Full research paper

MOBILE AUGMENTED REALITY IN BIOLOGICAL EDUCATION: PERCEPTIONS OF AUSTRIAN SECONDARY SCHOOL TEACHERS

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ABSTRACT

Today's teachers play a critical role in preparing students for the integration of educational technologies, such as augmented reality (AR), into their lessons. It is thought that AR implementation improves collaboration, motivation, and learning outcomes. Considering this, this study aims to determine the teachers' perceptions of the benefits and obstacles of employing mobile AR applications (mAR) in their biology education, along with suggestions for practice, app developers, and policymakers. Therefore, a mixed-methods study was used to examine Austrian secondary school biology teachers' opinions. A questionnaire containing open-ended and closed-ended questions was distributed to 35 teachers. Descriptive statistics were employed to process quantitative data, whereas grounded theory was utilized to process qualitative data. According to the findings, biology teachers likely utilize mAR apps to teach about human anatomy or to identify living things (e.g., plant determination). According to the teachers, mAR can improve students' learning outcomes, motivation, and collaboration, and further their enthusiasm for learning biology. The main obstacles that teachers encounter whilst integrating mAR into their lessons are lack of technical devices, Internet issues, inconsistency with the curriculum, and questionable scientific accuracy of information. Despite the promising results, additional future studies with larger sample sizes are needed.

KEYWORDS

Augmented reality, biology, mobile learning, secondary school, education, STEM

HOW TO CITE

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Highlights

- *Implementation of mAR apps in biology education is perceived by the surveyed teachers as innovative and increases enjoyment, collaboration, interest, and learning success.*
- *Main obstacles mentioned are a lack of devices, limited Internet connections, erroneous information, and a missing link between mAR apps and curriculum.*
- *The teachers need guidelines on where and how to find suitable mAR, and how to use the apps in their biology education.*
- *Further research with a larger sample size needs to stress this topic in the future.*

INTRODUCTION

Nowadays, teachers are responsible for introducing the latest technologies to their students, if it is possible at their school location, due to the digitization process. Therefore, digital technologies and methods in education have steadily gained an inherent role in recent years (Fernandez, 2017). According to a study by Tobinski and Cyra (2021), more than 90% of today's teachers are using digital educational applications in Germany to prepare lessons, and another 88% also include them in the classroom on a regular basis. So far, a substantial body of literature on digital educational technologies has shown that these technological innovations have the potential to improve learning processes, increase students' motivation, and promote engagement in the classroom (Saidin et al., 2015; Shapley et al., 2011). In this context, virtual (VR) and augmented reality (AR) have received considerable research attention in the last few years as two particularly promising examples of digital education. VR and AR are referring to modern technological devices that allow users to interact with video, pictures, music, and three-dimensional (3D) objects (Karacan and Akoglu, 2021). Despite their similarity in terms of names and functions, there are several important differences between VR and AR. Whereas VR enables us to immerse in an artificial environment, AR enhances reality rather than replacing it, by allowing users to perceive the actual environment with virtual elements overlaid on or composited with it (Elmqaddem, 2019; Jang et al., 2021). Further, VR accomplishes visual interactions by a head-mounted display, which can be either an independent device or one that is tethered to a computer that powers the visualisation gear (Barrow et al., 2019). By contrast, AR technology involves the three-dimensional (3D) arrangement of four separate elements in the actual world: a camera, computer infrastructure, a marker, and the real environment (Arena et al., 2022). Also, AR is a technique that involves the appearance of four-dimensional (4D) items designed on a developer's goal image, output, or materials and creates the illusion that the object is on said elements, therefore, enhancing existing reality by adding virtual components to it (Omurtak and Zeybek, 2022). Due to the broad adoption of AR technology over the last decades, requirements for expensive hardware and complex machinery (like head-mounted displays) have significantly decreased (Godoy, 2021). Furthermore, with the current use of mobile smartphone technology and the utilization of various applications, augmented reality has become widely available to use and function (Jumani et al., 2022).

Benefits in Educational Settings

Over the last few years, an increased interest in technologies such as VR and AR has emerged in the educational field (Ibáñez et al., 2018), especially in AR. Ke and Hsu (2015), for example, posed the question of whether the introduction of AR applications on smartphones would positively impact prospective teachers' learning processes. Their results indicated that AR could increase not just participants' conceptual comprehension and knowledge, but also further key abilities such as problem-solving, cooperation, and communication. Similarly, Akçayr and Akçayr (2017), who analyzed research mostly from kindergarten to 12th grade (K-12) settings, characterized increased accomplishment, motivation, and enjoyment as the primary benefits of utilizing AR. However, one of the most significant advantages of AR seems to lie in its capabilities to enable 3D learning settings that allow students to accomplish more than they would be able to do in the classroom context and, in addition, help them develop unique skills by allowing a more interactive environment (Celik et al., 2020).

