ENHANCING ELEMENTARY SCIENCE EDUCATION: A USER-CENTERED DESIGN CASE STUDY ON MOBILE AUGMENTED REALITY

Tarane Yari
taraneyari@gmail.com

ABSTRACT
This paper presents a user centered design case study focused on enhancing elementary science education through a mobile augmented reality application (mAR). The study was conducted in two phases of user research. In the first phase, teachers of elementary school students were surveyed to gather insights on the use of technology in the classroom and its impact on student engagement and learning. Key findings from this phase informed the design requirements for the AR application, prioritizing simplicity, interactivity and student engagement. The second phase involved an evaluation with elementary students, where mid-fidelity prototypes were tested to assess usability and effectiveness. A combination of qualitative and quantitative feedback was collected to refine the design further. The study began with a comprehensive literature review, exploring the role of AR in education and concluded with the final design recommendations. The results highlight the potential of mobile AR applications to improve focus and motivation in young learners, as well as the importance of a user friendly interface tailored to their needs. This case study offers insights for educators and designers seeking to integrate AR into educational environments.

INTRODUCTION

In recent years, with the popularity of mobile devices and mobile networks, digital learning can not only be applied to computers; learners now have more freedom and convenience in learning through mobile devices. Mobile technology is increasingly being used to replace analog media and technology, offering greater flexibility and accessibility to learners of all ages. According to research, children in elementary school have different learning styles than adults (Al Hunaiyyan, Al-Sharhan, & ..., 2017; Gabor & Péter, 2015; Wong, 2012). They process new information in different ways and possess distinct learning characteristics. Innovative techniques and pedagogical approaches can cater to these styles, particularly through the use of information and communication technology (ICT) and mobile technology in education (Oladele, 2014).One of the newer technologies that has been effectively integrated into education via mobile devices is augmented reality (AR). AR combines digital content with the physical world, allowing students to engage with learning material in immersive and interactive ways. According to Valk, Rashid, and Elder (2010), "mobile technology is important and necessary in today's society due to its presence, flexibility, ease of access, and wide range of capabilities." Yang and Wang (2011) similarly assert that "as mobile connectivity spreads around the world, the benefits of incorporating mobile technology into learning and teaching appear to be clear and unavoidable."If teachers do not embrace disruptive technologies such as digital games and interactive storytelling available through smartphone applications, they risk losing touch with modern cultural realities. As a result, today's primary school teachers should be aware of the usage of mobile technology, as it has the potential to dramatically enhance children's educational experiences.

AR technology has the ability to merge virtual objects with a physical, real-world environment, providing students with immersive learning experiences. This can make abstract learning content more approachable and engaging (Oladele, 2014). AR is increasingly recognized as a powerful tool for promoting interactive learning in elementary schools.

One example of AR's effectiveness is the combination of books with AR technology, which allows students to explore layered content in an engaging way. As Kim and Lee (2013) state, "AR can enhance traditional instructional materials by transforming static textbooks into interactive experiences, thereby fostering higher engagement and understanding in students."Instructional materials have evolved from physical textbooks to electronic course content, while learning strategies have shifted from traditional face-to-face methods to e-learning or mobile learning approaches. Many studies have revealed the potential of AR and computer-assisted instruction (CAI) to benefit blended learning environments, increasing instructional flexibility and enhancing student interaction (Azuma, 1997; Azuma, 2001).

The potential of AR in education is undeniable, as it allows for a richer, more engaging learning experience that aligns with the evolving technological landscape of modern classrooms. Teachers who embrace AR and mobile technologies can unlock new opportunities for student engagement, creativity, and deep learning.

Background

Augmented reality has been increasingly recognized for its potential to transform education, particularly for younger learners. Chiang, Yang, and Hwang (2014) proposed a location-based AR learning environment where students collaborated and shared knowledge using mobile devices. This study found that location-based AR learning improved student motivation and fostered greater interaction among peers. Ustun et al. (2022) further support this by suggesting that AR creates a fun and authentic learning environment that has the potential to increase students' motivation significantly. Similarly, Fan et al. (2020) demonstrated how 3D virtual visualizations via AR technology could create an interactive learning environment that promotes authentic, situated learning where students collaborate effectively.

