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Perceptions of K-12 teachers on Mobile Augmented Reality in Biology Education: A Descriptive Action Research

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ABSTRACT: This study aims to examine the perceptions of K–12 science teachers regarding the integration of Mobile Augmented Reality (mAR) as a pedagogical tool in Biology education. Specifically, it investigates current mAR usage, its perceived impact on student learning, and the challenges teachers face in its implementation. Using a mixed-method research design, data were collected from 34 teachers through surveys and interviews. Results reveal that only 44.1% of respondents have used mAR in their lessons primarily coming from private schools, while 55.9% have not, primarily due to limited access to devices, unstable internet, and insufficient training. Teachers who employed mAR reported improved student engagement, enhanced visualization of complex concepts, and increased motivation and collaboration. mAR was most used during the engagement and exploration phases, particularly in anatomy and cell biology lessons. Despite challenges in curriculum alignment, technical support, and classroom management, most teachers acknowledge the potential of mAR to enrich Biology education. The study highlights the need for improved infrastructure, targeted professional development, and curriculum-aligned AR content to support wider adoption.

Keywords: Augmented Reality, Mobile Augmented Reality, Biology Education, K-12 teachers

INTRODUCTION

In the context of the fifth industrial revolution or Industry 5.0, which is defined by the adoption of automation technologies like robotics and machine learning in addition to the encouragement of educators to employ immersive technology like virtual and augmented reality. Studies shows that the global AR in education market is believed to grow from $2.9 billion in 2022 to $20.1 billion by 2028 [1], but despite growth, only 35% of teachers globally feel confident in using AR into their lessons [2]. To better engage today's students, educators should embrace and put in practice interactive teaching methods and to fully integrate technology into their lesson plans, creating dynamic learning experiences that resonate with the preferences of the millennial generation of learners [1]. Augmented reality (AR) is unique among emerging technologies in that it has the potential to alter science education, particularly in topics such as biology. AR enables students to interact directly with virtual elements superimposed on their physical surroundings offering new experiences to learners [3]. By integrating visual, auditory, and video elements, augmented reality (AR) offers a powerful way to improve how teachers deliver education. With this, it can significantly enhance learning, especially by addressing challenges such as a lack of student motivation [4]. According to the OECD [5], over 50% of 15-year-old students in developing countries report low motivation to learn science this is where AR can help, it is proven effective in enhancing learning outcomes, fostering improved student attitudes towards academic subjects, and elevating levels of engagement and satisfaction [6].

In a systematic literature review, Santos [7] highlighted an educational theme where AR is used to boost biology teacher training through e-learning or mobile learning, powered by both AR and VR technologies. Its application necessitates the use of augmented reality tools to support biology instruction, thereby linking the teaching process directly to the concept of learning performance. The discipline of biology necessitates the comprehension of microscopic structures, complex physiological mechanisms, and dynamic ecological relationships. Conventional pedagogical methodologies, including textbooks and static two-dimensional representations, often prove inadequate in delivering an interactive educational paradigm conducive to the development of profound conceptual mastery [8]. A significant portion of students continue to struggle with science when taught through traditional methods. For instance, PISA [5] revealed that more than three-quarters of 15-year-olds across OECD countries failed to demonstrate proficiency in science. Augmented reality applications address this deficiency by facilitating student engagement with three-dimensional representations of cellular, organ, and organismal structures, consequently augmenting spatial cognition and knowledge retention [9].

The interactive framework of AR is epistemologically aligned with constructivist learning theories, which assert that knowledge retention is optimally achieved through experiential engagement and contextualized learning [10]. Furthermore, augmented reality instruments facilitate collaborative learning through the provision of real-time shared manipulation of virtual objects, thereby cultivating teamwork and problem-solving proficiencies [11].

Augmented Reality (AR) was initially developed in the 1990s as a training aid for airline and air force pilots, offering a technological means to integrate digital elements into real-world environments to enhance learning and operational performance [12]. AR is characterized by three core features: the seamless blending of virtual and real environments, real-time interactivity, and the accurate three-dimensional placement of virtual objects in physical space [13, 14]. These features allow users to interact with digital content in dynamic and immersive ways, setting AR apart from conventional teaching tools. This enables contextually rich and interactive learning experiences. In education, AR shows significant promise for improving teaching methods across many areas. It is already widely used in professional fields specifically healthcare for surgical training and clinical practice, when it comes to formal education, it also helps boost student engagement and active participation [15, 16]. AR's ability to deliver real-time interaction as well as its immersive design makes instructional content more relevant, accessible, and successful for a diverse variety of students. Studies shows that AR holds a significant promise when it comes to science education specifically in the fields of ecology, anatomy, molecular biology, and botany because these subjects is where students encounter abstract and spatial complicated concepts that is hard to visualize thus researches supports the help of AR in these kind of matters [17].

AR also creates digital 3D models that help in manipulating such complicated models that helps students in spatial understanding and content knowledge [18]. An example of this is an AR application called HuMAR this application is for teaching skeletal anatomy and that aids for a better academic performance of students and increased student interest in biology, according to [20]. Another example of of AR enhanced 3D e-book that are focused on human respiratory system that provides visual augmentations that are aligned with specific learning objectives where is proved to boost student enthusiasm and engagement, all while potentially reducing cognitive load. But its impact on students' self-efficacy and academic achievements wasn't statistically significant [21]. It’s important to look into teacher’s perspective because they are fundamental to the successful integration of any new technology. Although a significant body of research highlights the beneficial impacts of Augmented Reality (AR) in educational settings, it's important to acknowledge that other studies present either contradictory or, at times, even unfavorable outcomes. Furthermore, Wang [21] performed a study employing an AR-based 3D e-book to educate the human respiratory system and discovered that, while AR increased student engagement and decreased cognitive load, it did not substantially improve learning accomplishment or self-efficacy. This suggests that increased participation does not necessarily lead to improved academic performance. Furthermore, as what mentioned earlier AR is most successful in the field of anatomy, geometry or engineering due to its benefit on spatial visualization and interactive manipulation [9].

