomfort as a temporary hurdle that could be overcome with proper training and peer support. Several participants even articulated a readiness to ask for help or engage in self-directed learning behaviors that reflect a growth mindset toward professional development.

This aligns with literature on second-order barriers, such as those discussed by [43] and [44], which can be mitigated by creating communities of practice and collaborative learning environments. Thus, the discomfort reported in this study is better understood as a transitional phase than a fixed barrier that institutions can address through strategic intervention.

Science Teachers' Insecurity: Privacy and Data Protection

Another significant finding relates to teacher concerns over digital privacy, data security, and the reliability of AR platforms. Science Teachers worried about losing student data, exposing personal information, or dealing with malfunctioning systems during instruction. These concerns reflect a broader trend noted by the researchers [56] and [53], who emphasize that as AR applications become more mobile and cloud-based, ethical and Cybersecurity challenges also become more pronounced.

In the Omani context, where digital governance frameworks are evolving, such insecurities are especially salient. Teachers called for clear guidelines on how to use AR applications safely, especially when student data is involved. This demand aligns with recommendations by Saranya et al. [54] and Syed et al. [57], who advocate for robust institutional policies to ensure ethical and secure use of educational technologies.

These concerns underline the critical importance of not only training and technical readiness, but also systemic and policy readiness, particularly in governorates where digital transformation is in its early stages.

Access and Infrastructure Readiness

Technological developments have made AR more accessible, enabling it to operate on smartphones, tablets, and PCs [53,54]. However, this study revealed a gap between AR's technical feasibility and its practical implement ability in Omani classrooms. Several teachers cited lack of school-owned devices, limited student access to mobile phones, and unstable internet connections as significant barriers to AR integration. These findings highlight an infrastructural disconnect, and while AR tools are increasingly scalable and affordable, they rely on baseline technological readiness, which may not be present in all schools.

This reflects the argument made by the researchers in [43] and [44] that meaningful technology integration requires a local understanding of resource constraints and implementation challenges. Thus, educational technology strategies must go beyond software development to include hardware provision, network infrastructure, and policy alignment with the realities of local educational environments.

Study Differentiators and Contribution to the Field

This study provides a unique contribution to the body of literature on AR in education by focusing on Middle Eastern, under-researched context Omani post-basic schools. The insights generated are not only valuable for Oman but also for other countries with similar socio-educational structures and developmental priorities. Methodologically, the use of video-based AR demonstrations during interviews enabled participants to engage more concretely in the concept, leading to richer and more authentic responses. This approach bridges the gap between theoretical exploration and practical teacher experiences, offering a more grounded view of readiness. Moreover, we draw on foundational work by the researchers in [50] and [51] concerning spatial reasoning and problem-solving. While not a primary focus of the study, some teachers expressed interest in using AR to visualize biological or scientific systems, suggesting untapped potential in spatial learning within science education. This observation opens new avenues for future research.

Finally, by articulating the interconnected dimensions of teacher readiness optimism, innovativeness, discomfort, insecurity, and infrastructural access, this study offers a comprehensive, contextualized framework for AR adoption. The framework can serve as a guide for educational leaders, curriculum designers, and technology developers aiming to design inclusive, scalable, and pedagogically grounded AR strategies**.**

7. Implications

The use of TRI to support this qualitative research can pave the way for other researchers to conduct quantitative studies aimed at assessing the readiness of implementing AR technology in the educational Omani context. Regarding the practical implications, the extent of optimism revealed by the science teachers can be exploited to support their attitude toward incorporating AR technology into their teaching methods. This can help motivate science teachers who are hesitant to incorporate emerging technologies like AR. Moreover, our findings of this study can provide valuable insights for MOE policymakers to enhance innovation among science teachers who often underestimate their capabilities. Providing them with training courses on innovative teaching skills using AR could potentially encourage this. Continuous support will be beneficial for science teachers who may feel uncomfortable using AR. Furthermore, fostering networking among science teachers can lead to initiatives aimed at supporting each other and addressing any challenges they may encounter. MOE decision-makers need to set a strategic plan to create a positive environment of resilience and adaptation toward the use of AR. This might increase the number of adopters of AR in Omani schools. In addition, MOE needs to develop AR-enhanced platforms and applications that can encourage science teachers to employ this technology.