Bower et al. (2014) also noted that AR can be applied to various learning approaches, such as constructivist learning, game-based learning, inquiry-based learning, and situated learning. This makes AR a versatile tool in modern education. In another study, Olsson and Salo (2011) explored the use of mobile AR technology with 90 participants and concluded that AR applications successfully captured attention and aroused curiosity, further affirming its value in educational settings.

AR has also been shown to enhance students' attitudes toward complex subjects. For example, in physics education, AR was found to help students develop more positive attitudes toward laboratory work and improve practical skills (Akçayır & Akçayır, 2017).

The use of mobile learning in elementary schools has shown promising results. For instance, arithmetic and storytelling applications have been shown to help children improve their cognitive abilities, offering emotional benefits through interaction with others. Math games and digital storytelling applications, specifically, have proven effective in engaging students, encouraging problem-solving rather than passive learning (Oladele, 2014). This finding aligns with constructivist learning approaches, such as discovery-based learning, which promote active engagement and independent problem-solving.

AR in Children's Learning

AR technology can be a powerful tool for engaging elementary students in their learning. It can offer remedial solutions to issues such as lack of motivation and relevance to real-world scenarios, which have been identified as significant barriers to student interest in science education (Osborne et al., 2003; Van Aalsvoort, 2004). Law and Heintz (2021) highlight how mobile AR-based learning, especially in subjects like biology, can increase motivation by visualizing complex concepts and creating immersive learning scenarios. This allows students to learn by doing, which leads to deeper engagement and understanding, rather than mere memorization.

AR also allows students to interact with learning material in innovative ways. For example, storytelling through digital animations, integrated into AR applications, can stimulate cognitive and emotional engagement in children. This approach makes learning more enjoyable and relatable, further encouraging focus and participation in the classroom.

One of the primary issues in elementary science education is maintaining student focus. A lack of motivation and real-world relevance has led to a decline in students' interest in science over the past few decades (Porter & Parvin, 2008). Mobile AR-based learning addresses these issues by offering visual, interactive, and scenario-based learning experiences, which increase both focus and engagement (Akçayır & Akçayır, 2017).For example, through AR, science concepts can be presented in a dynamic, visual format, helping students to not only grasp abstract ideas but also remain engaged for longer periods. AR content allows students to assimilate information more effectively, rather than relying on rote learning. This increased level of interaction and immersion helps sustain student interest in science subjects.

Storytelling, particularly in the form of digital animations, plays a critical role in engaging students. Narrative structures integrated into AR applications can boost cognitive involvement and make learning more relatable and enjoyable. Characters, plots, and story arcs offer a means for students to emotionally invest in their learning material, keeping their attention and facilitating better information retention.

Research Objectives

The primary objective of this study is to assess the impact of AR on student focus and engagement during elementary science lessons. The study aims to evaluate how AR applications affect students' ability to maintain attention, reduce distractions, and retain information. A secondary objective is to explore the role of storytelling within AR applications,

examining how narrative elements such as characters and plots can enhance both cognitive and emotional engagement in science education.

Related work

several studies and projects that have explored similar approaches to the use of mobile augmented reality or mAR in educational settings. These works provide valuable insights into how AR can enhance learning experiences, particularly for younger students. By analyzing the methodologies and outcomes of these projects, we aim to identify best practices and potential areas of improvement for our own AR app development. The selected studies focus on key factors such as user engagement, educational effectiveness, and usability, all of which are critical to the success of our design.

1.Latif (2012) discussed two instances of mobile Augmented Reality (mAR) applications, with one focused on using mAR to enhance clinical skills training in a lab setting. This method exposed students to necessary skills for real-world situations such as operating rooms and emergency scenarios. The AR technology helped simulate these environments during regular practice, enriching students' clinical knowledge while reducing anxiety. The Centre for Excellence in Teaching and Learning (CETL) in London, UK, supports this self-directed learning approach, which allows students to learn in labs without the need for additional instructors or technicians.

2.In 2023, Singh, Bangay, Grossek, and Sajjanhar conducted a study combining a storybook with an AR application to create a literacy primer. This approach integrated three different frameworks to enhance educational content, boost motivation and engagement, and highlight essential features of the AR application.

3.Several applications of AR in schools have yielded promising outcomes. For instance, in secondary education, an AR-based mobile system for learning chemistry was found to significantly improve students' understanding, knowledge retention, and motivation (Ustun et al., 2022). Similar results were observed in primary education, where AR applications contributed to enhanced learning, greater motivation, and a deeper grasp of various concepts (Bower et al., 2014).

