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Mobile AR in Inquiry-Based Primary Teacher Education

Mária Fuchsová - Martin Droščák*

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Abstract:

Introduction: Mobile augmented reality (AR) is increasingly integrated into biology education to support inquiry-based learning by visualizing abstract anatomical structures and system interrelationships, particularly in teacher education.

Methods: A qualitative case study was conducted with 17 pre-service primary teachers using a mobile AR application to explore the circulatory system in relation to first aid procedures, supported by observation, record sheets, and an open-ended questionnaire.

Results: Although students showed strong interest in using AR and preferred it over a physical 3D model, technical difficulties and limited digital skills constrained independent exploration and conceptual understanding.

Discussion: The findings indicate that while mobile AR enhances motivation and collaborative inquiry, its educational effectiveness depends on prior digital literacy training and active teacher mediation.

Limitations: The study is limited by a small sample size, reliance on a single AR application, and short-term classroom implementation.

Conclusions: Mobile AR is a valuable supplementary tool in inquiry-based primary teacher education, provided it is carefully selected, pedagogically integrated, and supported by systematic digital skills development.

Key words: teacher preparation, augmented reality (AR), biology education, learning, primary science education.

* Mária Fuchsová, Comenius University, Faculty of Education, Bratislava, Slovakia, fuchsova@fedu.uniba.sk; ORCID: 0000-0002-9606-4521
Martin Droščák, Comenius University, Faculty of Education, Bratislava, Slovakia, droscak@fedu.uniba.sk; ORCID: 0000-0001-9379-6404

Introduction

The rapid technological advancements characteristic of the contemporary era has instigated transformative shifts across various domains of human activity, notably including education (Fortuna et al., 2023). These technological developments are inextricably linked to the burgeoning utilization of augmented reality (AR) as a pedagogical medium (Permana et al., 2024). Augmented reality is frequently posited as a pertinent educational technology amenable to integration within biology education, offering a potential remedy for the inherent limitations of traditional instructional methodologies. Such limitations encompass the challenges associated with visualizing abstract content within the classroom setting, diminished student engagement with biological topics, and difficulties in comprehending intricate concepts (Stojšić et al., 2022). The AR modality, defined by the co-existence of virtual constructs and the real-world environment, facilitates the visualization of complex spatial relationships and abstract conceptualizations, exemplified by the intricate architecture of the human body (Fuchsová, Adamková, & Pirháčova Lapšanska, 2020). AR exerts a significant impact on biology education by augmenting diverse facets of the learning process. The application of AR in biological education demonstrably enhances students' comprehension of the curriculum and bolsters motivation by rendering abstract and multifaceted concepts more tangible and engaging, consequently mitigating students' cognitive load (Ciloglu & Ustun, 2023; Wang et al., 2022). Within a biology education context leveraging molecular visualization tools via smartphones, AR applications have emerged as potent educational instruments offering flexibility and ease of implementation without necessitating extensive IT infrastructure (Weng et al., 2020). Mobile applications incorporating AR solutions enable the understanding of both external and internal anatomical structures without requiring students to be physically present in a dedicated anatomy laboratory (Dreimane & Daniela, 2021). Dreimane and Daniela (2021) underscore that mobile AR applications constitute a category of digital learning resources accessible anytime, anywhere for anatomy education, obviating the need for supplementary physical artifacts. For successful integration into the educational process, three critical criteria must be considered during their selection: technical design, information structure, and educational value. They observe that numerous commercially available free mobile AR applications frequently fail to adequately meet the latter criterion, rendering them unsuitable for autonomous learning and necessitating pedagogical mediation by the instructor. Consequently, they recommend employing this methodology as a complement to other instructional approaches utilized in the educational process. Furthermore, the synergistic integration of AR with inquiry-based and research-oriented pedagogical strategies has been shown to significantly enhance students' critical thinking, creative thinking, and the capacity to construct robust knowledge frameworks, proving particularly advantageous for students with lower academic achievement (Safadel & White, 2019). Our research focused on the application of a mobile AR application to elucidate the interrelationships of organ systems. A comprehensive understanding of the intricate interdependencies among different human body systems is paramount for accurate diagnosis of functional impairments and the effective administration of first aid to preserve human life. Prior observations indicate that while students may possess adequate declarative knowledge regarding the functioning of individual components of the human body, this knowledge often remains at the level of rote memorization, lacking a cohesive understanding of the interconnectedness of their functionalities. The participants in this research cohort are prospective primary education teachers; hence, a thorough comprehension of such interrelationships is crucial for their future successful teaching practice. Therefore, to facilitate the understanding of these complex interconnections, we employed an augmented reality methodology that enables detailed visualization of the internal architecture of organs, thereby augmenting students' comprehension of the biological phenomenon under investigation. Prior to the actual instructional intervention, we meticulously considered all three criteria (technical design, information structure, and educational value) during the selection of the mobile AR application to minimize potential limitations associated with the utilization of the AR method within the educational context. We implemented the AR method as a supplementary approach to other exploratory methodologies (notably the experimental method) employed to explain a specific biological phenomenon, thereby accommodating diverse learning styles of students. Fuchsova and Korenova (2019) have noted that some students may exhibit a lack of sustained interest in a singular AR application within their learning. Mobile AR applications may either lack a coherent logical structure for information delivery or lack engaging gamification elements and therefore may not intrinsically sustain student interest. Given that AR mobile applications are predominantly developed by commercial entities for profit-driven purposes, the AR method attains its pedagogical utility and engenders student interest primarily through its appropriate incorporation into the educational process by the educator.