According to research, a teacher's attitude, beliefs, and confidence may have a significant influence on how they use mobile augmented reality (mAR) in the classroom [22, 23]. Even in schools when resources are accessible, unfavorable impressions or a misalignment with educational philosophies of the teachers might impede successful adoption [24]. Gaining insight into these impressions is essential. It not only reveals the real-life dynamics within classrooms but also informs the creation of professional development initiatives and support structures that are thoughtfully tailored to meet educators' specific needs. This study is focused on how K–12 science teachers perceive the use of Mobile Augmented Reality (mAR) in Biology classes. Also, it aims to show how this technology is already being used in schools and how teachers rate its effectiveness in delivering Biology lessons. Furthermore, the study focuses on how mAR is shaping the teaching experience and how this may influence students' interest and engagement in biological concepts, it also assesses its impact on students' academic performance, and how this technology will boost motivation and collaboration during class activities. It also aims to uncover the potential benefits and challenges teachers face when it comes to integrating mAR into Biology instruction, including both challenges and teaching opportunities. This can be achieved by addressing teachers' perspectives, also identifying barriers to wider adoption of (mAR), and offering practical solutions for inclusive and effective use, the research intends to make meaningful contributions. Ultimately, it aims to improve biology education, by giving access to digital tools, and help students build critical 21st century learning skills in classrooms.

RESEARCH METHODS

Materials and Tools

This research uses a mixed-methods design that combines survey questionnaire and interviews to answer the objectives. Likert-scale items was employed to identify patterns in how mobile augmented reality (mAR) is used, the perceived benefits it offers, and its frequency of application. The survey instrument was adapted from a previously validated tool used in a related AR study in science education [26], ensuring both its reliability and relevance to this research. For data collection Google Forms are used.

For the qualitative aspect of the study, open-ended questions were included within the same survey. These questions will let the instructors to contribute or expound more about their experiences, issues, and recommendations for better incorporating MAR into their lessons. The data was then evaluated thematically, that utilizes a coding procedure that aims to identify common patterns, themes, and insights. Combining numerical data from surveys with human viewpoints enables triangulation, increasing the reliability and depth of the conclusions. This technique considerably increases the legitimacy and depth of the findings in this study, providing a more full picture of how MAR is seen, utilized, and experienced in K-12 biology instruction. The following sections describe the methodological approach used in this study to evaluate Filipino K-12 science teachers' perspectives of the use of Mobile Augmented Reality as an educational tool for biology themes.

Participants

A total of 34 Filipino K-12 Science teachers from various institutions participated in this study. Purposive sampling was employed to deliberately select participants who exhibited the particular characteristics under investigation. Participants in this study comprise teachers from local schools that utilize both English and Filipino as instructional mediums. For educational inquiries focused on the in-depth analysis of a particular phenomenon, opinion, attitude, or concept within a defined participant cohort, purposive sampling is deemed an appropriate methodological choice [26]. The following criteria were applied to the selection of respondents: (1) should be teaching K-12 Science Subjects specifically biology, (2) must be currently teaching, (3) could be teaching science subjects in a public school or private school. In total, 34 teachers who satisfied the criteria participated in this study.

Instruments

To explore the perceptions of K-12 Science teachers regarding the implementation of Mobile Augmented Reality as a pedagogical tool for biology topics, this research used an adapted version of a validated questionnaire originally developed by Schmidthaler, Wagner, and Glawischnig in their study on AR acceptance among Biology teachers in Austria [25]. This research questionnaire consisted of 4-point Likert Scale, in order to capture and compare the different teachers' opinions on mAR, and open-ended questions. The tool was created to assess educators' experiences, attitudes, and challenges to the use of Augmented Reality in science education. The questionnaire included Likert-scale items grouped into themes like how often AR is used, the teaching benefits teachers associate with it, ease of adopting the technology, how well it fits with lesson plans, and whether needed resources are readily available.

Data Collection

A formal approval from the designated research coordinator was obtained, it includes the study's purpose, ethical considerations, and detailed procedures, ensuring ethical standards was followed. Once approved, informed consent forms were distributed to all qualified student participants clearly outlined the study's objectives, any potential benefits and risks, privacy, and confidentiality. The survey itself was carried out using Google Forms an online platform that simplified the data collection process and provided a clear explanation of the research goals. Participants officially gave their consent by ticking a checkbox before beginning the questionnaire.

Data Analysis

The responses of the participants to the questionnaire about the perceptions of K-12 Science teachers to the implementation of Mobile Augmented Reality as a pedagogical tool for biology topics were analyzed using descriptive statistics with the help of Microsoft Excel version 16.74 to establish the perceptions of K- 12 Science teachers regarding the implementation of Mobile Augmented Reality as a pedagogical tool for biology topics. For the qualitative results of this study, the creation of codes and themes are generated with the help of Chat-GPT. ChatGPT can efficiently generate themes and initial codes based on textual responses, making it a useful tool for preliminary content analysis [27].

RESULT AND DISCUSSION

Participants' Demographics

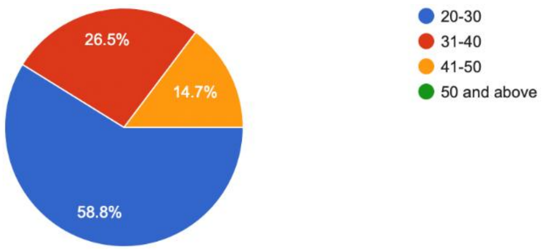

FIGURE 1. Age distribution of participants

The age distribution of the participants was categorized into four age brackets. 58% or 20 of them falls within the 20-30 age group, 26% or 9 falls within the 31-40 age group, 14% or 5 of them falls within the 41-50 age bracket and no respondents are in the 50 and above age category. This distribution suggests a concentration of younger individuals among the survey participants.