Benefits in STEM Education

Especially in the fields of science, technology, engineering, and mathematics (STEM), teachers are often confronted with various issues such as expensive or insufficient laboratory facilities, equipment errors, and difficulties recreating experimental settings (Godoy, 2021). AR seems to address these problems not only through its easy and cost-saving applicability or its intrinsic interactivity between the physical and the virtual world but also through its potential to improve students' understanding and knowledge at the same time (Restivo et al., 2014; Hsu et al., 2017). For instance, Petrov and Atanasova (2020) found that the use of AR tools significantly improves students' grasp of the subject matter at the secondary school level. Likewise, Wahyu et al. (2020) demonstrated that AR-assisted learning could lead to superior students' science literacy as well as science learning achievements compared to conventional learning strategies. In addition, Ajit et al. (2021), who have conducted an extensive discussion of the existing literature on the advantages and disadvantages of using augmented reality in STEM, argue that AR significantly improves conceptual understanding, learning outcomes, collaboration skills, and student engagement. Another major benefit of using AR in STEM fields seems to lie in its ability to increase students' interest and motivation in those subjects. Rarely, as some teachers are looking for innovative instructional methods to solve fundamental issues related to students' motivation and engagement, current research appears to support the notion that the use of various AR-based applications could contribute to the solution of this problem (Mystakidis et al., 2022). As an example, Hsu et al. (2017) demonstrated in their study on high school students that AR-enhanced lessons with a medical task profile could both increase students' motivation and act as an inspiration for a future STEM-oriented career. This finding is also congruent with a recent study by Dakeev et al. in 2021, who examined the effects of AR-based lessons during an intervention study with primary school students. Their results showed that incorporating AR tools into STEM lessons increased students' enthusiasm for learning, interactions between the students, as well as their engagement in the classroom.

Benefits in Biology Education

According to Saidin et al. (2015), AR is viewed as one of the technologies that has a lot of promise in life science education, especially when it comes to visualizing abstract concepts. In this sense, teaching biology seems to be particularly challenging because the concepts that make up scientific knowledge in this area are often abstract and unfamiliar to students, and the links between the concepts are complex (Celik et al., 2020). In accordance with another study by Fuchsova and Korenova (2019), AR technology assists in understanding difficult subjects regarding biological teaching topics (e.g., human anatomy). Further, Bogomolova et al. (2020) demonstrated that students with limited visual-spatial ability may benefit from 3D anatomical models which are viewed stereoscopically in AR. Likewise, the findings of Yapıcı and Karakoyun (2021) indicate that AR activities could lead to a better understanding of abstract concepts in biology classes. Lastly, Celik et al. (2020), who analyzed the effects of AR implementation on laboratory learning in pre-service teachers, concluded that AR facilitates concept understanding regarding biological topics (e.g., anatomic construction of the heart). Additionally, by using AR in their biology lesson, the authors also noticed a favorable change in the learning environment, which was considered a result of increased student engagement and motivation. Given these potential positive effects that AR may offer to education, it seems critical to raise awareness among teachers to incorporate them into their (science) lessons (Jang et al. 2021). Fortunately, a considerable amount of research on the use of VR and AR-based applications and mobile augmented reality (mAR), and further, the attitudes of teachers towards it in biology lessons have emerged over recent years. Unsurprisingly, current empirical evidence appears to confirm the notion that teachers increasingly view AR and VR as promising teaching methods in biology classes (Çakır et al., 2021; Kalana et al., 2020). For instance, Tan and Waugh (2013), who conducted a study on the use of a VR-based technology for molecular biology in secondary schools, showed that the introduction of additional digital resources was generally well-received by most teachers. This view is supported by Garcia-Bonete et al. (2019) who argue that VR- and AR-enhanced learning is positively associated with biology students at the University of Gothenburg. In addition, the authors showed that participants rated the implementation of VR and AR as advisable in a range of instruction-related content. In the same vein, a recent study by Çakır et al. (2021) on thirty-one pre-service biology teachers demonstrated that interest in technology was positively affected by AR applications incorporated over the duration of the investigation. Moreover, when asked about a potential future implementation, 93% of the participants responded that they would also like to use AR-based technology in their teaching later. Also, participants cited ease of use, visual support, and the ability to improve student attention and learning during lessons as the main reasons for future use.

Disadvantages and Limitations in Educational Settings and STEM

Apart from the advantages, current research also seems to frequently highlight possible limitations regarding the use of AR in educational settings (Akçayır and Akçayır, 2017). Common issues include technical difficulties (e.g., poor Internet connection, glitches), interfered student interactions, vision problems, necessitating technical hardware, and teachers' lack of technological competency (Uluyol and Eryılmaz, 2014; Yapıcı and Karakoyun, 2021). Other disadvantages include marker detection problems, insufficient device usability, and high acquisition costs (Ajit et al., 2021). To address these issues, Osadchyi et al. (2021) argue that the utilization of AR in STEM fields is required to form accessible three sorts of resources: 1) Adequate digital educational resources, 2) Quality control over educational content, and 3) Specialized content creators and trained teachers.

Regarding appropriate digital educational resources and quality assurance, it is also important to develop guidelines for the material and content development, at school or for the application itself. Further, for the utilization of the mAR apps, a quality-assurance strategy is needed, such as a "certification process", as there has been for educational applications (learning apps) in Austria since 2021. The "seal of quality" for learning apps, introduced by the Austrian Federal Ministry of Education, Science, and Research, is a proof of quality for learning apps that have gone through a new standardized state evaluation and certification process (Federal Ministry of Education, Science, and Research, 2021; Agency for Education and Internationalization, 2021). However, no certified learning apps with AR features in Austria for the subject "biology" are still available (Agency for Education and Internationalization, 2021).

Besides quality control, mAR applications need specialized content creators, ideally biologists, and trained teachers for all school types who can use mAR correctly in the classroom.