1 Methodology

The research was conducted during the academic year 2023/2024 at the Faculty of Education, Comenius University in Bratislava, Slovakia, involving a cohort of 17 master’s students enrolled in a primary education teacher training program. In this investigation, the augmented reality mobile application "Anatomy AR - A view of the human body in real life" (Anatomy AR, 2023) was employed to assess students' comprehension of biological content within the classroom setting, specifically focusing on the circulatory system's function in the context of appropriate first aid procedures in the event of its failure.

Prior to its implementation, a comprehensive evaluation of the mobile application's content and pedagogical suitability was undertaken. The application exhibited characteristics typical of a freely available commercial mobile application, compatible with Android or iOS tablets and smartphones commonly owned by educational institutions, teachers, and students. It incorporates 3D representations within an AR environment encompassing the skeletal, cardiovascular, digestive, endocrine, urinary, genitourinary, lymphatic, muscular, nervous, respiratory, and sensory systems of the human body. A significant advantage of this application lies in its capacity to display individual organ systems as well as their integrated configurations, thereby facilitating the understanding of the intricate interrelationships among various physiological systems. Furthermore, the mobile AR application enables the visualization of organ 3D models in real spatial dimensions within the user's physical environment. By orienting the mobile device towards the AR marker, students can explore the internal structures of human systems and manipulate the virtual object through rotation. Additional rationale for selecting this specific AR application included the persistent accessibility of the AR object within the application interface after marker recognition, the well-structured organization of individual graphical elements, and the satisfactory graphical fidelity of the application for the purpose of explaining biological concepts. Although explicit operational instructions were not provided within the application, its navigation and functionality were deemed intuitive and logically organized. System icons are directly accessible on the screen, and manipulation (movement and zooming) of the 3D objects is facilitated through touch gestures. The definitions and technical terminology integrated within the application are grounded in established anatomical nomenclature. The application also offers multilingual support, including an English version, which was utilized in our biology instruction. A crucial criterion for the selection of the AR application for teaching biological content was its capacity to operate in offline mode, thereby mitigating potential disruptions due to internet connectivity issues or inconsistent network quality within the classroom, which could impede the learning process.

Prior to the exploratory activity, the participating students installed the "Anatomy AR - A view of the human body in real life" application on their personal mobile phones equipped with a functional camera. A representative screenshot of the application interface is presented in Figure 1. The requisite marker for realistic visualization of blood circulation, of which the heart is a component, is directly integrated within the application. The instructor advised the students that optimal engagement with the application would be achieved through collaborative group work, wherein one member would display the application's marker on their mobile phone, the second member would utilize another mobile phone to load the marker and visualize the human body's structure, and the third member would employ a mobile phone to capture photographic documentation. Consequently, the utilization of the AR application is conducive to student group collaboration, aligning with the principles of a constructivist pedagogical approach. During the instructional session, students worked in groups of five, assigning specific roles such as recorder, speaker, and documenter. The teacher assumed the role of a learning facilitator. The augmented reality applications were to be downloaded onto the students' mobile phones prior to the lesson to ensure independence from internet connectivity during the evaluation of class assignments and to allow for prior familiarization with the application's functionalities. Following the download of the application and the marker required for loading the anatomical structures, students were able to operate the application in an "offline" mode.