4.Another study by Ternier and Vries (2011) utilized mAR for a cultural science field trip, incorporating different game designs, delivery channels, and pedagogical approaches. In one case study, "Florence," students participated in a scavenger hunt-like game set in a situated learning environment. The application used GPS navigation to allow students to explore street views, and upon discovering a new view, they were tasked with completing specific challenges.

METHODOLOGY

For the first phase of this user centered design case study, a survey was conducted from 25 elementary school teachers. They were asked 5 background questions, 7 questions related to the use of technology in their teaching and 7 about their familiarity with AR and its use in teaching to kids.

For this phase teachers were chosen as the audience(n=15), as they act as the primary gatekeepers and facilitators of classroom technology, determining which tools are useful and how they are incorporated into the curriculum. Their role is crucial in ensuring that any application is both practical and feasible for classroom use, as they guide students in the effective use of educational technology. With their deep understanding of educational content, learning objectives, and teaching strategies, teachers offer valuable insights into aligning AR applications with curriculum standards to support learning outcomes and enhancing the teaching of any complex concept. Their experience with students of diverse abilities and learning styles allows them to identify features that accommodate varied needs, ensuring that AR applications are inclusive and accessible. They also possess a keen awareness of the practical constraints within classroom environments, such as time limitations, available resources, and technological infrastructure, and can highlight potential challenges in implementation while suggesting practical solutions. Furthermore, their feedback on the necessary support and training is essential for the successful adoption and sustained use of new technologies ensuring that they have the resources and knowledge required to integrate AR effectively into their teaching practices.

The following statements guided the theme of survey questions:

- **Technology Utilization**: What types of technologies are primarily employed by teachers in their classrooms?

- **Student Motivation and Engagement**: Which technological tools are most effective in enhancing student motivation and maintaining focus?
- **Instructional Methods**: What instructional strategies or methods of explanation are perceived to best encourage student concentration and engagement?
- **Mobile Application Integration**: What has been the teachers' experience with the use of mobile applications as educational tools in the classroom?

Findings

Findings were grouped into six distinct themes using affinity mapping (Figure1), a method that organizes ideas and data based on their natural relationships, which included: Engagement through technology, Mobile apps, Student preferences, Storytelling and media engagement, the Teacher's role, and Ease of use.
The outcomes of this mapping were as follows:

- Engagement through technology: Elementary students are more encouraged to interact and remain focused on the subject matter when technology or media is integrated into the learning process.
- Ease of use and flow: Having a simple, intuitive user flow and a non-complicated interface is crucial when students are directly involved. Complexity can discourage them from continuing their study or distract them from the content.
- Preference for modern approaches: Students show a stronger interest in newer technologies and methods over traditional approaches, as they find these more interesting and interactive.
- Media preferences: Students display a preference for animations, illustrations and cartoons over real life images and videos. This preference was further validated during the A/B testing session with the students.
- Independence with mobile technology: Elementary students require minimal assistance when using mobile applications and gadgets, especially compared to other study methods, demonstrating their ability to adapt to technology with ease.

Figure1: Affinity map from survey insights, highlighting key themes from teacher responses on the AR app's usability and engagement.

Design consideration

Based on the feedback gathered from teachers, the educational app should prioritize an easy flow, a minimal and intuitive user interface, and engaging media content. These elements are crucial to keeping students focused and motivated while using the app.

Also for the AR part of the app Azuma [18] defines an AR has the following three features: (1) combining virtual objects in a real world environment, (2) providing the real-time interaction with users, and (3) interacting with users in three-dimension space

Liarokapis [19] stated that an AR system should have the following components: (1) marked cards which are graphics pattern for encoding information of objects, (2) capturing input device that could be a webcam, (3) computer device such as PC, laptop or mobile device, (4) AR software that is used to encode/decode and track the marked cards, (5) input device such as mouse and keyboard, and (6) output device such as head-mounted display, computer monitor or mobile device.

Wu, Lee, Chang, and Liang [20] classified the AR learning approached into three categories: (1) engaging students into “roles” that emphasize students' interactions with mobile-AR, multiplayer AR learning; (2) interacting with physical “locations” that emphasize students to interact in physical environment with location-based AR learning; (3) design the learning for “tasks” that can be game-based AR learning.