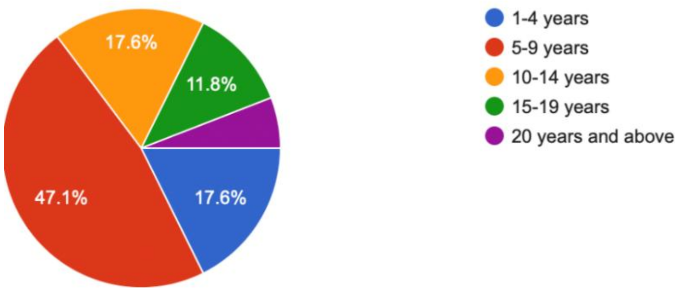

FIGURE 2. Distribution of participants' teaching experience

The distribution of teaching experience among the 34 respondents are categorized into five ranges. 47% or 16% of them acquires 5-9 years of teaching experience. Both 1-4 year and 10–14-year categories account for 17% or 6 respondents each. 11% or 4 respondents were in the 15–19-year experience and for 20 years above category shows no representation in this study. This distribution suggests a concentration of teachers with mid-range experience.

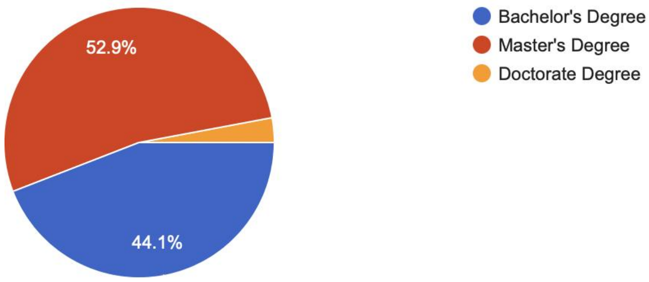

FIGURE 3. Distribution of participants' highest education attainment

For the participant's highest educational attainment, 52% or 18 respondents hold a master's degree, representing the largest segment of the participants. 44% or 15 of the respondents have attained a bachelor's degree. And 2% or 1 participant holds a Doctorate degree. This distribution suggests a concentration of respondents with postgraduate education, particularly master's degrees, among the survey participants.

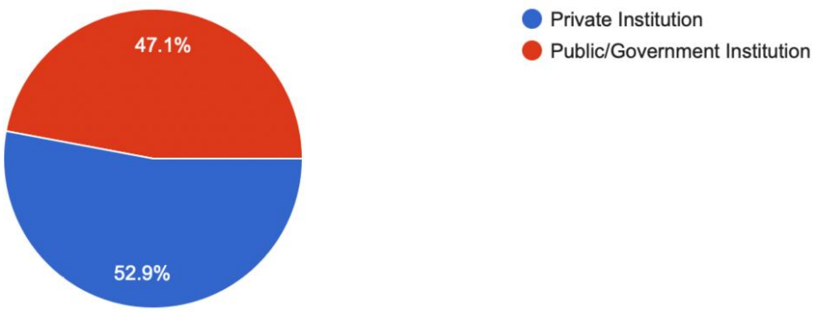

FIGURE 4. Distribution of participants' educational affiliation

The distribution of the participants education affiliation consists of 52% or 18 are affiliated with private institution and 47% or 16 respondents are affiliated with Public or Government Institution. This distribution indicates a slightly higher representation of individuals associated with private educational entities within the survey participants.

Result of Quantitative Analysis

Figure 5 revealed that 55.9% have not utilized mobile augmented reality (AR) applications in their biology or science lessons, while 44.1% reported having done so. This data indicates that a slight majority of respondents are not currently integrating mobile AR technology into their science instruction. Some applications stated by the participants who used AR are Holocell, Beak-a-boo, Anatomy 4D, Phet simulation, Leo AR Camera, Assemblr Edu, Google Lens, Haynayan AR, Labster, Online Free VR Activities and Google AR.

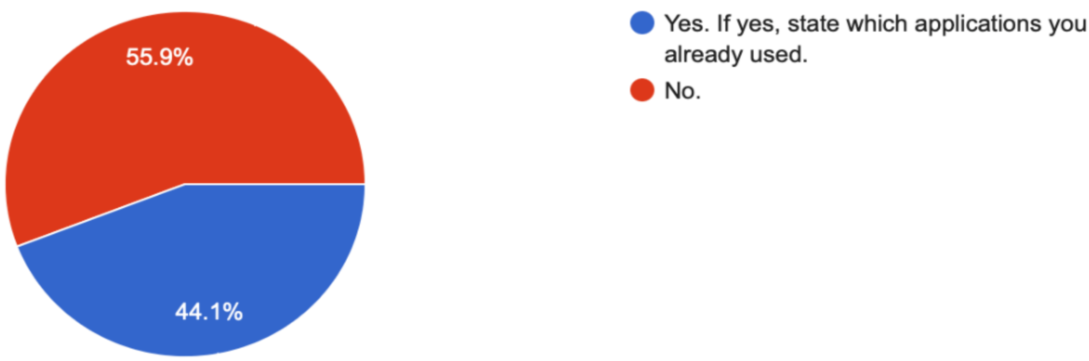

FIGURE 5. Experience on mAR Application in Biology/Science Lessons

Figure 6 reveals the frequency of mobile augmented reality (AR) application usage in biology lessons of the teacher participants. The data reveals that a significant majority, 55.9% or 19, of respondents reported never utilizing mobile AR apps within this context. Among those who do employ these applications, 14.7% or 5 respondents do so once a school year, another 14.7% or 5 respondents once a semester, 8.8% or 3 respondents once or twice a month, and the remaining 2 respondents use them several times a month or weekly. This distribution indicates that while a considerable proportion of respondents do not integrate mobile AR technology into their biology instruction, a smaller subset utilizes them with varying degrees of regularity.