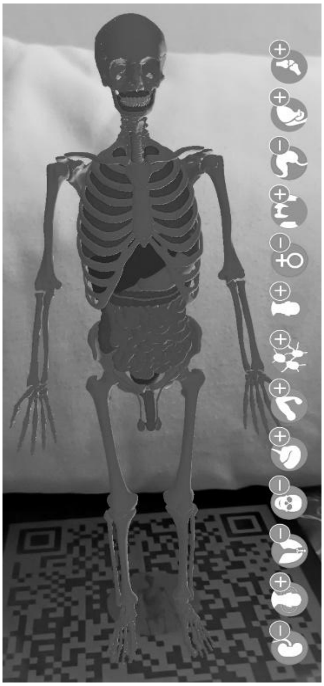

Figure 1. Sample of the application "Anatomy AR - A view of the human body real life".

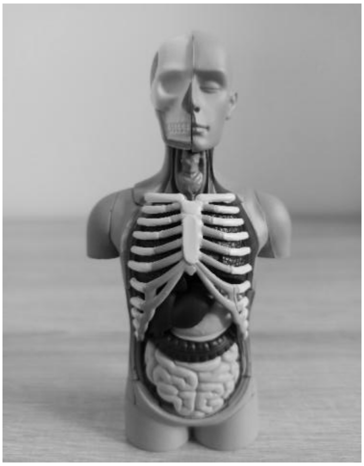

Figure 2. Decomposable real 3D model of the human body.

Concurrently, the teacher furnished an alternative pedagogical modality for the evaluation of tasks and the elucidation of biological content, employing a realistic 3D exploded model of the human body (Figure 2) to accommodate the diverse learning preferences of the student population.

After the lesson's exploratory activity, which incorporated the utilization of a mobile AR application, the students completed a questionnaire. An anonymous online questionnaire, administered via Google Forms, was developed as the primary data collection instrument for this research, comprising seven open-ended questions. These questions were designed to elicit the prospective teachers' perspectives on the advantages, limitations, and overall satisfaction associated with integrating augmented reality within the biology classroom. Given the voluntary nature of participation in the research, 17 students out of the initial 20 students enrolled in the biology class completed the online questionnaire.

The present study focused on three distinct levels of inquiry: (1) students' engagement with the AR methodology, (2) a comparative analysis of the interaction with the AR application versus the 3D model of the human body, and (3) students' opinions and attitudes concerning their experience with the AR application. The study was designed as a case study, characterized by its in-depth investigation of a specific situation (Yapıcı & Karakoyun, 2021). For the comprehensive analysis of the collected data, we employed the method of unstructured observation of students' in-class activities, the evaluation of students' record sheets generated during the research lesson, and the questionnaire method. The qualitative data obtained in this study were subjected to content analysis, a method involving the synthesis of similar data into thematic categories and conceptual frameworks, followed by their interpretation and presentation in a manner accessible to the reader (Yapıcı & Karakoyun, 2021).

In the initial phase of this research, we conducted observations of students engaging with either the AR methodology or a 3D exploded model of the human body within a biology lesson centered on comprehending the anatomy and function of the heart in relation to the respiratory system. At the commencement of the lesson, a brief teacher-led discussion revealed that while students often possess factual knowledge regarding this subject matter, their understanding frequently remains at the level of rote memorization, with a limited capacity to articulate the functional interconnections among different organ systems. Accurate diagnosis of dysfunctions within these two systems is critical for identifying health issues in affected individuals and potentially saving lives through the appropriate administration of first aid for circulatory arrest. This challenge may be attributed to the abstract nature of biological concepts and the functional complexity inherent in these systems. The AR method offers a potential solution by providing a detailed and realistic representation of individual structures in conjunction with one another, thereby facilitating a more comprehensive understanding of these intricate relationships. The students' task involved observing the detailed structure of the circulatory system in isolation, and subsequently in combination with the respiratory and skeletal systems, within an AR application. Concurrently, students were informed that should they encounter difficulties with the visualization of objects within the AR application, they could utilize a substitute decomposable 3D model of the human body to complete the task. The pedagogical intent of the task was that by meticulously examining the structure of the heart within the context of the circulatory system, students would gain a clearer understanding of its proper composition, its anatomical location within the body, and the interconnectedness of these systems in the processes of diagnosis and the effective administration of first aid for circulatory arrest. During the students' interaction with the AR application, three key dimensions were noted by the instructor: the students' digital skills, a comparison of the efficacy of the AR method versus the 3D model of the human body, and the students' ability to collaborate effectively within a group.