Methodology

The methodology used to design this application followed a structured approach that included the following key steps:

1. **User Research**: A thorough analysis of the end-users, focusing on their needs, behaviors, and preferences in a learning environment.
2. **Understanding the Learning Domain**: Gaining a deep insight into the educational field to ensure that the application aligns with effective teaching practices and learning outcomes.
3. **Identifying Educational Needs**: Clearly defining the specific educational gap or challenge the app aims to address, ensuring that it serves a purposeful role in the classroom.
4. **Designing the AR Application**:

In line with the principles recommended by Meyer, Rose, and Gordon, this application supports diverse learning styles by offering multiple modes of content delivery. For example, information is presented using icons, alternative text, images, written content, and videos with subtitles. AR’s ability to engage multiple senses, such as sight, sound, and potentially touch, makes it an ideal tool for varied forms of content presentation.

Additionally, the app provides several ways for students to express their understanding. This can include self-assessment tools, personal note-taking features, and a "Contact Your Teacher" option to maintain communication with instructors.

To promote ongoing engagement, the app challenges students with interactive elements at each step of the learning process. For example, instructional videos demonstrate expert techniques, and puzzle-like activities allow students to sequence steps in a process. This approach ensures that tasks are appropriately challenging and encourages students to actively complete them

What needs to be defined:

Based on the gathered data and user insights, several key elements were identified that need to be defined in the development of the educational app. These design considerations focus on simplicity and clarity to ensure an optimal learning experience for elementary students:

- A **simple scan page**, allowing students to interact with the AR feature easily.
- A **scanning guide integrated within books**, ensuring that students can effortlessly scan relevant materials.
- A **result page with no distractions**, ensuring the focus remains on the educational content.
- A **clear and straightforward path** for additional text guides related to the science topic, divided into manageable sections.
- **Lessons presented as storyboards** for an alternative storytelling approach, catering to different learning preferences.

After gathering and analyzing the data from the initial survey, we defined the key design requirements based on user needs and insights. The survey results highlighted specific areas for improvement in the app’s usability and learning experience. With this data, we began the design process by creating wireframes that outlined the basic structure and layout of the app, focusing on core functionalities and user flows.

Once the wireframes were validated, we developed detailed user flows to map out how students would navigate through the app, ensuring a smooth and intuitive user experience. This stage helped visualize the steps users would take to complete various tasks, such as accessing learning modules and interacting with AR elements.

Following the wireframe and flow development, we created mid-fidelity designs, adding more visual elements and interactive features. These mid-fid designs were used during the A/B testing session to evaluate the effectiveness of different design approaches. This iterative process allowed us to refine the user interface based on real-world feedback, ensuring the app was both functional and engaging for the target audience.

Evaluation

To evaluate the effectiveness and user-friendliness of the AR app designed for elementary students, we conducted an A/B testing session (Figure2) as our user testing step. The goal was to determine which design approach would best serve the needs of young users in terms of engagement, ease of navigation, and overall educational impact.

Two versions of mid-fidelity prototypes were developed and presented to a group of students. Each group of participants interacted with a different version of the app, completing a set of predetermined tasks designed to reflect typical use scenarios. Throughout the session, I observed the students' interactions, gathered qualitative feedback, and tracked key performance metrics such as time taken to complete tasks, error rates, and user satisfaction levels. The insights gained from this process were critical in guiding the final design decisions, ensuring that the app would meet the intended learning outcomes and be enjoyable for the students.

Figure 2:Two elementary school students during the A/B testing phase

RESULT

The following section presents the UI designs of the AR app, which were developed based on user feedback and testing insights. These designs aim to enhance the user experience, ensuring that the app is both engaging and easy to navigate for elementary school students. Each screen has been crafted with a focus on clarity, interactive learning, and accessibility.

The app's interface uses solid yet engaging colors and intuitive simple icons to create an inviting learning environment. The typography was selected for its readability, ensuring that young users can easily navigate the app without unnecessary complexity. The design adheres to principles of minimalism while incorporating playful elements to hold the students' attention (Figure 3).