8. Conclusions

The research conducted on the readiness of science teachers in post-basic schools in Oman to incorporate AR in teaching science subjects has revealed several encouraging findings that indicate significant potential for improving education in the Sultanate of Oman. As this investigation has progressed, it has become clear that many science teachers would like to see AR used to improve the learning experience in science classrooms. The users' inclination to actively participate in the use of this advanced technology displays their commitment to delivering a thorough and stimulating educational experience for their students. One of our primary discoveries pertains to the acknowledgment made by science teachers regarding the possible advantages that AR might offer in terms of instructional and educational practices.

The researchers recognize the potential of this technique in fostering active student engagement, deepening comprehension of intricate science subjects, and cultivating students' curiosity and inventiveness. The aforementioned degree of consciousness, coupled with their fervor, establishes a robust basis for the triumphant incorporation of AR into the realm of science teaching. Furthermore, the research findings indicate that science teachers acknowledge the necessity for ongoing professional growth and exhibit a willingness to engage in training programs and seminars centered on the proficient use of AR within educational settings. The favorable attitude toward professional growth exhibited by science teachers in the study area indicates their dedication to being current with the most recent educational materials and approaches, eventually resulting in advantages for themselves and their students.

Additionally, the Ministry of Education and educational administrators' support for the adoption of AR technology has been crucial in cultivating science teachers' readiness to use this cutting-edge approach. The availability and allocation of essential resources, such as AR devices and instructional software, have provided science educators with an opportunity to investigate the educational possibilities of AR in the instruction of scientific disciplines while ensuring their proficiency in its use. The research findings underscore the significance of science teacher's cooperation and information exchange. Moreover, our findings indicate that science teachers who have effectively integrated AR into their instructional methods have a willingness to disseminate their experiences and insights among their colleagues in the teaching profession. The extensive implementation of collaborative initiatives within this context contributes to the collective progress and development of AR integration in science subjects. The implementation of a collaborative method facilitates science teachers in acquiring valuable insights from the achievements and difficulties encountered by their peers.

In summary, the degree of readiness demonstrated by Omani teachers in post-basic schools regarding the use of AR in science classrooms is indicative of their commitment to providing an enhanced educational encounter for their students. The adoption of AR is likely to be successful due to its optimistic outlook, readiness to embrace change, and realization of its potential benefits. The use of AR in teaching science subjects in Oman exhibits excellent prospects, owing to the consistent backing from school administration, the Ministry of Education, and a cooperative attitude among teachers.

Author contributions

Adnan Abdallah Al Buraiki: Conceptualization, Methodology, Formal Analysis, Writing original draft and the revised manuscript; Sharifah Intan Sharina Binti Syed Abdullah: Supervision, Methodology, review and validation; Mas Nida Binti Md Khambari: Supervision, Methodology, review and validation. All authors have read and approved the final version of the manuscript for publication.

Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

We would like to thank all the science teachers who participated in the study; their willingness to contribute and share insights was greatly appreciated; the principals at their schools who facilitated the process of the study.

Conflict of interest

The authors declare no conflict of interest related to this study.

Ethics declaration

Ethical considerations were rigorously sustained to safeguard the rights and welfare of participants. Respondents were informed about the study's purpose, assured of confidentiality, and made aware that their participation was voluntary.