2 Results

2.1 Students' digital skills

Observation of the students' engagement with the AR application during the biology lesson revealed that they encountered considerable difficulty in completing the assigned task using this method. Given that the augmented reality methodology is contingent upon the technical functionality of the devices, students appeared to allocate a significant portion of their focus towards the installation and operation of the application, rather than the substantive evaluation of the task itself. We consider it a positive finding that, despite these technical challenges associated with the augmented reality application, students demonstrated a sustained interest in the methodology. They exhibited a willingness to invest additional time in working with the application to ensure the completion of all aspects of the activity. Ultimately, all groups successfully managed to display and capture photographic representations of the three systems utilizing the AR method; however, no group was able to effectively visualize the internal structures of these systems. Figure 3 provides illustrative examples of the system representations constructed by the students within the AR application.

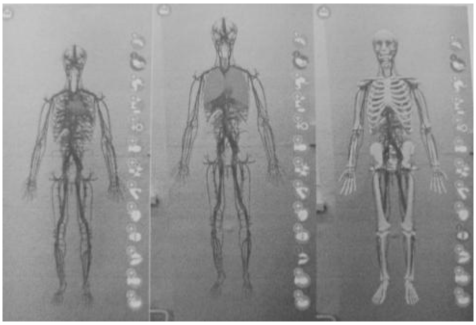

Figure 3. Example of students' work in the AR application "Anatomy AR - A view of the human body real life".

The students demonstrated proficiency in independently installing the AR application on their personal mobile devices and could manipulate their devices to activate the application using a marker, enabling the visualization of 3D objects and navigation among the various anatomical systems within the application's interface. All student groups successfully generated photographic representations of the systems, both individually and in combination, and rapidly discerned the functionality to scale the 3D objects to the approximate dimensions of a human body. However, they did not independently discover the feature allowing for the exploration of the internal structures of the human systems. This capability was only realized by the students during the collective task evaluation phase, facilitated by the teacher's guidance and interaction among all groups. The crucial connection between the circulatory system and the respiratory or skeletal systems in the context of diagnosing circulatory arrest and administering appropriate first aid was only fully comprehended by the students when the teacher provided a demonstration and explanation of this interrelationship (Figure 4).

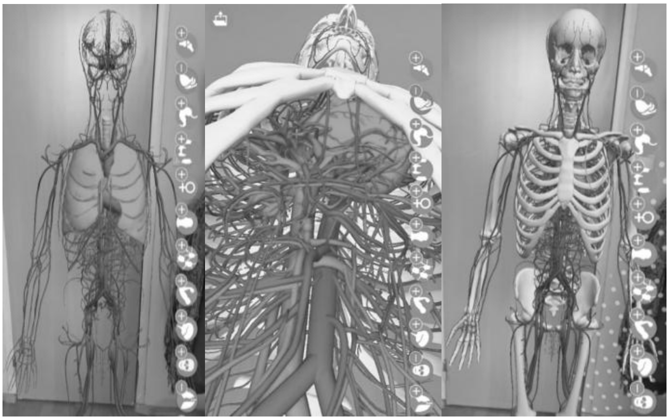

Figure 4. Example of illustration of individual internal structures of the human body in the AR application "Anatomy AR - A view of the human body real life" made by the teacher.

From the augmented reality visualization of the internal architecture of the heart and lungs, it is evident that the heart establishes a connection with the lungs at their interstitial interface, the site of entry for the pulmonary and bronchial arteries and the exit point for the pulmonary and bronchial veins. This anatomical arrangement facilitates the crucial transfer of oxygen and carbon dioxide via the circulatory system between these two vital organs of the human body. Respiratory arrest precipitates cardiac arrest precisely due to the resultant oxygen deprivation. Consequently, circulatory arrest can be diagnosed by the clinical observation of the affected individual's cessation of breathing. Furthermore, the spatial relationship reveals the heart's medial location between the lungs, with its apex oriented towards the left and inferiorly relative to the sternum. In the context of indirect cardiac massage, the established recommendation to position the rescuer's palm on the lower third of the sternum of the affected individual is anatomically justified. This specific point on the sternum directly overlies the heart, rendering cardiac compression at this location effective. The representation of the circulatory and skeletal systems within the augmented reality application provides an indication of the heart's approximate dimensions and its depth relative to the sternum. One of the application's functionalities includes the magnification of bodily organs to their actual size, facilitating the visualization of this spatial relationship. Considering that the heart is roughly equivalent in size to a person's clenched fist and accounting for the thickness of the sternum, it can be inferred that to achieve effective indirect cardiac massage in an adult by physically compressing the heart beneath the sternum, a chest compression depth of at least 5 cm is necessary.