The subjects within Biology in which respondents implemented Mobile Augmented Reality in their teaching predominantly included Anatomy and Cell Biology. Additionally, some participants indicated the use of AR in topics such as Human Physiology, Evolution, General Science, and Zoology. Conversely, a number of respondents reported that they did not utilize AR in any topics.

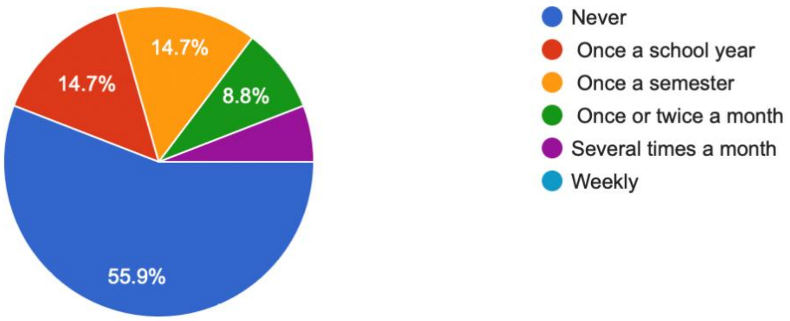

FIGURE 6. Frequency of Mobile AR Application Use in Biology Lessons

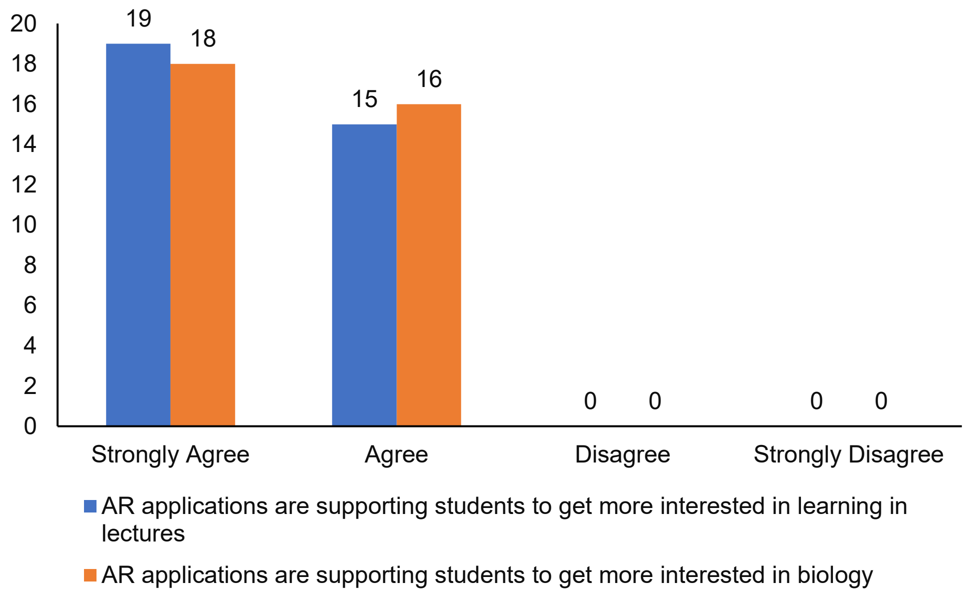

FIGURE 7. Effect of mAR to the students' interests in learning and learning biology-oriented content

Figure 7 illustrates the impact of mobile Augmented Reality (mAR) applications on students' interest in learning and biology-oriented content. The results show that 19 teachers strongly agree that AR applications enhance their interest in learning during lectures, while 18 teachers strongly agree that these applications increase their interest in biology. Additionally, 15 teachers agree that AR applications support their engagement in lectures, whereas 16 teachers agree that these applications enhance their interest in biology. Notably, no teachers selected Disagree or Strongly Disagree, indicating a generally positive perception of AR technology as a tool for fostering student engagement in both general learning and biology-related content. Empirical investigations, as exemplified by [28], demonstrate a positive correlation between the utilization of augmented reality (AR) in educational contexts and enhanced student engagement and enjoyment. This, in turn, is associated with demonstrable improvements in academic performance.

Figure 8 illustrates the perceived impact of mobile Augmented Reality (mAR) applications on students' learning success in science, specifically in terms of their learning ability and preparedness for biology exams. The data reveals that 17 teachers strongly agree that AR applications support their learning ability, while 10 teachers strongly agree that these applications help them prepare for biology exams. Similarly, 16 teachers agree that AR enhances their learning ability, whereas 23 teachers agree that it aids in their exam preparation. A minimal number of respondents, only 1 for each category, disagreed with these statements, while no students strongly disagreed. These findings suggest that most students acknowledge the positive influence of AR applications on their science education, particularly in improving their learning experience and readiness for assessments [29] provide evidence that augmented reality (AR) facilitates the development of students' higher-order cognitive abilities, specifically critical thinking and problem-solving, both of which are deemed indispensable competencies within contemporary educational frameworks.