References

1. Yu, Z., RETRACTED ARTICLE: Meta-Analyses of Effects of Augmented Reality on Educational Outcomes over a Decade. *Interactive Learning Environments*, 2024, 32(8): 4739–4753. doi:10.1080/10494820.2023.2205899.
2. Villagran-Vizcarra, D.C., Luviano-Cruz, D., Pérez-Domínguez, L.A., Méndez-González, L.C. and Garcia-Luna, F., Applications Analyses, Challenges and Development of Augmented Reality in Education, Industry, Marketing, Medicine, and Entertainment. *Applied Sciences*, 2023, 13(5): 2766. https://doi.org/10.3390/app13052766
3. Papakostas, C., Troussas, C., Krouska, A. and Sgouropoulou, C., Personalization of the Learning Path Within an Augmented Reality Spatial Ability Training Application Based on Fuzzy Weights. *Sensors*, 2022, 22(18): 7059. https://doi.org/10.3390/s22187059
4. Mayer, R.E., Multimedia Learning. In *The Psychology of Learning and Motivation/The psychology of Learning and Motivation*, 2002, 41: 85–139. https://doi.org/10.1016/s0079-7421(02)80005-6
5. Nikou, S.A., Perifanou, M. and Economides, A.A., Development and Validation of the Teachers' Augmented Reality Competences (TARC) Scale. *Journal of Computers in Education*, 2023, 11(4): 1041–1060. https://doi.org/10.1007/s40692-023-00288-6
6. Lidiastuti, A.E., Suwono, H., Sueb, S. and Sulisetijono, S., A Review of Augmented Reality Implications and Challenges for Science Education: Current and Future Perspective. *Pakistan Journal of Life and Social Sciences (PJLSS)*, 2024, 22(2): 20267–20288. https://doi.org/10.57239/pjlss-2024-22.2.001486
7. Hidayat, R. and Wardat, Y., A Systematic Review of Augmented Reality in Science, Technology, Engineering and Mathematics Education. *Education and Information Technologies*, 2023, 29(8): 9257–9282. https://doi.org/10.1007/s10639-023-12157-x
8. Eswaran, M. and Bahubalendruni, M.R., Challenges and Opportunities on AR/VR Technologies for Manufacturing Systems in the Context of Industry 4.0: A State of the Art Review. *Journal of Manufacturing Systems*, 2022, 65: 260–278. https://doi.org/10.1016/j.jmsy.2022.09.016
9. Wu, H.K., Lee, S.W.Y., Chang, H.Y. and Liang, J.C., Current Status, Opportunities and Challenges of Augmented Reality in Education. *Computers & Education*, 2013, 62: 41–49. https://doi.org/10.1016/j.compedu.2012.10.024
10. Yen, J.C., Tsai, C.H. and Wu, M., Augmented Reality in the Higher Education: Students' Science Concept Learning and Academic Achievement in Astronomy. *Procedia - Social and Behavioral Sciences*, 2013, 103: 165–173. https://doi.org/10.1016/j.sbspro.2013.10.322

11. Yilmaz, O., Augmented Reality in Science Education: An Application in Higher Education. *Shanlax International Journal of Education*, 2021, 9(3): 136–148. https://doi.org/10.34293/education.v9i3.3907
12. Meyer, J., Schlebusch, T., Fuhl, W. and Kasneci, E., A Novel Camera-Free Eye Tracking Sensor for Augmented Reality Based on Laser Scanning. *IEEE Sensors Journal*, 2020, 20(24): 15204–15212. https://doi.org/10.1109/jsen.2020.3011985
13. Avilés-Cruz, C. and Villegas-Cortez, J., A Smartphone‐based Augmented Reality System for University Students for Learning Digital Electronics. *Computer Applications in Engineering Education*, 2019, 27(3): 615–630. https://doi.org/10.1002/cae.22102
14. Chan, C.M. and Lau, S.L., Using Augmented Reality and Location-Awareness to Enhance Visitor Experience: A Case Study of a Theme Park App. In *IEEE Graphics and Multimedia, Game 2020 Conference*, 2020, 49–54. https://doi.org/10.1109/game50158.2020.9315158
15. Zulfiqar, F., Raza, R., Khan, M.O., Arif, M., Alvi, A. and Alam, T., Augmented Reality and Its Applications in Education: A Systematic Survey. *IEEE Access*, 2023, 11: 143250–143271. https://doi.org/10.1109/access.2023.3331218
16. Mota, J.M., Ruiz-Rube, I., Dodero, J.M. and Arnedillo-Sánchez, I., Augmented Reality Mobile App Development for All. *Computers & Electrical Engineering*, 2017, 65: 250–260. https://doi.org/10.1016/j.compeleceng.2017.08.025
17. Iatsyshyn, A.V., Kovach, V.O., Lyubchak, V.O., Zuban, Y.O., Piven, A.G., Sokolyuk, O.M., et al., Application of Augmented Reality Technologies for Education Projects Preparation. *CTE Workshop Proceedings*, 2020, 7: 134–160. https://doi.org/10.55056/cte.318
18. Raajan, N.R., Suganya, S., Priya, M.V., Ramanan, S.V., Janani, S., Nandini, N.S., et al., Augmented Reality Based Virtual Reality. *Procedia* Engineering, 2012, 38: 1559–1565. https://doi.org/10.1016/j.proeng.2012.06.191
19. Aso, B., Navarro-Neri, I., García-Ceballos, S. and Rivero, P., Quality Requirements for Implementing Augmented Reality in Heritage Spaces: Teachers' Perspective. *Education Sciences*, 2021, 11(8): 405. https://doi.org/10.3390/educsci11080405.
20. Dunleavy, M., Dede, C. and Mitchell, R., Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, 2018, 18(1): 7–22. https://doi.org/10.1007/s10956-008-9119-1
21. Cheng, K.H. and Tsai, C.C., Affordances of Augmented Reality in Science Learning: Suggestions for Future Research. *Journal of Science Education and Technology*, 2012, 22(4): 449–462. https://doi.org/10.1007/s10956-012-9405-9
22. Bower, M., Howe, C., McCredie, N., Robinson, A. and Grover, D., Augmented Reality in Education – Cases, Places and Potentials. *Educational Media International*, 2014, 51(1): 1–15. https://doi.org/10.1080/09523987.2014.889400
23. Küçük, S., Yılmaz, R., Baydaş, Ö. and Göktaş, Y., Reality Applications Attitude Scale in Secondary Schools: Validity and Reliability Study. *Education and Science*, 2014, 39(176): 383–392. https://doi.org/10.15390/eb.2014.3590
24. Hou, H.T., Fang, Y.S. and Tang, J.T., Designing an Alternate Reality Board Game With Augmented Reality and Multi-dimensional Scaffolding for Promoting Spatial and Logical Ability. *Interactive Learning Environments*, 2021, 31(7): 4346–4366. https://doi.org/10.1080/10494820.2021.1961810