The observations underscore that while contemporary technology enjoys considerable popularity among students within the educational context, their digital literacy may not invariably be sufficient for effective curriculum comprehension. Mobile AR applications frequently lack explicit procedural guidance, rendering their pedagogical utility contingent upon the instructor's introduction and integration strategies. Therefore, it is advisable to provide students with prior familiarization with the application's operation before engaging in biology exploration activities, perhaps within a technology education class. This would enable students to develop proficiency with this form of digital technology and enhance their navigational skills within the application prior to its use in the biology lesson.

2.2 Comparison of student work utilizing two AR methods and a 3D model of the human body

During the biology lesson, it was a notable observation that despite the students' challenges in navigating the AR application, none of the students opted to complete the assigned task using the provided decomposable 3D model of the human body. Instead, all students dedicated a significant amount of time to attempting task completion via augmented reality, even though a technically simpler alternative was readily available. Conversely, the students displayed a marked lack of interest in the decomposable 3D model of the human body, a pedagogical tool that is typically a common and readily accessible resource across various grade levels. The most prevalent difficulties encountered by students while interacting with the AR application involved maintaining the mobile phone's orientation for consistent 3D object rendering and comprehending the representation of internal structures. The physical, unfolding 3D model of the human body inherently circumvented these technological limitations; however, this aid was largely disregarded by the students in their approach to the task. As future educators of primary-level students, we emphasized to the participants the continued relevance of utilizing 3D models of the human body for younger learners. The tangible nature of the 3D model allows students to explore organ structures through multiple sensory modalities, facilitating information retention in a more accessible and accurate manner. A potential limitation of the physical model, however, may be the visualization of the dynamic interplay between different organ systems, as the unfolded model does not directly depict real-time functional connections, a feature offered by the AR method. Consequently, we posit that a judicious combination of both methodologies represents a suitable approach for teaching the functioning of the human body, although the implementation of AR methods in the context of primary education necessitates a more cautious and structured approach. The utilization of school-provided tablets is recommended, and it is essential to provide pupils with advance instruction on application usage prior to biology lessons. Furthermore, any integration of these two methods must necessarily occur under the direct supervision and guidance of the teacher.

The implementation of an augmented reality application within a group-based learning environment revealed that students with initially weaker digital proficiencies and biological knowledge demonstrated an enhanced ability to independently navigate the application following the biology lesson. Furthermore, their comprehension of the interrelationships among anatomical structures also exhibited improvement. At the conclusion of the lesson, most students reported positive experiences with the activity, effective collaboration within their groups, and satisfaction with their assigned roles in the assessment tasks. However, a subset of students indicated a preference for the role of note-taker, suggesting a potentially lower level of active engagement in the assessment tasks for some individuals. Consequently, we recommend structuring group work with a maximum of three members and pre-defining all tasks that students will be expected to perform during the evaluation activity. Nevertheless, our overall findings indicate that the utilization of the AR application is conducive to student group collaboration, thereby aligning with the principles of constructivist pedagogy.

2.3 Students' opinions and attitudes towards working with AR application

In the final phase of this research, we evaluated the students' perspectives on their experience with the AR application "Anatomy AR - A view of the human body in real life." It is pertinent to recall that within the framework of explaining the proper diagnosis of circulatory arrest and the administration of first aid in the biology class, we employed methodologies beyond the AR method in the research activity, notably including experimental methods utilizing constructed aids. The students, as prospective primary education teachers, were solicited for their opinions via an online questionnaire following the exploratory activities lesson. The questionnaire inquired about which activities they found most and least interesting, most problematic, most time-consuming, and which they deemed inappropriate for primary science education. The questionnaire also included an open-ended item allowing students to articulate specific advantages or disadvantages of using the AR method that they personally observed after its application in the biology class, with a request for justification of their responses. While 17 students completed the questionnaire, individual students could provide multiple responses to certain questions, potentially resulting in a total count of answers exceeding the number of respondents.