Efficiency and Responsibility in Austrian Biology Education

The utilization of new technologies such as mAR in Austrian biology lessons is essential for several reasons. Firstly, the implementation of educational applications and other new technologies (e.g., AR) into biology education was specified and required by the Austrian Federal Ministry of Education, Science, and Research. The use of modern and new technologies is anchored in the curriculum of secondary schools (Federal Ministry of Education, Science, and Research, 2019). The guiding principles of the general educational goal state: 'The education and training process takes place against the background of rapid social changes, particularly in the areas […] of science, demography, business, technology, the environment, and law. […] Innovative technologies of information and communication as well as the mass media are increasingly penetrating all areas of life. Multimedia and telecommunications have become determining factors for the evolving information society. […] In order to promote digital competence, these developments must be considered in the context of teaching, and the didactic potential of information technologies must be harnessed while at the same time critically and rationally examining their mechanisms of action in business and society. The creation of independent work using information technology is to be encouraged to an age-appropriate extent'. Furthermore, the utilization can be found in the areas of responsibility of the school, such as strengthening self-reliance and personal responsibility, and in the creation of references to the pupils' everyday life: 'The materials and media used in the lessons have to be as up-to-date and clear as possible, to encourage active participation of the students. […] New technologies are becoming increasingly important, […] [and the] creation of independent work using information technology is to be encouraged' (Federal Ministry of Education, Science, and Research, 2019). Therefore, Austrian biology teachers need to employ the latest technologies, which include mobile AR applications, in their classes to fulfill the general Austrian educational goal. Further, the teachers are encouraged to educate their students to use them in a careful and critical way. Moreover, the students are learning through the example of the teacher the efficient and meaningful employment of mAR in school or in self-study. Furthermore, regarding the disadvantages of smartphone use and mobile learning (Uluyol and Eryılmaz, 2014; Ajit et al., 2021; Yapıcı and Karakoyun, 2021) with the assistance and guidance of their teachers, students can possibly use mAR or other mobile applications in a responsible and safe way in biology education.

METHODOLOGY

Research Aim and Design

Despite all these above-mentioned positive findings regarding AR, the vast majority of work in this area has focused on potential effects that seem to lead to improvements in student learning, motivation, and engagement. However, comparatively few attempts have been made to investigate the motivational and methodological background of AR and mAR apps utilization from the teachers' perspective, especially in biological education. With the aim to examine Austrian biology teachers' perceptions of mAR apps, a mixed-methods research design was employed. For this purpose, the following research questions addressed in this paper are

a) *Why are teachers using mAR apps in biology classes?*

b) *In what part of the lessons are mAR apps used?* and

c) *What barriers and suggestions for improvement are expressed regarding the use of mAR?*

Therefore, in September 2021, an online survey for in-service Austrian biology teachers explored which mAR apps teachers use in their classrooms on a regular basis. Results of the first online survey were that the most frequently used apps are the following: *Insight Heart*, *Anatomy 3D Atlas*, *Seek by iNaturalist*, and *Atlas der Humananatomie (Visible Body)*. After the data collection, another questionnaire with closed-ended and open-ended questions was designed and sent to biology teachers.

Sample

The participants of the research were included by using the purposive sampling approach. Purposive sampling is recommended for educational research that aims to examine a certain phenomenon, opinion, attitude, or concept among a specific group of participants (Cohen et al, 2002). The primary requirements for including teachers in this study were that they are in-service biology teachers in Austria and have some experience using mAR in their teaching. The online questionnaire was sent to six different higher and lower secondary schools in Upper Austria (two middle schools (MS), two general secondary schools (AHS), and two vocational higher and middle schools (BHMS)) and was additionally posted in an Austrian-wide online forum on social media for in-service and pre-service biology teachers. Thirty-five (27 female, 8 male) biology teachers) participated in this research. The participants were from all parts of Austria and did not collaborate with the research team beforehand in previous studies. The teachers were mainly female (77.1%) with an average age of 31.7 years. The majority were between 22 and 37 years old, only five teachers were older than 56.

Questionnaire Design

The questionnaire contained five open-ended and fourteen closed-ended questions (as seen in *Appendix 1*). During the development of the methodology for the collection and processing of monitoring data, the methodology that was used and recommended in previous similar studies was used (Anđić, et al., 2018; Mikropoulos et al., 2003). Four of the closed-ended questions were multiple-choice, and ten could be answered via a 5-point Likert Scale, in order to capture and compare the different teachers' opinions on mAR. The teachers indicated which mAR apps they have already used or are currently using. Further, the teachers had to delineate their frequency of utilization. Onwards, the teachers had to rate the various statements regarding students' motivation, collaboration, exams, interest in science, and in addition, learning ability, support, and preference. After the assessment of the statements, the teachers had to depict what they particularly like about using mAR. Furthermore, they had to give a description of how and in which part of the learning unit mAR applications can be used in a creative and innovative way. Lastly, the teachers had to display possible problems and issues with mAR, and describe what may be improved in the future, to implement those applications safely and in a correct manner into biology lessons to teach the required curriculum. The questionnaire used in this research contained more closed and some open questions, and the reason for this survey design is twofold. First, when creating the questionnaire, we followed the suggestions of previous research (Anđić, et al., 2018; Anđić, et al., 2021; Anđić, et al., 2022; İpek et al., 2020; Mikropoulos et al., 2003) which dealt with the application of different digital technologies in biology education. Another reason for this kind of questionnaire design is that participants who complete an online survey are more willing to answer closed-ended questions than open-ended questions because they are less time-consuming and require less commitment (Zhou et al., 2017; Fan and Yan, 2010). In this way, the authors tried to ensure a higher response rate.