25. Wen, P., Lu, F. and Mohamad Ali, A.Z., Using Attentional Guidance Methods in Virtual Reality Laboratories Reduces Students' Cognitive Load and Improves Their Academic Performance. *Virtual Reality*, 2024, 28(2): 110. https://doi.org/10.1007/s10055-024-01012-0
26. Piaget, J., Intellectual Evolution From Adolescence to Adulthood. *Human Development*, 1972, 15(1): 1–12. https://doi.org/10.1159/000271225
27. Vygotsky, L., *Mind in Society: The Development of Higher Psychological Processes*, 1978. https://ci.nii.ac.jp/ncid/BA03570814
28. Kuhn, D., Teaching and Learning Science as Argument. *Science Education*, 2010, 94(5): 810–824. https://doi.org/10.1002/sce.20395
29. Ibáñez, M.B., Di Serio, Á., Villarán, D. and Kloos, C.D., Experimenting With Electromagnetism Using Augmented Reality: Impact on Flow Student Experience and Educational Effectiveness. *Computers & Education*, 2014, 71: 1–13. https://doi.org/10.1016/j.compedu.2013.09.004
30. Ragab, K., Fernandez-Ahumada, E. and Martínez-Jiménez, E., Engaging Minds -Unlocking Potential with Interactive Technology in Enhancing Students' Engagement in STEM Education. In *Interdisciplinary Approaches for Educators' and Learners' Well-Being*, edited by A. ElSayary and R. Olowoselu, Springer, 2024, 53–66. https://doi.org/10.1007/978-3-031-65215-8_5
31. Abdollahzade, Z., Hadian, M.R., Khanmohammadi, R. and Talebian, S., Efficacy of Stretching Exercises Versus Transcranial Direct Current Stimulation (tDCS) on Task Performance, Kinematic and Electroencephalography (EEG) Spectrum in Subjects With Slump Posture: A Study Protocol. *Trials*, 2023, 24(1): 351. https://doi.org/10.1186/s13063-023-07359-0
32. Chujitarom, W. and Piriyasurawong, P., Animation Augmented Reality Book Model (AAR Book Model) to Enhance Teamwork. *International Education Studies*, 2017, 10(7): 59–64. https://doi.org/10.5539/ies.v10n7p59
33. Kesim, M, and Ozarslan, Y., Augmented Reality in Education: Current Technologies and the Potential for Education. *Procedia - Social and Behavioral Sciences*, 2012, 47: 297–302. https://doi.org/10.1016/j.sbspro.2012.06.654
34. Reeves, L.E., Bolton, E., Bulpitt, M., Scott, A., Tomey, I., Gates, M., et al., Use of Augmented Reality (AR) to Aid Bioscience Education and Enrich Student Experience. *Research in Learning Technology*, 2021, 29: 2572 https://doi.org/10.25304/rlt.v29.2572
35. Al-Issa, A.S., The Language Planning Situation in the Sultanate of Oman. *Current Issues in Language Planning*, 2020, 21(4): 347–414. https://doi.org/10.1080/14664208.2020.1764729
36. Alainati, S. and Al-Hunaiyyan, A., The Role of Educational Systems in Developing the Twenty-First Century Skills: Perspectives and Initiatives of Gulf Cooperation Council Countries. *Journal of Research Administration*, 2024, 6(1): 1252–1277. https://journlra.org/index.php/jra/article/view/1255
37. Shahat, M.A., Khalsa H.A.B. and Sulaiman M.A., Enhancing Elementary Teacher Preparation. In *Advances in Early Childhood and K-12 Education*, 2024, 50–67. https://doi.org/10.4018/978-1-6684-5939-3.ch003
38. Al Balushi, J.S.G., Al Jabri, M.I.A., Palarimath, S., Maran, P., Thenmozhi, K. and Balakumar, C., Incorporating Artificial Intelligence Powered Immersive Realities to Improve Learning using Virtual Reality (VR) and Augmented Reality (AR) Technology. *2024 3rd International Conference on Applied Artificial Intelligence and Computing (ICAAIC)*, 2024, 760–765. https://doi.org/10.1109/icaaic60222.2024.10575046