Table 1

Student interest in the AR method compared to other exploratory methods in teaching biological phenomena

The most popular exploration method	*f*
construction of a stethoscope	7
valve construction	4
heart rate/echo measurement	4
making a "blood cocktail"	2
working with a ball to approximate the work of the heart	1
augmented reality	*1*
reading a comic book	1
The least popular research method	*f*
working with a ball to approximate the work of the heart	2
augmented reality	*1*

Table 1 illustrates that the augmented reality method was not among the most favored exploratory activities in the biology classroom for comprehending the accurate diagnosis of circulatory arrest and the administration of first aid. Only a single student identified this method as their preferred approach among the implemented options. Conversely, the experimental method garnered the highest number of selections as the most favorite activity (n=8). Regarding unpopular exploration methods, the AR method was cited as the least favorite by only one student, who attributed this to the suboptimal performance of the AR application on their mobile phone, describing the 3D object's image as unstable ("the image of the 3D object on the mobile screen jumped around"). Students exhibited a greater interest in the experimental method, which involved hands-on engagement with readily available materials to construct models of the heart or devices for measuring cardiac function (e.g., utilizing a hose and funnel to create a rudimentary stethoscope). These activities were perceived as more engaging due to their lower technical demands and the requirement for greater active participation from the students in setting up the experiments. It is therefore paradoxical that students demonstrated a stronger inclination towards evaluating the task by visualizing the structure of the circulatory, respiratory, and skeletal systems using the AR method, despite the technical challenges encountered, rather than utilizing the standard 3D human body model, which was available as a technically simpler alternative for task completion.

Table 2

Technical difficulty of using the AR method compared to other exploratory methods in teaching biological phenomena

The most technically problematic research method	*f*
augmented reality	*6*
making a "blood cocktail"	5
construction of a stethoscope	4
recognition of heart attack and stroke	1

Table 3

Time intensity of using the AR method compared to other exploratory methods in teaching biological phenomena

The most time-consuming research method	*f*
augmented reality	*4*
reading a comic book	4
construction of a stethoscope	3
listening to the heartbeat with a stethoscope	1
working with the flap	1
spilling a "blood cocktail"	1
heart drawing	1

As a potential explanation for the relatively low popularity of the augmented reality activity, we posit the technical complexities associated with the application's usage and its potentially time-intensive nature within the context of biology instruction. This interpretation is supported by the research findings presented in Table 2 and Table 3, where the AR method emerged as the most frequently selected option when students were asked to rate the technical demands and time consumption associated with each research method. The primary technical challenges encountered by students with the AR application pertained to difficulties in loading the application or reservations stemming from its Android-specific compatibility, necessitating group consensus regarding which member's mobile phone could accommodate the installation. Consequently, students also identified the AR method as the most time-consuming among the evaluated approaches. Therefore, it is advisable to consider replacing personal mobile phones with school-provided tablets in biology lessons employing the AR method. This would allow the teacher to either pre-install the AR applications or ensure students develop familiarity and comfort with the AR application within the technical education curriculum, thereby mitigating technical obstacles during biology instruction.

Table 4

Use of the AR method in primary science education compared to other research methods

Unsuitable activity for primary education	*f*
augmented reality	*6*
making a "blood cocktail"	3
all activities suitable	3
listening to the heartbeat with a stethoscope	2
squeezing the ball to simulate the work of the heart	2
valve construction	1

The augmented reality (AR) method was also frequently identified by students as unsuitable for primary science education, citing technical complexities and organizational challenges (Table 4). Student perspectives indicated that the utility of AR in this context is contingent upon direct teacher control of student application use or its exclusive deployment as a demonstrative tool via interactive whiteboards. Furthermore, two students expressed a preference for replacement of the AR method with static visuals or physical 3D models.

Table 5

Advantages and disadvantages of using the AR method in teaching biological phenomena according to students' statements

Positives of using AR	*f*
detailed depiction of the system structure	8
interesting activity	6
different body size adjustment	1
multiple systems simultaneously	1
Negatives of using AR	*f*
difficult orientation in the application	6
The image often disappeared in the application	6

it was only for android	5
didn't work well, "jumped"	3
poor quality graphics	2
financially demanding	1
time-consuming	1
unsuitable for children	1

Student observations in the biology class highlighted the detailed visualization of individual system structures and the engaging application of augmented reality (AR) for elucidating organ system interrelationships relevant to circulatory arrest diagnosis and lifesaving first aid as positive aspects (Table 5). Conversely, complex application navigation and technical issues with 3D image loading were identified as primary disadvantages (Figure 5). These findings suggest that while modern technologies like AR retain pedagogical appeal for understanding abstract and complex human physiology, careful pedagogical design and prior student familiarization with the application are crucial for effective classroom implementation. Despite detailed teacher preparation, the results underscore the necessity of enhancing students' digital literacy within technical education to facilitate seamless integration of AR into science education and mitigate technical challenges.