Data Collection and Processing

The data collection took place from 1st December 2021 to 21st February 2022 via an online survey on Google Forms. The quantitative data, collected in an Excel sheet, were processed using descriptive statistics (using the program SPSS), as it is recommended in previous similar research (Anđić et al., 2018; Mikropoulos et al., 2003). The grounded theory was employed for processing the qualitative data. Each of the three authors participating in this study independently read and reread the answers to the open-ended questions before coding the data. This coding procedure used grounded theory (Strauss and Corbin, 1990). The open coding was done manually. The codes' frequency served as the standard for acceptance or rejection. The creation of subcategories, categories, and themes was then conducted using the constant comparative technique (Strauss and Corbin, 1990). The authors in this study assigned the codes to distinct subcategories, topics, and themes. The degree of agreement between the fundamental codes, as well as the placement of the codes inside subcategories, categories, and themes, were used by the researchers to assess the dependability of the codes and the accuracy and precision of the coding. This approach to analyzing data in research related to biological and scientific education has been recommended by previous research (Anđić et al., 2021; Maloney, 2005; Bahng and Lee, 2017).

RESULTS

Results of the Quantitative Data

Quantitative data in this study indicate that mAR can be used for the promotion of natural sciences and scientific principles among secondary school students. Summarizing the data, according to the opinions of the teachers about mAR, the app brings a double benefit in teaching biology. Firstly, the impact on students' knowledge, and secondly, the contribution to students' motivation to acquire new biological knowledge. The results of the quantitative evaluation are described in more detail and shown in *Figures 1-4*.

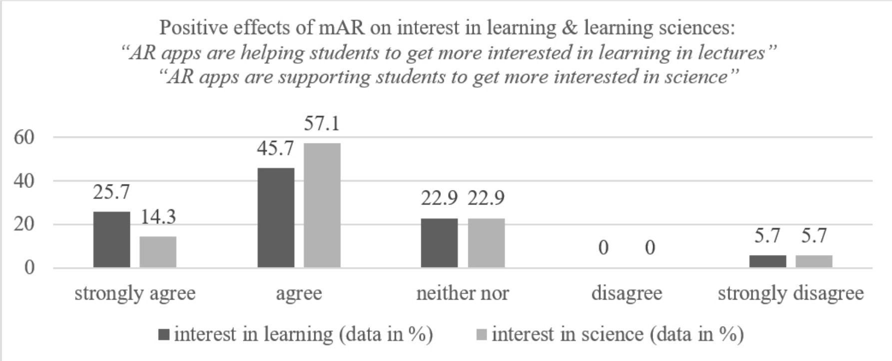

Figure 1: Teachers' opinions about the positive contribution of mAR to the students' interests in learning and learning science-oriented content

Most of the teachers who participated in this research chose the option *I agree* (57.1%) or *completely agree* (14.3%) that mAR positively influences students' interests in learning science-related content, as shown in *figure 1*. Only 5.7% of teachers expressed full disagreement with this statement. In addition, 71.4% of all teachers agreed or strongly agreed that mAR helps students to increase their learning interest in their lessons. Also, only 5.7% fully disagreed with this statement.

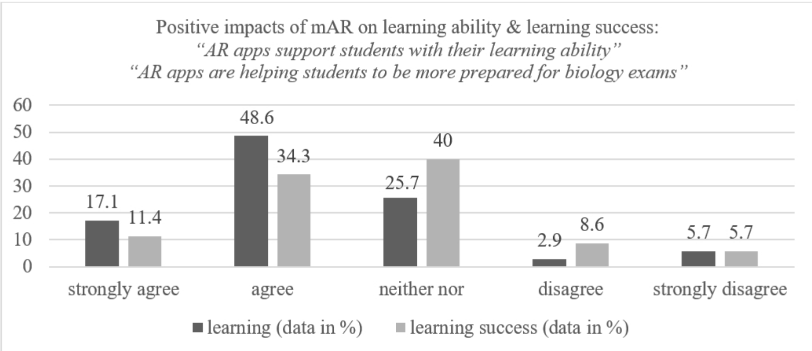

Figure 2: Teachers' opinions about the positive impact of mAR on students' learning success in science

As could be seen from *figure 2*, most of the teachers had a positive opinion about the contribution of mAR to students' learning success (45.7%). However, a significant number of teachers (40%) were indecisive (neither option *agree* nor *disagree*) about the contribution of mAR to the students' learning success. Furthermore, most teachers (65.7%) think that mAR positively affects their learning because students prefer to learn with their smartphones compared to a textbook. 25.7% were indecisive and only 8.6% disagreed.

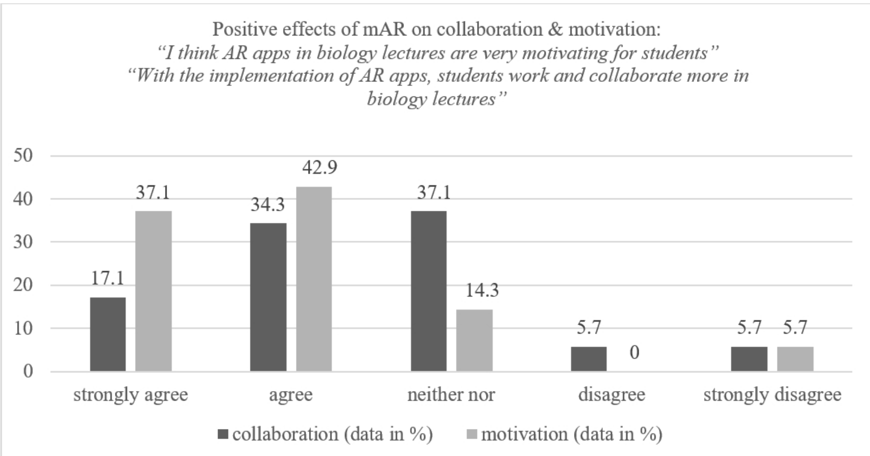

Figure 3: Teachers' opinions about the positive effects of mAR on students' motivation and collaboration in biology lessons

The surveyed teachers mostly agreed that mAR positively affects students' motivation to learn science and collaborate with their peers in this learning process. Only 14.3% of the teachers were hesitant or disagreed with the statement that mAR positively affects students' motivation to learn science and collaborate with their peers in the learning process, as shown in *Figure 3*.