39. Andersson, N., Argyrou, A., Nägele, F., Ubis, F., Campos, U.E., De Zarate, M.O., et al., AR-Enhanced Human-Robot-Interaction - Methodologies, Algorithms, Tools. *Procedia CIRP*, 2016, 44: 193–198. https://doi.org/10.1016/j.procir.2016.03.022
40. Mladenovic, R. and Mladenovic, K., Boring to Engaging: Using Gamification to Transform Dental Education and Practice. In *Springer eBooks*, 2024, 223–241. https://doi.org/10.1007/978-3-031-54475-0_11
41. Huerta-Cancino, L. and Alé-Silva, J., Augmented Astronomy for Science Teaching and Learning. In *Lecture Notes in Computer Science*, 2024, 235–253. https://doi.org/10.1007/978-3-031-60458-4_16
42. Wu, W.C.V., Lin, R.P. and Darmawansah, D., Effects of Augmented Reality-supported Experiential Learning on Low-achieving EFL Students in Rural Elementary School. *Innovation in Language Learning and Teaching*, 2025, 1–23. https://doi.org/10.1080/17501229.2025.2510522
43. Asmayawati, Yufiarti and Yetti, E., Pedagogical Innovation and Curricular Adaptation in Enhancing Digital Literacy: A Local Wisdom Approach for Sustainable Development in Indonesia Context. *Journal of Open Innovation Technology Market and Complexity*, 2024, 10(1): 100233. https://doi.org/10.1016/j.joitmc.2024.100233
44. Grimus, M., Emerging Technologies: Impacting Learning, Pedagogy and Curriculum Development. In *Bridging Human and Machine: Future Education with Intelligence*, 2020, 127–51. https://doi.org/10.1007/978-981-15-0618-5_8
45. Singh, G., Singh, G., Tuli, N. and Mantri, A., Hyperspace AR: An Augmented Reality Application to Enhance Spatial Skills and Conceptual Knowledge of Students in Trigonometry. *Multimedia Tools and Applications*, 2023, 83(21): 60881–60902. https://doi.org/10.1007/s11042-023-17870-w
46. Lee, K., Augmented Reality in Education and Training. *TechTrends*, 2012, 56(2): 13–21. https://doi.org/10.1007/s11528-012-0559-3
47. Pang, C.G. and Cai, Y., Transforming Learning Experiences Through Affordances of Virtual and Augmented Reality. In *Gaming Media and Social Effects*, 2023, 109–65. https://doi.org/10.1007/978-981-99-4958-8_6
48. Ateş, H., Integrating Augmented Reality Into Intelligent Tutoring Systems to Enhance Science Education Outcomes. *Education and Information Technologies*, 2024, 30: 4435–447. https://doi.org/10.1007/s10639-024-12970-y
49. Mystakidis, S., Christopoulos, A. and Pellas, N., A Systematic Mapping Review of Augmented Reality Applications to Support STEM Learning in Higher Education. *Education and Information Technologies*, 2021, 27(2): 1883–1927. https://doi.org/10.1007/s10639-021-10682-1
50. Buckley, J., Seery, N. and Canty, D., Investigating the Use of Spatial Reasoning Strategies in Geometric Problem Solving. *International Journal of Technology and Design* Education, 2018, 29 (2): 341–62. https://doi.org/10.1007/s10798-018-9446-3
51. Markey, S.M., The Relationship Between Visual-Spatial Reasoning Ability and Math and Geometry Problem-Solving. PhD thesis, 2009, *American International College ProQuest Dissertations & Theses*. https://eric.ed.gov/?id=ED532420