3 Discussion

The potential of augmented reality solutions to enhance student motivation in learning complex biological concepts is evident, as they facilitate active student participation in knowledge construction, thereby fostering discovery-based learning (Dreimane & Daniela, 2021). Our research findings corroborate this potential, demonstrating that despite initial challenges in navigating the AR application, students exhibited interest in utilizing a digital tool for a biological task. Notably, all students expressed a preference for this method over the tangible 3D collapsible model of the human body. However, a key finding is that while students display heightened motivation and interest in contemporary digital technologies, their digital literacy may not be commensurately developed, which can inadvertently impede their engagement in the learning process itself. Although all student groups demonstrated a willingness to collaborate on the task using the digital tool, their completion of the task was primarily technical in nature. Analysis of the record sheets revealed that no group focused on the systemic interconnections relevant to accurate diagnosis and first aid for circulatory arrest. This likely stems from the fact that no student group realized the capability to explore the internal structures of organ systems, leading them to prioritize the technical execution of the task over the conceptual understanding of the biological content. This observation aligns with the common issue of students possessing rote memorization of individual organ functions without a robust understanding of the interconnectedness of organ system functionalities. A recognized limitation of many freely available mobile AR applications is their educational value beyond basic visualization. While the graphic fidelity of these applications is advancing, challenges arise when educators need to adapt the content to meet specific educational objectives and cater to the diverse needs of individual students, a point previously highlighted by Bergig et al. (2009). Consequently, many mobile AR applications are primarily utilized by teachers as graphically and technically enhanced visualization aids for understanding anatomical structures, akin to a physical 3D model. However, our research findings support the notion that students often cannot effectively utilize AR applications with anatomical content for independent study. The students in our study only grasped the application of mobile AR technology for explaining the correct diagnosis of circulatory system dysfunction and the administration of appropriate first aid after direct teacher explanation and contextualization within the augmented reality environment.

The technical quality of mobile AR applications exerts a significant positive influence on their perceived usefulness and ease of use, a relationship reported by Stojšić et al. (2022) in their study on the interest in this method among secondary and primary school students. The conclusions of our research echo this finding. In our study, students reported difficulties in working with the specific AR application employed. Their primary challenges involved loading the application, which necessitated maintaining a precise spatial relationship between the marker and the mobile phone to render the 3D model of the human body within the augmented reality space. The relatively lower level of digital skills observed among our student participants likely contributed to these difficulties and may also correlate with their lower engagement in the process of learning biological content and a comparatively lower interest in this method compared to other instructional approaches utilized in biology classes, particularly experimental methods.

As prospective teachers, the students expressed positive opinions regarding augmented reality activities, specifically citing the concretization of abstract concepts through detailed visualization, the ability to manipulate organ size in virtual space, and the depiction of systemic interconnectedness, consistent with the findings of Yapıcı and Karakoyun (2021). However, the technical complexity of its use was the most frequently cited reason why students would be hesitant to implement this method in their own primary education pedagogical practice or would only do so in a modified format (e.g., utilizing school-provided tablets, implementing teacher-led checks of student work, or employing it solely as a demonstrative tool via an interactive whiteboard). We recommend AR applications as a valuable supplementary tool for teaching intricate biological relationships, particularly because physical 3D models often do not provide visualization of specific systems in combination after disassembly. Nevertheless, it is imperative to ensure that students possess a sufficient level of digital literacy and are well-acquainted with the AR method prior to its implementation in biology lessons. Therefore, the integration of activities involving AR applications into the technical education curriculum, even before the commencement of biology lessons utilizing augmented reality technology, is a prudent pedagogical strategy.