Concerning the teachers' opinions on the most important characteristics that mAR offers in biology teaching, the results are presented in *Figure 4*. Findings indicate that the majority of the teachers (71.4%) thought that the most important contribution of using mAR in biology teaching is creativity in the lesson structure and the learning unit's design. Another important feature that mAR brings into the teaching of biology according to a large number of teachers (65.7%) is to increase the visualization of teaching content, innovation in teaching, and enables learning with the use of smartphones. Teachers felt that the following features of mAR applications were also important for teaching: creating a sense of enjoyment in learning (62.9%), enabling learning that is independent of time and place (40%), free availability (37.1%), and furthermore, that the content is provided quickly (34.3%), and user-friendly (34.3%).

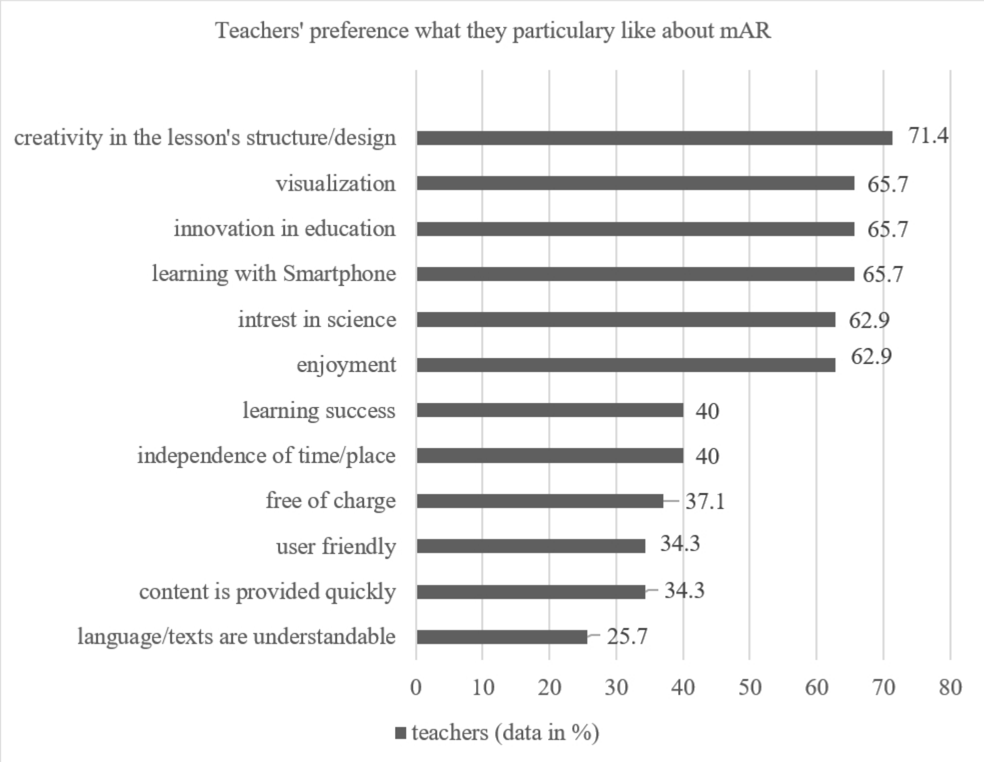

Figure 4: Teachers' opinions on the most important characteristics that mAR offers in biology teaching

Results of the Qualitative Data

The data obtained in this research are classified within 254 codes, 11 sub-categories, and 2 core phenomena (*Challenges* and *Potentials)* and 4 core consequences (*"I need…", "I do…", I create…", and "I can…").* In order to ensure the validity of the obtained data, the degree of agreement in the distribution of codes into categories and themes was calculated between members of the research team, as well as between members of the research team and external experts in the field of STEAM qualitative research. Krippendorff (2013), Bowers (2019), and Miles et. (2014) suggest using this method to check the validity and reliability of qualitative data. The concordance in the classification of codes in categories and themes among the members of the research team was 90%, while the concordance between the members of the research team and external experts in STEM education research methods was 84%. These data indicate that the results obtained are valid.

From the coding of the participating educators in this study regarding mAR, the authors developed a grounded theory-based model "The Perceptions of mAR in Biological Education" for secondary school biology teachers in Austria (as shown in *Figure 5*). The developed model incorporates the main components of a grounded theory: *strategies* (selected learning and teaching strategies and their impact), *core phenomena* (challenges and potentials regarding mAR, its impact, and consequences regarding students' and educators' teaching process, content, and competencies), *contextual* and *intervening conditions* (participant characteristics, subject "biology") (Corbin and Strauss, 2015). Bowers (2019), used a similar model to present his qualitative results in his dissertation. With this study, the codes of the consequences according to the teachers for themselves, their subject/lessons, and their students were additionally evaluated and rated according to a "positive" (green colors) or "negative" (red color) influence or conditions.