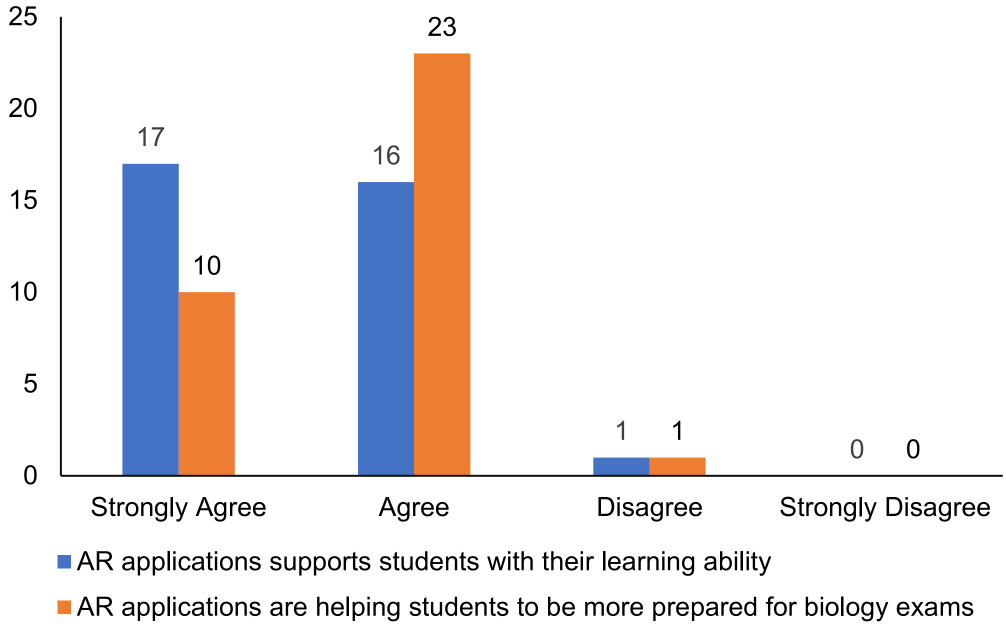

FIGURE 8. Effect of mAR on students' learning success in science

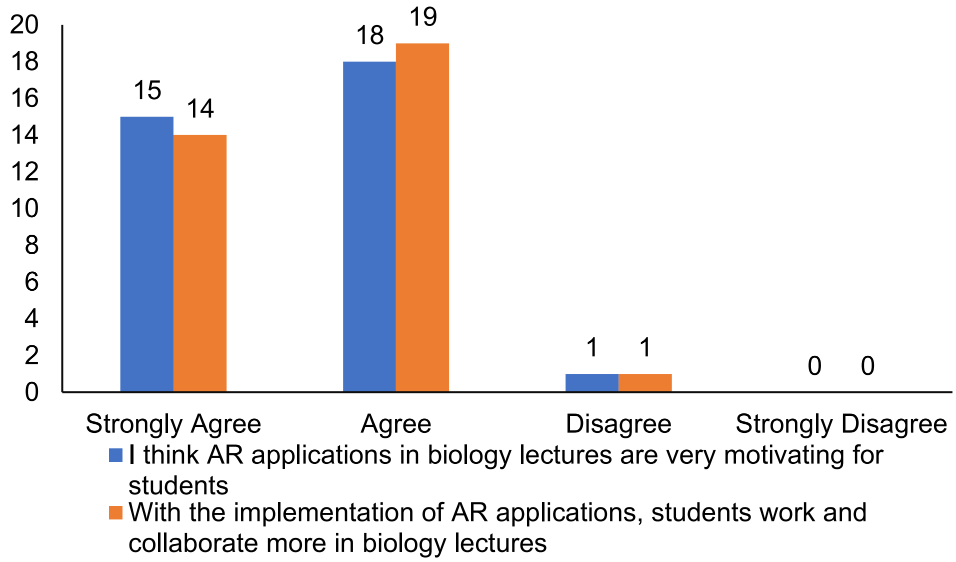

FIGURE 9. Effect of mAR on students' motivation and collaboration in biology lessons

Figure 9 illustrates the impact of mobile Augmented Reality (mAR) applications on students' motivation and collaboration in biology lessons. The data indicates that 15 teachers strongly agree that AR applications in biology lectures are highly motivating, while 14 teachers strongly agree that these applications enhance student collaboration. Additionally, 18 teachers agree that AR applications serve as a motivating factor, whereas 19 teachers agree that AR fosters increased collaboration in lectures. Only one student in each category expressed disagreement, and no students strongly disagreed. These results suggest that the majority of students perceive AR technology as a beneficial tool in promoting engagement and teamwork in biology education. Augmented reality applications facilitate interactive learning environments, enabling students to engage with virtual objects. This modality has been observed to enhance student motivation and cultivate heightened interest in disciplines such as biology and physical education [30].

Teachers' preference on what they particularly like about mAR

Figure 10 illustrates teachers' preferences regarding the aspects they particularly appreciate about mobile Augmented Reality applications. Among the various features, the most favored aspects include

"Illustrations and presentation of objects/Visualization" with 31 responses, "Innovation in learning and teaching" with 29 responses, and "Fun" with 27 responses. These findings indicate that teachers highly value the engaging and innovative nature of mAR technology in education. Additionally, "Creativity in class or study" with 24 responses and "Learning success" with 16 responses suggest that teachers recognize the positive impact of mAR on student engagement and educational outcomes. Other notable aspects include "Freedom to use the app anywhere" and "Learning content is delivered quickly," both receiving 14 responses, highlighting the convenience of mAR applications. "Language and texts are easy to understand" with 8 responses indicates that the language (may be in English language) and texts are perceived as easy to understand by some teachers. However, "mAR app is free or inexpensive" received the least preference with 4 responses, suggesting that cost is not a primary concern for teachers. Overall, the data suggest that teachers appreciate mAR technology for its ability to enhance visualization, foster creativity, and make learning more engaging and effective. Indeed, according to the study of [31], Augmented reality (AR) serves as a pedagogical tool that enhances student comprehension of abstract concepts by rendering them in a concrete, visual format. This facilitation of tangible representation is particularly beneficial within disciplines such as engineering and the social sciences.