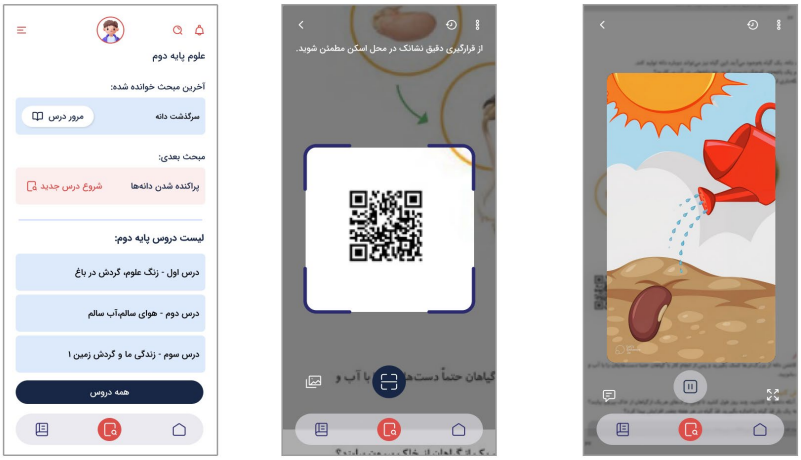

Figure 3: scan page, animation area, and lesson overview

Home Screen

The home screen welcomes students with a user-friendly, colorful interface. The key navigation elements are clearly arranged, allowing students to quickly find lessons, quizzes, or other resources. A balance between visual and text-based components ensures that young users are not overwhelmed by excessive information.

Features: Large, child-friendly icons for easy navigation. Minimal text is used to cater to the learning needs of elementary students. A direct scan button is integrated into the bottom menu for easy access to AR features. Additionally, the list of lessons presents the last lesson studied and the upcoming one, helping students maintain their learning flow.

Scan Page

The scan page provides a focused and simplified interface for students to scan QR codes effortlessly. The scanning area is highlighted clearly, while the surrounding region is blurred and grayed out to reduce distractions and guide the user's attention.

Features:

- A designated scan area prominently displayed in the center of the screen for QR code detection.
- Blurred and grayed-out surroundings to create a visually focused experience.
- A clear "Scan" button at the bottom to trigger the scanning process.
- A guiding text positioned above or below the scan area, instructing students on how to properly align the QR code for accurate scanning.

Icons for **Back**, **Settings**, **History**, and **Gallery** are placed in the top corners to offer students easy access to essential controls without cluttering the scan interface.

AR Learning Page

The AR Learning Page presents the results of the scan by displaying educational animations that correspond to the student's lesson. The main area is dedicated to the animation, ensuring a focused and immersive experience, while additional interactive options are available to enhance learning.

Features:

- **Animation Area:** A central space where the AR content (animation) is displayed. The surrounding area is grayed out to maintain focus on the animation and reduce distractions.
- **Full-Screen CTA (Call to Action):** A button allowing the user to expand the animation to full screen for a more immersive viewing experience.
- **Text Display CTA:** An option to view accompanying text from the lesson book if students need additional context or explanation.

The clean and minimal layout ensures that students remain focused on the content, while the availability of full-screen mode and text support enhances engagement and comprehension.

In addition to the home screen and AR learning page, several other key pages are incorporated into the design to enhance user experience and ensure a comprehensive learning journey (Figure 4). The Lessons List Page provides students with an overview of all available lessons, clearly distinguishing between those they have already completed and those yet to be explored, ensuring easy tracking of their progress. The Progress Page displays read and unread lessons, allowing students to visually monitor their learning achievements and motivate them to complete remaining topics. Each lesson is presented in a Storyboard/Comic Style format, making it more engaging for young learners by visually breaking down complex subjects into digestible scenes. Furthermore, a detailed list accompanies each lesson, indicating which parts are available as animations and can be scanned within the app, guiding students in utilizing the AR features for an enriched learning experience.