In the following the findings of the two core phenomena and their four consequences, based on grounded theory (Corbin and Strauss, 2015), are further described in more detail and are shown in *Figures 6-9*. The core phenomenon *"Potentials"* includes all the stated and rated benefits of mAR in relation to the teaching/learning process *(I do: Impact of mAR on the learning and teaching process)*, the biological content learned and taught *(I create: Impact of mAR on the learning and teaching content),* and also the competencies acquired *(I can: Impact of mAR to the development of students and* *teachers' skills and competencies).* Furthermore, the core phenomenon *"Challenges"* describes all the issues, barriers, limitations, and problems related to mAR in biology lessons (e.g., technical requirements) that the teachers reported (I need: *Barriers to the use of mAR in learning and teaching*). Within each of these four consequences, additional subcategories are described, as well as examples, and frequencies of codes from teachers' narratives. The bubbles are linked, and colors are also adjusted depending on whether the codes/subcategories are more relevant to students or teachers, or both. The codes are shown as bubbles. According to the frequency of mentions, they are either larger or smaller. Also, they are related/overlap when related (e.g., outdoor learning can be done as homework, as shown in Figure 6).

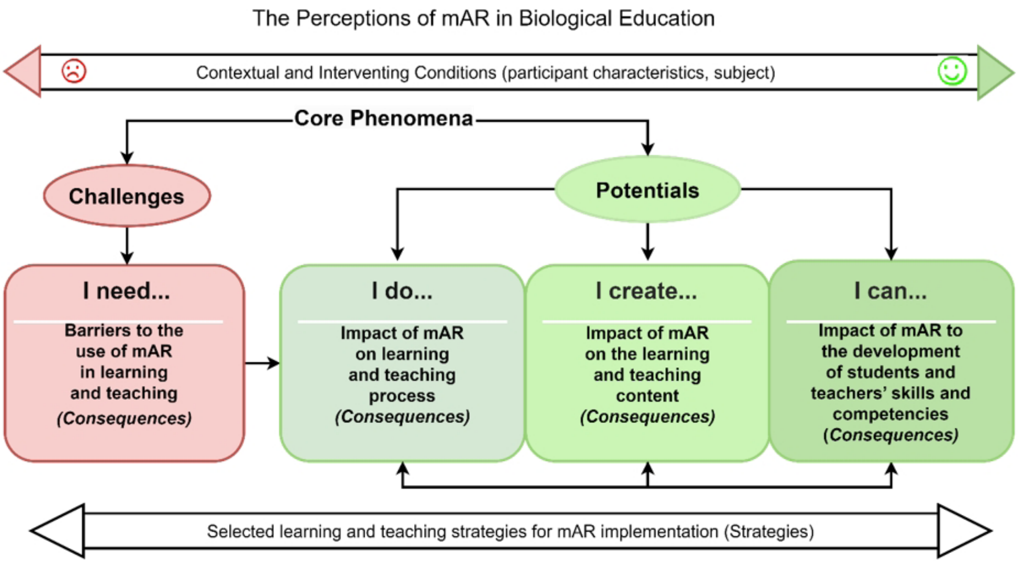

Figure 5: The Perceptions of mAR in biological education. A grounded theory-based model for secondary school biology teachers in Austria (Corbin and Strauss, 2015)

What is interesting about this data is that teachers who participated in the study considered that the implementation of mAR can contribute to both the teaching and learning process as well as to the students' and teachers' digital skills. Qualitative results indicate that the application of mAR improves students' learning activities as well as contributes to teachers' ability to better organize teaching. Further analysis showed that mAR improves the presentation and visualization of teaching content, which is very important in science education, but of particular importance for biological education. However, the qualitative data also revealed very significant obstacles that teachers face when using mAR in teaching. Among these are the lack of resources and the sometimes surprisingly questionable teaching content shown in the described applications, as well as the connection of the content with the teaching curriculum.

Impact of mAR on Learning and Teaching Process (I Do)

This topic includes teachers' opinions on the use of mAR applications as teaching media to improve learning and teaching. Most teachers felt that mAR could contribute to teaching and learning processes. Within this topic, four subcategories have been made: *development of student activities and tasks*, *support in the organization of classes*, *teaching approaches and methodology of teaching*, and *student motivation*. Examples of codes and their frequencies (*f*) per participant, as well as their classification in these categories within this theme, are shown in *Figure 6*.

The teachers believe that mAR teaching materials are very suitable for the '*Development of student activities and tasks*'. In this category, the code with the highest frequency is '*Determination of living beings*' (*f* = 22). Teachers believe that mAR can be utilized very successfully in student activities that involve the determination of living things, fungi, plants, and animals. (Respondent 1, male teacher, 31: '*Students can use mAR for determination exercises*'.)

Teachers generally had a very positive opinion when it comes to the application of mAR for the determination of organisms from their environment.

In addition to this activity, many teachers believe that these applications can be successfully used for the realization of students' homework, fieldwork of students in the field of biology, as well as for the exchange of ideas-brainstorming. The category '*Support in the organization of classes*' includes codes used by teachers to describe the application of mAR applications in the organization of honor. Most teachers believe that mAR can be used very successfully in the main part of the class (f = 13), while a significant number of teachers believe that these applications can be used in any part of the class. However, it was also emphasized in this research, that the successful implementation of mAR depends on the respective teachers and their (mobile) abilities: Respondent 2: female teacher, 23: '*In theory, AR can be used everywhere in the lecture, but its utilization always depends on the teacher herself, and how she uses it*'.