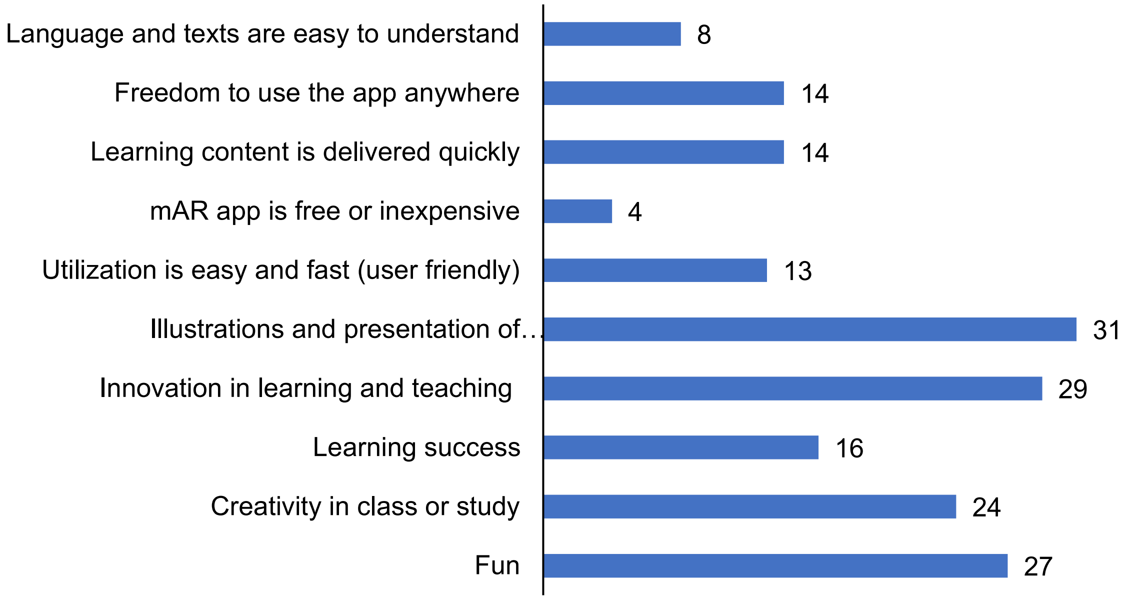

FIGURE 10. Teachers' preference on what they particularly like about mAR

Result of Qualitative Analysis

The second part of this study is the qualitative data from the teacher respondents to further explore the perception of teachers in the use of mobile Augmented Reality. While ChatGPT was used in this study to assist with generating initial codes and themes from qualitative data, it is important to acknowledge several methodological limitations associated with relying on AI-assisted thematic analysis. First, the use of a single coder—particularly an AI model—lacks the benefits of intercoder reliability checks, which are essential for validating the consistency and interpretive accuracy of qualitative coding [32]. This absence introduces a risk of interpretive bias, as AI-generated themes may reflect language patterns rather than deeper contextual meanings. Figure 11 illustrates the frequency of Augmented Reality (AR) integration within specific lesson phases and biological topics. On the left, the codes denote the number of instances where AR is utilized across different pedagogical phases: the Explore phase (f=4), where teachers reported, "It can be used in the explore phase, so students can investigate various components or elements"; the Engage phase (f=3), with educators stating that "AR apps can be used for Motivation where the learners' attention will be grabbed and spark their curiosity"; the Explain phase (f=2), where teachers noted, "Can also be in the explain part for teacher demonstration of concepts"; the Application phase (f=3), with respondents suggesting, "If an actual laboratory tool or equipment isn't available for use, we can resort to AR"; and the Assessment phase (f=1), where a teacher mentioned "assessing learning via AR-based quizzes.". This is consistent with Radu [12], who emphasized that AR's interactive and visual features align with constructivist pedagogies by promoting student engagement and inquiry-based learning early in the instructional process. Similarly, Liu [33] found that AR's ability to stimulate learner curiosity contributes significantly to student motivation during the introduction of new content. The codes on the right measure how common AR usage is in the following biological topic areas: General Science Concepts (f=3), Chemistry and other sciences (f=2), Human Anatomy and Physiology (f=7), Cell Biology (f=5), and Body Systems and Organ Systems (f=3). The increased frequencies seen in the fields of cell biology and human anatomy and physiology suggest that these fields rely more heavily on augmented reality tools to see and engage with complicated ideas. Studies reveal that the application of augmented reality (AR) in biology education often centers on the physical characteristics of human organs and the human heart [34].

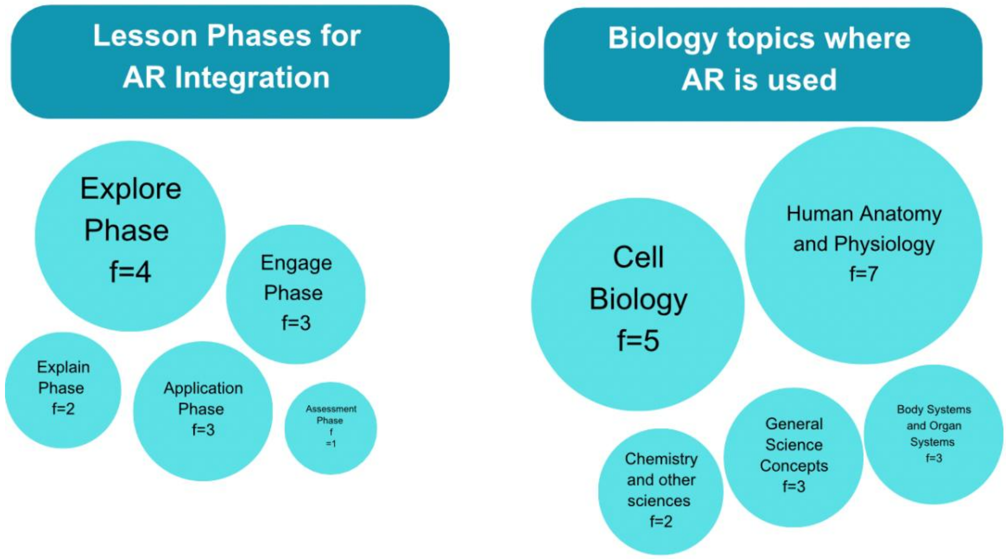

FIGURE 11. Thematic codes for Implementation strategies of mAR and integration in biology topics