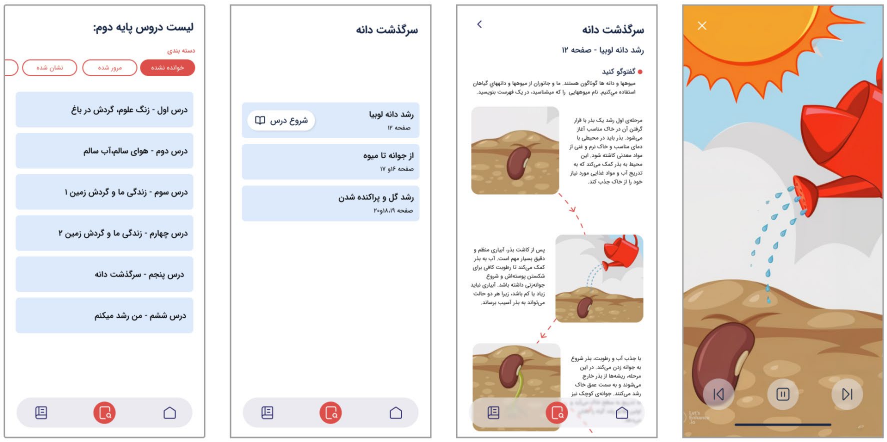

Figure 4: Additional UI designs of the AR educational app, including the lesson list, progress tracking page, and storyboard-style lesson presentations.

CONCLUSION

The final UI designs of this educational AR app are the result of an iterative process that incorporated extensive user feedback and applied best practices in both educational app design and augmented reality technology. By emphasizing usability, engagement, and visual appeal, the app delivers an effective and enjoyable learning experience for elementary school students. Through a combination of interactive storytelling, simple UI elements, and dynamic visual content, the app enhances focus and motivation for young learners while making complex scientific concepts more accessible.

The user-centered design approach led to several key insights during the A/B testing and surveys with teachers and students. A standout finding was the impact of storytelling on student engagement. Storyboarding and comic-style lessons, which visually present scientific concepts in a narrative format, were particularly effective in maintaining student interest. The narrative structure not only encouraged curiosity but also made it easier for students to relate to and retain the material. This storytelling approach, combined with illustrations and animations, created a multi-sensory learning experience that students found enjoyable and memorable.

Moreover, the simplicity of the UI played a significant role in reducing cognitive load for young users. A clean, minimal design with large icons and intuitive navigation allowed students to focus on learning without being overwhelmed by unnecessary distractions. The use of illustrations further enriched the visual experience, providing context and clarity, especially in complex topics. Teachers reported that the clear, interactive visuals helped students understand abstract concepts more easily, leading to improved participation and focus during lessons.

The A/B testing also demonstrated that children performed better with a less cluttered interface. Versions with more text or additional options were found to confuse or distract younger students, while a streamlined layout—particularly on the result and scan pages—kept them engaged with the core content. Additionally, feedback from the surveys emphasized the importance of a flexible design that accommodated different learning styles, with features like alternate text, subtitles for videos, and the ability to explore lessons at their own pace.

One limitation of the study was the challenge of conducting comprehensive testing across a wide variety of classroom settings and with students from different educational backgrounds. While the app was tested in a controlled group of students and teachers, further testing in more diverse environments would help to ensure its broader applicability. Additionally, the reliance on AR-compatible devices may pose an accessibility issue in schools with limited resources.

Several design principles from this study can be universally applied to enhance the learning experience in educational applications. Prioritizing a clear and simple user interface allows for easier navigation, which is crucial for maintaining young students' attention. Storytelling and illustrations significantly boost engagement, allowing students to learn through narratives that are more relatable and memorable than traditional methods. Integrating features such as

animations, interactive quizzes, and direct feedback mechanisms enriches the learning environment and provides multiple means for students to express their understanding of the material.

The A/B testing results confirmed that the balance between interactive content and minimal distractions is critical in supporting student focus and learning. By leveraging these design insights, the app effectively combines modern mobile technology with educational needs, paving the way for a more interactive and immersive learning experience.

This research highlights the potential of augmented reality to reshape science education by making it more engaging, relatable, and aligned with how young students naturally learn. As mobile and AR technologies continue to evolve, their role in education will likely expand, providing new opportunities for innovative, interactive learning experiences.