The category '*Teaching approaches and methodology of teaching*' includes codes by which teachers have described the teaching methods and approaches used in the application of mAR. As can be deduced from *table 1*, the largest number of teachers consider that these applications are suitable for

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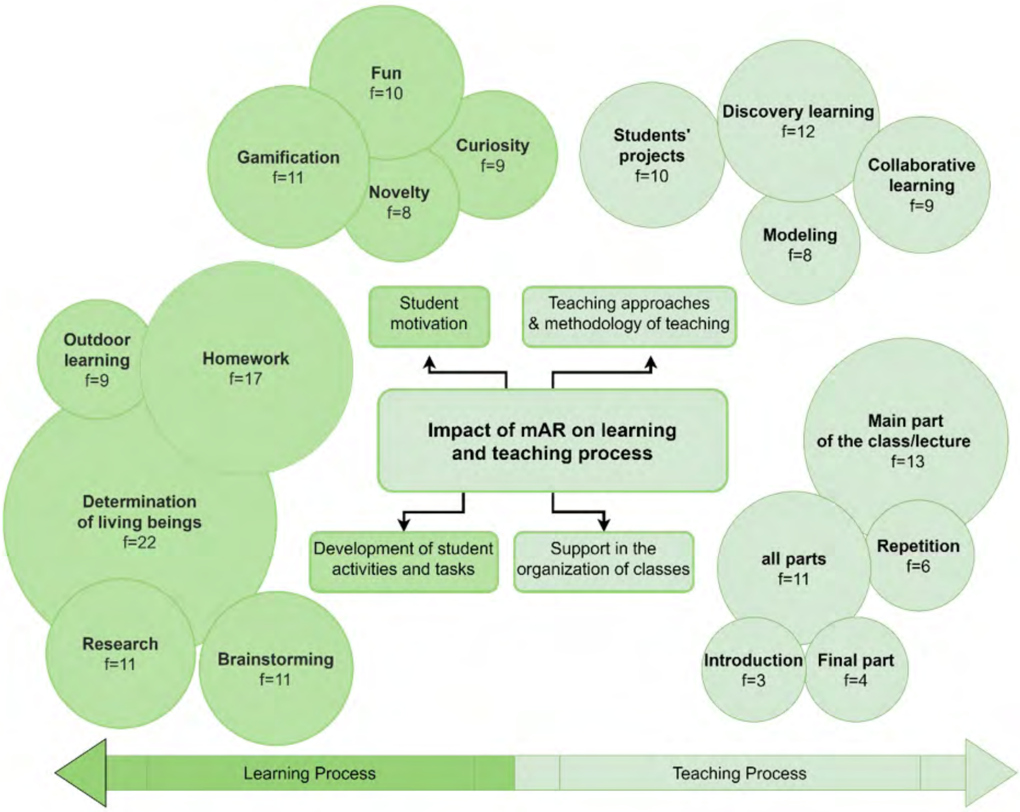

Figure 6: Example of codes within the core phenomenon "Potentials" impact of mAR on learning and teaching process (I do). The frequency per participant is shown in a bubble (larger/smaller according to the frequency of mention), and the subcategory in which they are classified are given

discovery learning (*f* = 12) (e.g., fieldwork), then students' project approach (*f* = 10) (e.g., leaf collection), but also collaborative learning (*f* = 8), and modeling (*f* = 8).

Impact of mAR on the learning and teaching content (I create)

Within this theme are classified codes by which teachers described the use of mAR applications to display teaching content or parts thereof. Two categories have been developed, namely: *presentation of teaching content to students* and *the development of materials by students*, as shown in *Table 2*.
The '*presentation of teaching content to students*' category includes those codes by which teachers have expressed their opinion on how mAR can be employed to present teaching content to students. The code with the highest frequency in this category is '*the vividness of the illustrations*' (*f* = 13), with which teachers expressed their opinion that these applications are particularly useful for a clearer and better presentation of teaching content than two-dimensional photographs. (Respondent 3, male teacher, 31: '*You can use mobile AR for the illustration of the content*'.)
The teachers believed that mAR provides the possibility of better presentation of teaching contents in biology, improving their attractive and more interesting appearance.
Visual representation of anatomical structures (*f* = 12) also stands out with its frequency and indicates the opinion of teachers that mAR applications are very useful for presenting teaching content in anatomy and morphology. Teachers also thought that mAR was useful for depicting different types of organisms, such as plants, animals, fungi, etc., but also for presenting processes in biology teaching. Teachers who participated in this research expressed their opinion that mAR can also be used as teaching media for the development of materials by students. Thus, for example, teachers felt that students could consciously use these applications for map and schema development (*f* = 5) or for the modeling process (*f* = 7).

Impact of mAR to the development of students' and teachers' skills and competencies (I can)

This topic includes teachers' opinions on the contribution of mAR applications to the skills of teachers and students. Teachers are of the opinion that the utilization of mAR applications contributes to students' digital skills (*category 1*) and teachers' digital skills (*category 2*). Examples of codes and their frequencies per participant and their classification in these categories within this theme are shown in *Table 3*.
As can be seen from Image, the teachers who participated in this research believe that the application of mAR applications contributes to students' skills to use smartphones for educational purposes (*f* = 9) and contributes to their digital skills (*f* = 8), as well as safe Internet utilization (*f* = 7). Teachers also felt that these applications contribute to teachers' abilities to use smartphones in teaching (*f* = 9) but also contribute to the development of their digital skills (*f* = 7).
Respondent 4, female teacher: '*You can use the AR apps to increase the fun of learning and teaching, for creative new lessons, and for a safe use of smartphones in the classroom*'.
As can be seen, the opinion of the teachers from this category

is not oriented towards the teaching content, but rather towards the achievements of the students and the learning outcomes that the students achieve with the application of MAR in learning. It is very interesting that teachers indicate the skills that students acquire by applying mAR in biology classes, which contribute to their digital skills. Teachers also experienced that applying mAR in teaching contributes to developing their digital skills and abilities.