A graphical representation of the thematic codes taken from respondent data regarding the use of mobile augmented reality (mAR) in biology education is shown in Figure 12. The two main categories under which these codes are arranged are "Learning" and "Teaching," each of which outlines particular difficulties. In the "Learning" domain, there are issues with: (1) "Accessibility and Availability of Devices" (f=12), as demonstrated by respondent statements like "Not all schools possess the capacity to furnish tablets or mobile phones capable of executing mAR," and "Resource availability (learners' end), particularly in public schools, where not all learners have access to devices and stable internet connectivity/data," thereby indicating a significant concern regarding student access to crucial tools. Examples of "Internet Connectivity Issues" (f=10) include "Inadequate internet stability impedes its implementation within classroom settings," which highlights how crucial dependable internet access is for mAR applications. For the teaching domain, these are the issues that arose that effects the way teachers teach inside the classroom. One of the most pressing issues was "Teacher Training and Familiarity with AR" (f=7), which emphasized the need of providing educators with the necessary skills and confidence to properly use mobile augmented reality (mAR) solutions. The participants also identified barriers such as poor curricular integration and the potential of student distraction, both of which can be a problem withing the successful implementation of (mAR) in the classroom. "Curriculum Alignment and Limited AR Content" (f=3) was also mentioned, highlighting how a shortage of appropriate AR materials makes it difficult to incorporate mAR into existing educational frameworks. Another important concern, "Technical Issues and Software Compatibility" (f=7), this indicated persistent technological issues that can hinder mAR's effective implementation in classrooms. In addition, "Classroom Management and Distractions" (f=3) highlighted the difficulty of keeping students focused when using mAR during lessons. These findings are consistent with those of [3], who found that, while AR has significant educational potential, its widespread implementation is frequently disadvantaged by technological restrictions, poor teacher preparation, and mismatches with present curricula. Finally, "Infrastructure and Institutional Support" (f=2) emphasized the importance of strong support from schools, particularly access to reliable infrastructure, for mAR technologies to truly take root in teaching practice.

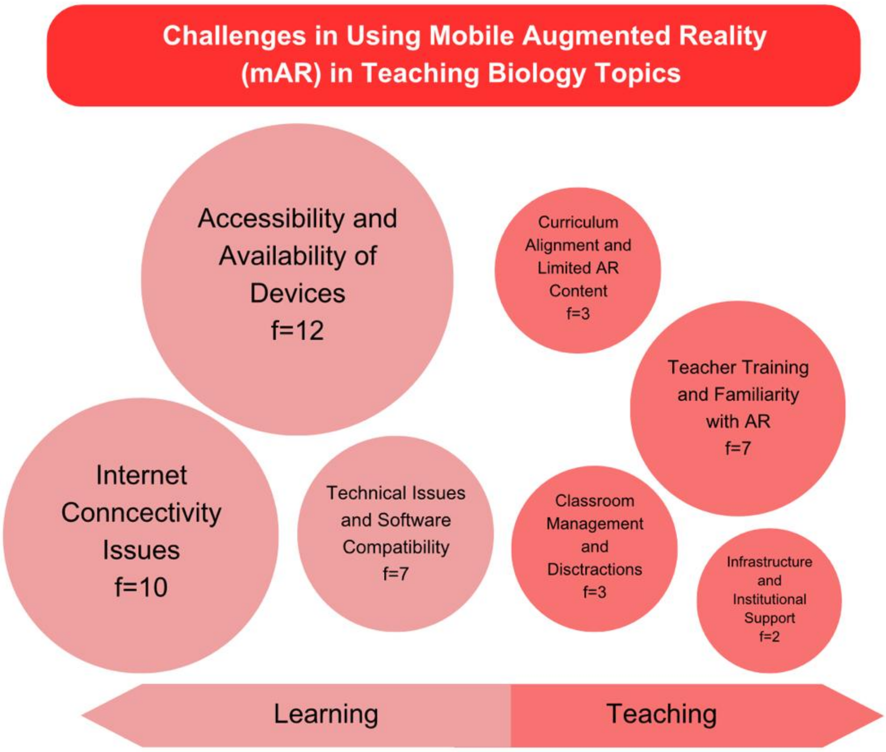

FIGURE 12. Identified Key Challenges in the Use of Mobile Augmented Reality for Biology Instruction