REFERENCES

Alakärppä, I., Jaakkola, E., Väyrynen, J., & Häkkilä, J. (2017). Children using nature elements in mobile AR for education. *International Journal of Child-Computer Interaction, 13*(3), 1-9. 10.1145/3098279.3098547

Almoosa, A. S. (2018). *A qualitative case study in augmented reality applications in education: Dimensions of strategic implementation* (Doctoral dissertation). University of Northern Colorado. https://digscholarship.unco.edu/dissertations/485

Bacca, J., Baldiris, S., Fabregat, R., Kinshuk, & Graf, S. (2015). Mobile augmented reality in vocational education and training. In *2015 International Conference on Virtual and Augmented Reality in Education (VARE 2015)* (pp. 118-123). Elsevier B.V. https://doi.org/10.1016/j.procs.2015.12.203

Cao, J., Lam, K.-Y., Lee, L.-H., Liu, X., Hui, P., & Su, X. (2023). Mobile augmented reality: User interfaces, frameworks, and intelligence. *ACM Transactions on Multimedia Computing, Communications, and Applications*, 19(1), Article 189. https://doi.org/10.1145/3557999

Chen, C.-H., Huang, C.-Y., & Chou, Y.-Y. (2017). Integrating augmented reality into blended learning for elementary science course. *Journal of Educational Technology & Society*, *20*(3), 169-180. Available:http://dx.doi.org/10.1145/3029387.3029417

Ciloglu, T., & Ustun, A. B. (2023). The effects of mobile AR-based biology learning experience on students' motivation, self-efficacy, and attitudes in online learning. *Journal of Science Education and Technology, 32*(3), 309–337. https://doi.org/10.1007/s10956-023-10030-7

Djibril, D. H., & Çakır, H. (2022). Students' opinions on the usage of mobile augmented reality application in health education. *Journal of Learning and Teaching in Digital Age*, 7(2), Article 1076286. https://doi.org/10.53850/joltida.1076286

Gómez-García, G., Hinojo-Lucena, F.-J., Alonso-García, S., & Romero-Rodríguez, J.-M. (2021). Mobile learning in pre-service teacher education: Perceived usefulness of AR technology in primary education. *Education Sciences, 11*(6), 275. https://doi.org/10.3390/educsci11060275

Herpich, F., Nunes, F. B., Petri, G., & Tarouco, L. M. R. (2019). How mobile augmented reality is applied in education? A systematic literature review. *Creative Education*, 10(7), Article ID: 93878. https://doi.org/10.4236/ce.2019.107115

Jamali, S. S., & Shiratuddin, M. F. (2014). A review of augmented reality and mobile-augmented reality technology. *International Journal of Learning in Higher Education, 20*(2), 1-15. https://doi.org/10.18848/1447-9494/CGP/v20i02/48690

Kim, S., & Dey, A. K. (2009). AR interfacing with prototype 3D applications based on user-centered interactivity. *Computer-Aided Design*, 41(2), 123-135. https://doi.org/10.1016/j.cad.2008.10.001

Laine, T. H., Nygren, E., Dirin, A., & Suk, H.-J. (2016). Science Spots AR: A platform for science learning games with augmented reality. *Educational Technology Research and Development, 64*(3), 507-531. https://doi.org/10.1007/s11423-015-9419-0

Lo, J.-H., Lai, Y.-F., & Hsu, T.-L. (2021). The study of AR-based learning for natural science inquiry activities in Taiwan's elementary school from the perspective of sustainable development. *Sustainability*, 13, 6283. https://doi.org/10.3390/su13116283

Perdana, I., Aisyah, S., Cakranegara, P. A., Fauzi, Z. A., & Destari, D. (2022). The use of mobile learning in elementary school: Is it important? *Al-Ishlah: Jurnal Pendidikan*, 14(2), 1431-1438. https://doi.org/10.35445/alishlah.v14i1.1098

Singh, M., Bangay, S., Grossek, H., & Sajjanhar, A. (2023). Forest classroom: A case study of educational augmented reality design to facilitate classroom engagement. *Multimodal Technologies and Interaction, 7*(5), 46. https://doi.org/10.3390/mti7050046

Widianto Atmojo, I. R., Ardiansyah, R., Saputri, D. Y., & Purnama Adi, F. (2021). The effectiveness of STEAM-based augmented reality media in improving the quality of natural science learning in elementary school. *Alishlah: Jurnal Pendidikan*, 13(2), 643. https://doi.org/10.35445/alishlah.v13i2.643

Wu, J., & Chen, V. D.-T. (2020). A systematic review of educational digital storytelling. *Computers & Education*, 103786. https://doi.org/10.1016/j.compedu.2019.103786

Yuen, S. C.-Y., Yaoyuneyong, G., & Johnson, E. (2011). Augmented reality: An overview and five directions for AR in education. *Journal of Educational Technology Development and Exchange*, 4(1), 119-140. https://doi.org/10.18785/jetde.0401.10