52. De Paolis, L.T., Arpaia, P. and Sacco, M., (Eds) *Extended Reality: International Conference, XR Salento 2023, Lecce, Italy, September 6–9, 2023, Proceedings, Part II*. Vol. 14219. Cham: Springer Nature, 2023.
53. Durrani, U.K., Akpinar, M., Adak, M.F., Kabakus, A.T., Ozturk, M.M. and Saleh, M., A Decade of Progress: A Systematic Literature Review on the Integration of AI in Software Engineering Phases and Activities (2013-2023). *IEEE Access*, 2024, 12: 171185–171204. https://doi.org/10.1109/access.2024.3488904
54. Saranya, S.M., Komarasamy, D., Mohanapriya, S., Iyapparaja, M. and Prabavathi, R., Industry 4.0: The Role of Industrial IoT, Big Data, AR/VR, and Blockchain in the Digital Transformation. In *Studies in Computational Intelligence*, 2024, 11–39. https://doi.org/10.1007/978-981-97-7494-4_2
55. Kurni, M. and Srinivasa K.G., Intelligent IoT-Based Tutoring Systems, Including AR, VR. In *Intelligent IoT-Based Tutoring Systems, Including AR, VR*, 2024, 79–96. https://doi.org/10.1007/978-3-031-67387-0_6
56. Devagiri, J.S., Paheding, S., Niyaz, Q., Yang, X. and Smith, S., Augmented Reality and Artificial Intelligence in Industry: Trends, Tools, and Future Challenges. *Expert Systems With Applications*, 2022, 207: 118002. https://doi.org/10.1016/j.eswa.2022.118002
57. Syed, T.A., Siddiqui, M.S., Abdullah, H.B., Jan, S., Namoun, A., Alzahrani, A., et al., In-Depth Review of Augmented Reality: Tracking Technologies, Development Tools, AR Displays, Collaborative AR, and Security Concerns. *Sensors*, 2022, 23(1): 146. https://doi.org/10.3390/s23010146
58. Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Alzahrani, A.I. and Sarsam, S.M., Challenges and Prospects of Virtual Reality and Augmented Reality Utilization Among Primary School Teachers: A Developing Country Perspective. *Studies in Educational Evaluation*, 2020, 66: 100876. https://doi.org/10.1016/j.stueduc.2020.100876
59. Annamalai, N., Uthayakumaran, A. and Zyoud, S.H., High School Teachers’ Perception of AR and VR in English Language Teaching and Learning Activities: A Developing Country Perspective. *Education and Information Technologies*, 2023, 28(3): 3117–3143. https://doi.org/10.1007/s10639-022-11275-2
60. Barrot, J.S., K To 12 Curriculum Reform in the Philippines: Towards Making Students Future Ready. *Asia Pacific Journal of Education*, 2021, 43(4): 1193–1207. https://doi.org/10.1080/02188791.2021.1973959
61. Mokmin, N.A.M., Hanjun, S., Jing, C. and Qi, S., Impact of an AR-based Learning Approach on the Learning Achievement, Motivation, and Cognitive Load of Students on a Design Course. *Journal of Computers in Education*, 2023, 11(2): 557–574. https://doi.org/10.1007/s40692-023-00270-2
62. Demir, C.G. and Önal, N., The Effect of Technology-assisted and Project-based Learning Approaches on Students’ Attitudes Towards Mathematics and Their Academic Achievement. *Education and Information Technologies*, 2021, 26(3): 3375–3397. https://doi.org/10.1007/s10639-020-10398-8
63. Arici, F. and Yilmaz, M., An Examination of the Effectiveness of Problem‐based Learning Method Supported by Augmented Reality in Science Education. *Journal of Computer Assisted Learning*, 2022, 39(2): 446–476. https://doi.org/10.1111/jcal.12752