Conclusion

The findings of our study affirmed the students' interest in digital technologies, as evidenced by their preference for the AR method over a tangible 3D model of the human body for evaluating a biological task, despite initial difficulties in manipulating the AR object. However, when presented with a range of engaging research methods, the AR method was not rated as the most popular among the students. The primary reasons cited were its technical demands and time-consuming nature, leading some students to express reluctance to use the AR method in their primary education pedagogical practice, or only under close teacher supervision. While the potential of the AR method to enhance student interest in learning complex and abstract biological topics is evident, mitigating its technical complexities in biology lessons necessitates improving students' digital literacy within technical education. Nevertheless, it is crucial to acknowledge that the BYOD (bring your own device) model remains the sole avenue for many schools and teachers to integrate certain digital innovations into their teaching practice (Atanasković et al., 2022). Consequently, freely available mobile AR applications appear to be a financially accessible option for schools. Conversely, the rapid evolution of technology does not guarantee the long-term usability of a specific application for successive academic years. This raises the question of whether investing in a stable AR application might be a more appropriate strategy from the perspective of teaching quality, thereby reducing the technical preparation burden on educators.

Acknowledgements

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References

Anatomy AR: A view of the human body in real life. (2022). Retrieved from https://play.google.com/store/apps/details?id=com.ChutoEskills.ARAnatomy

Atanasković, M., Stojšić, I., Stanisavljević, L., & Stanisavljević, J. (2022). Stavovi učenika o primeni digitalnog kviza u nastavi biologije u srednjoj školi. *Pedagoška stvarnost, 68*(1), 48-63. https://doi.org/10.19090/ps.2022.1.48-63

Bergig, O., Hagbi, N., El-Sana, J., & Billinghurst, M. (2009). In-place 3D sketching for *authoring* and augmenting mechanical systems. In *8th IEEE international symposium on mixed and augmented reality* (pp. 87-94). ISMAR: Orlando.

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.

Dreimane, S., & Daniela, L. (2021). Educational potential of augmented reality mobile applications for learning the anatomy of the human body. *Technology, Knowledge and Learning, 26,* 763-788. https://doi.org/10.1007/s10758-020-09461-7

Fuchsova, M., & Korenova, L. (2019). Visualisation in basic science and engineering education of future primary school teachers in human biology education using augmented reality. *European Journal of Contemporary Education*, *8*(1), 92-102. https://doi.org/10.13187/ejced.2019.1.92\

Fuchsova, M., Adamkova, M., & Pirháčova Lapšanska, M. (2020). *Uses of Augmented Reality in Biology Education. Augmented Reality in Educational Settings.* Leiden: Brill. Retrieved from https://brill.com/display/book/edcoll/9789004408845/BP000017.xml

Fortuna, A., Waskito, Purwantono, Kurniawan, A. R., Andriani, W., & Alimin, M. (2023). Designing learning media using augmented reality for engineering mechanics course. *Journal of Engineering Researcher and Lecturer, 2*(1), 18-27. https://doi.org/10.58712/jerel.v2i1.20

Permana, T. I., Husamah, H., Nurhamdani, M. I., Zaskia, A., Savitri, A., & Salsabila, D. A. (2024). Augmented reality in biology education: A systematic literature review. *Research and Development in Education (RaDEn), 4*(1), 630-652. https://doi.org/10.22219/raden.v4i1.32636

Safadel, P., & White, D. (2019). Facilitating molecular biology teaching by using augmented reality (AR) and protein data bank (PDB). *Techtrends*, *63*(2), 188-193. https://doi.org/10.1007/S11528-018-0343-0

Stojšić, I., Ostojić. N., & Stanisavljevic, J. D. (2022). Students' acceptance of mobile augmented reality applications in primary and secondary biology education, *International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE), 10*(3), 129-138. Retrieved fro https://www.ijcrsee.com/index.php/ijcrsee/article/view/1968

Wang, X.-M., Hu, Q., Hwang, G.-J., & Yu, X. (2022). Learning with digital technology-facilitated empathy: An augmented reality approach to enhancing students' flow experience, motivation, and achievement in a biology program. *Interactive Learning Environments*, 1-17. https://doi.org/10.1080/10494820.2022.2057549

Weng, C., Otanga, S., Christianto, S. M., & Chu, R. J. (2020). Enhancing students' biology learning by using augmented reality as a learning supplement. *Journal of*

Educational Computing Research, 58(4), 747-770. https://doi.org/10.1177/0735633119884213

Yapıcı, İ. Ü. & Karakoyun, F. (2021). Using augmented reality in biology teaching. *Malaysian Online Journal of Educational Technology, 9*(3), 40-51. http://dx.doi.org/10.52380/mojet.2021.9.3.286