Figure 13 highlights the main challenges and possible improvements tied to using mobile Augmented Reality (mAR) in teaching biology. Most of the these that are shown in red, revolve around accessibility. A common issue raised by participants that was mentioned by the participants 12 times was that many apps are either too expensive or don't work well on Android devices, making them harder to access for a wide range of users. Alongside these access barriers, technical limitations were also mentioned. In 10 instances, respondents pointed out that some apps tend to malfunction or offer only limited features, raising doubts about their dependability and overall usefulness in the classroom. Moreover, the financial demands of implementing AR technology pose a major obstacle. The substantial costs associated with both hardware and software make it particularly challenging for educational institutions, especially those in developing regions, to adopt and integrate mAR into their biology curricula, as pointed out by reference [35]. Additionally, usability and interface design issues (f=9) are noted, highlighting the fact that "Complex user interfaces and insufficient instructional support can hinder teachers from seamlessly integrating AR into their lessons." Additionally, content limitations and pedagogical integration issues (f=7) are apparent in statements such as "There is a limited selection of free AR software available for various biology topics." Language barriers and localization needs (f=1) also contribute to these issues, as evidenced by issues like "Some students struggle with English comprehension." Are scientific augmented reality applications available in Filipino?". Language accessibility and content localization were cited as minor but noteworthy concerns. Some respondents highlighted the absence of Filipino-language options in scientific AR apps. This reflects a broader issue identified by [36], who stressed that localization is essential to ensure inclusivity and equitable learning in diverse linguistic contexts. The effective pedagogical integration of augmented reality (AR) is frequently impeded by educators' deficiency in requisite technical competencies, thereby underscoring the necessity for comprehensive training initiatives [38]. Additionally, Insufficient tech capabilities present a barrier to using AR effectively in vocational and engineering education, as highlighted by [38].

Conversely, the green-coded section highlights potential areas for improvement, such as enhancing offline functionality and accessibility (f=3), exemplified by the suggestion, “Offline functionality should be developed to allow students to use AR tools without requiring constant internet access.” Additionally, simplifying navigation (f=2) is recommended, with insights such as, “mAR apps have complex interfaces, and not all users are tech-savvy. Navigation can be improved by simplifying the interface.”

Further recommendations include increasing platform accessibility and app availability (f=2), ensuring that “Clear and comprehensive instructions should be provided for both teachers and students to facilitate ease of use.” Other suggested improvements involve securing government funding (f=2), enhancing internet connectivity (f=2), as indicated by concerns such as, “Reliable internet access and compatible devices are essential for AR use,” and providing professional development and training (f=3). According to Mau-Duc [39], Studies emphasized the need for sustained training programs and institutional support to enable teachers to adopt AR meaningfully in their practice.

Addressing these areas can support the more effective and inclusive integration of mAR technology in biology education, ultimately improving user experiences and learning outcomes. These recommendations are congruent with the findings of [40], who advise for the development of user-friendly AR solutions and increased institutional investment in infrastructure and training to encourage long-term adoption in education.

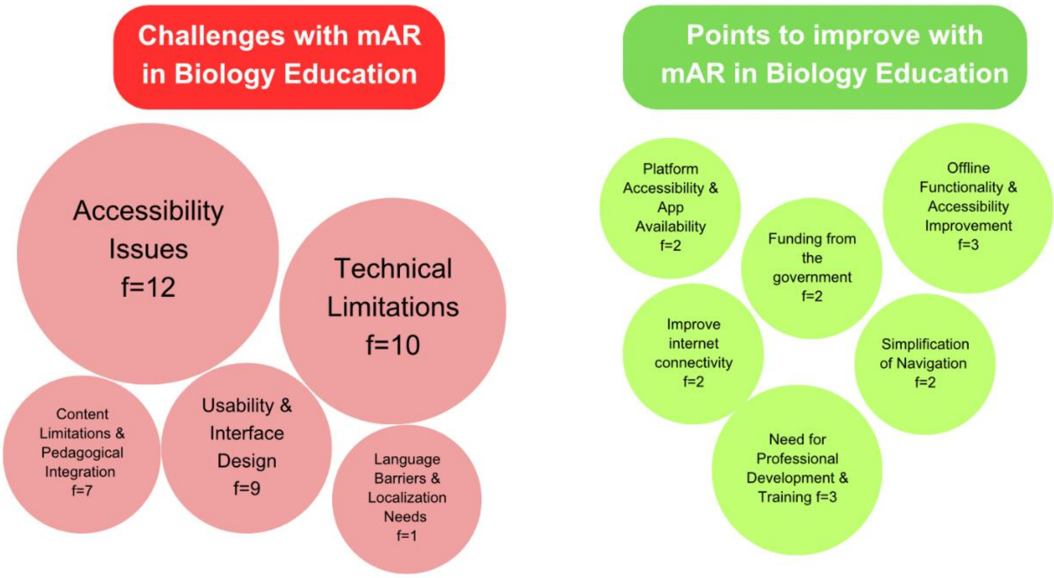

FIGURE 13. Thematic codes indicating problems and areas for improvement with mAR in biology education

CONCLUSION

This study is focused on the perception of 34 science teachers in the use of Mobile Augmented Reality (mAR) in biology classes. The data shows that while mAR has significant potential to make learning more immersive and effective, it’s not yet widely used in classroom. Some barriers that are mentioned by the teacher participants are they experienced unstable internet connections, insufficient teacher training and misalignment of AR with the curriculum. Despite the limitations that are experienced by the teacher participants, they also expressed enthusiasm for implementing Mobile Augmented Reality (mAR) in their biology classrooms. Because it immerses students in the learning environment, allowing them to easily visualize abstract ideas and promoting active participation. This technology was viewed as a promising teaching aid for increasing interactivity and curiosity in learning. For mAR’s success in the classroom, this study recommends providing a better access on mobile devices, more consistent internet service, and teacher training. To lessen reliance on internet connection, developers could also create offline AR experiences. Additional institutional and government support is required to unlock the benefits of Mobile Augmented Reality. With continued funding and strategic policies, especially those targeting under-resourced schools, mAR can become far more accessible and effective. Broader adoption also hinges on making AR technologies intuitive, cost-effective, and linguistically inclusive, so they can accommodate a diverse variety of learners. For augmented reality to be widely used in education, especially in biology, it needs to be easy to use, affordable, and support many languages. By focusing on these areas, educators and developers can help augmented reality truly transform learning and offer richer experiences for students.

ACKNOWLEDGMENT

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