64. Bubou, G.M. and Job, G.C., Individual Innovativeness, Self-efficacy and E-learning Readiness of Students of Yenagoa Study Centre, National Open University of Nigeria. *Journal of Research in Innovative Teaching & Learning*, 2020, 15(1): 2–22. https://doi.org/10.1108/jrit-12-2019-0079
65. Chung, E., Subramaniam, G. and Dass, L.C., Online Learning Readiness Among University Students in Malaysia Amidst Covid-19. *Asian Journal of University Education*, 2020, 16(2): 46–58. https://doi.org/10.24191/ajue.v16i2.10294
66. Larasati, N., Technology Readiness and Technology Acceptance Model in New Technology Implementation Process in Low Technology SMEs. *International Journal of Innovation Management and Technology*, 2017, 8(2): 113–117. https://doi.org/10.18178/ijimt.2017.8.2.713
67. Srivastava, S. and Bhati, N.S., A SEM Approach to Assess M-Learning Intentions Among Students of Design: An Empirical Analysis Using the TRUTAUT Model. *Journal of Information Technology Education Research*, 2024, 23: 015. https://doi.org/10.28945/5306
68. Parasuraman, A. and Colby, C.L., An Updated and Streamlined Technology Readiness Index. *Journal of Service Research*, 2014, 18(1): 59–74. https://doi.org/10.1177/1094670514539730
69. Alam, S.S., Ahmed, S. and Kokash, H.A., Interplay of Perceived Organizational and External E-readiness in the Adoption and Integration of Augmented Reality and Virtual Reality Technologies in Malaysian Higher Education Institutions. *Education and Information Technologies*, 2023, 29(11): 13735–13761. https://doi.org/10.1007/s10639-023-12428-7
70. Lampropoulos, G., Keramopoulos, E., Diamantaras, K. and Evangelidis, G., Augmented Reality and Gamification in Education: A Systematic Literature Review of Research, Applications, and Empirical Studies. *Applied Sciences*, 2022, 12(13): 6809. https://doi.org/10.3390/app12136809
71. Waller, P.P. and Maxwell, K.L., Mathematics Teachers' Perceptions of Resources and Curriculum Availability in Post-Apartheid Schooling. *International Journal of Science and Mathematics Education*, 2016, 15(4): 741–757. https://doi.org/10.1007/s10763-016-9713-2
72. Walsham, G., Doing Interpretive Research. *European Journal of Information Systems*, 2006, 15(3): 320–330. https://doi.org/10.1057/palgrave.ejis.3000589
73. Maxwell, J.A., *Qualitative Research Design: An Interactive Approach*, 1996. Available from: http://ci.nii.ac.jp/ncid/BA27933242
74. Parasuraman, A., Technology Readiness Index (Tri). *Journal of Service Research*, 2000, 2(4): 307–320. https://doi.org/10.1177/109467050024001
75. Guest, G., Bunce, A. and Johnson, L., How Many Interviews Are Enough? An experiment with data saturation and variability. *Field Methods*, 2005, 18(1): 59–82. https://doi.org/10.1177/1525822x05279903
76. Braun, V. and Clarke, V., Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*, 2006, 3(2): 77–101. https://doi.org/10.1191/1478088706qp063oa

Author's biography

Adnan Abdallah Al Buraiki is a PhD candidate at the Department of Foundation of Education, Faculty of Educational Studies, Universiti Putra Malaysia. He has over 30 years' working experience in teaching and managing post-basic schools in the Sultanate of Oman. His research interests in emerging technologies and STEM.

Sharifah Intan Sharina Syed Abdullah is a senior lecturer at the Faculty of Educational Studies, Universiti Putra Malaysia. Her research interests are mainly in the areas of environmental education, sustainability education, science education, curriculum and instruction, and non-formal learning. Drawing on this interest, she has been involved in the aforementioned areas at the national and international level.

Mas Nida Md Khambari is a Graduate Technologist and Associate Professor in Instructional Technology and Learning Design at the Department of Science and Technical Education, Faculty of Educational Studies. She is the deputy Director at the International Institute for Online Learning (IIOE UNESCO-ICHEI) Malaysia. She is also the Executive Committee of the prestigious Asia-Pacific Society for Computers in Education (APSCE) and is actively involved in the Special Interest Group: Practice-driven Research, Teacher Professional Development and Policy of ICT in Education under the APSCE flagship conference – the International Conference on Computers in Education, since 2014.