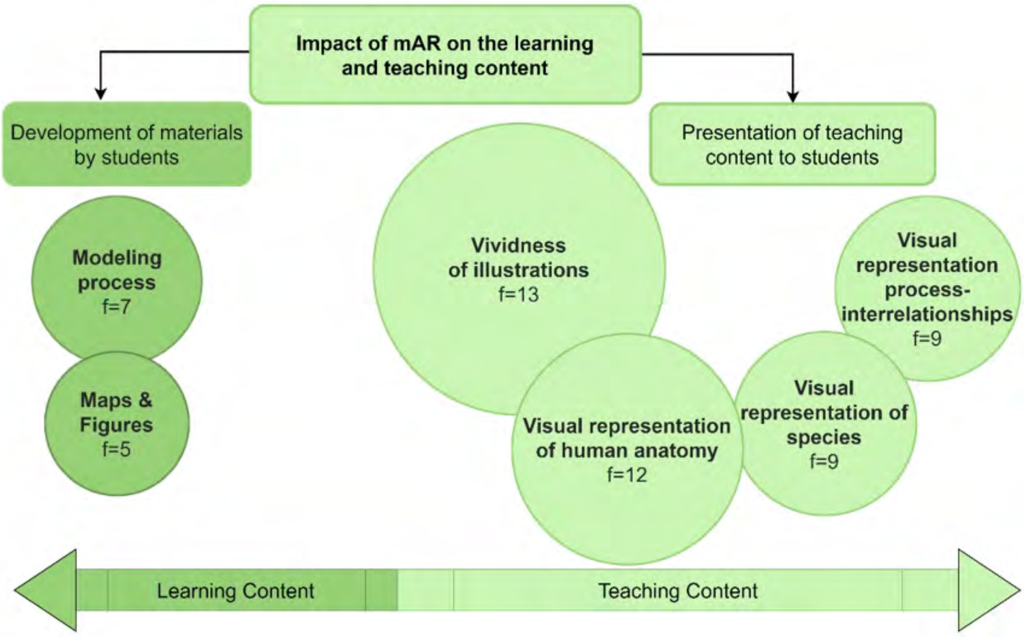

Figure 7: Example of codes within the core phenomenon "Potentials" impact of mAR on learning and teaching content (I create). The frequency per participant is shown in a bubble (larger/smaller bubble according to the frequency of mention), and the subcategory in which they are classified are given

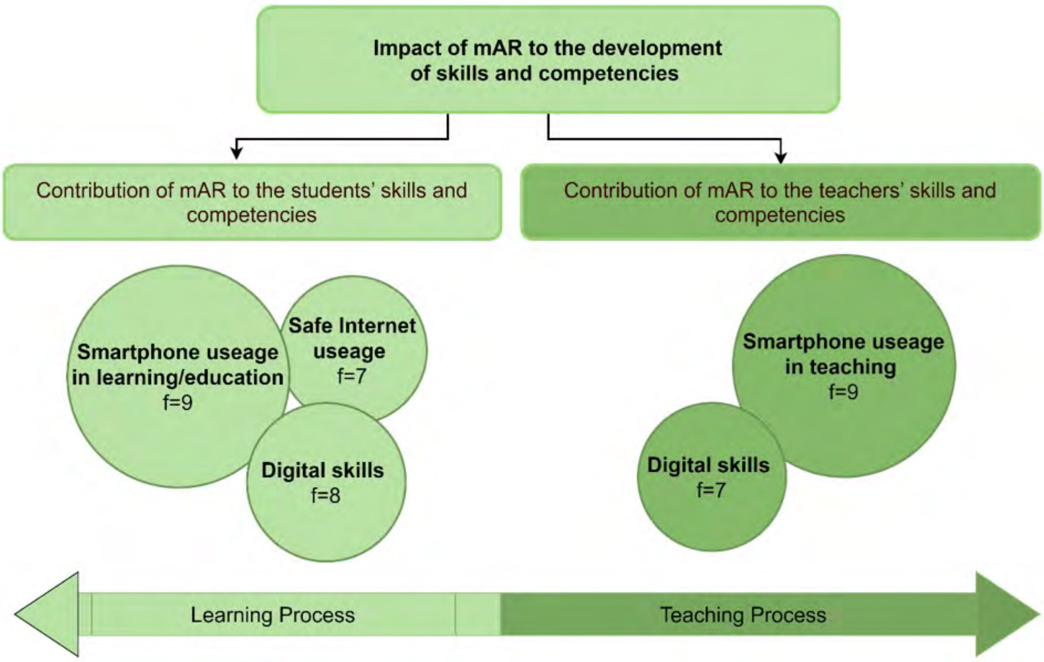

Figure 8: Example of codes within the core phenomenon "Potentials" impact of mAR on learning and teaching competencies and skills (I can). The frequency per participant is shown in a bubble (the larger/smaller bubble according to the frequency of mention), and the subcategory in which they are classified are given

Theme 4: Barriers to the use of mAR in learning and teaching

The fourth theme includes teachers' opinions on the obstacles and issues biology teachers face when applying mAR in their teaching. Three categories have been developed within this theme: '*lack of resources*', '*questionable teaching content in applications*', and '*curriculum connections*'.

As can be seen from *Image 4*, teachers considered the lack of devices to be one of the main obstacles to the use of mAR in teaching (*f* = 15), but also limited Internet access.
Respondent 5: female teacher: '*Every child must have a suitable device for mobile exercises, which is not always the case!*'.

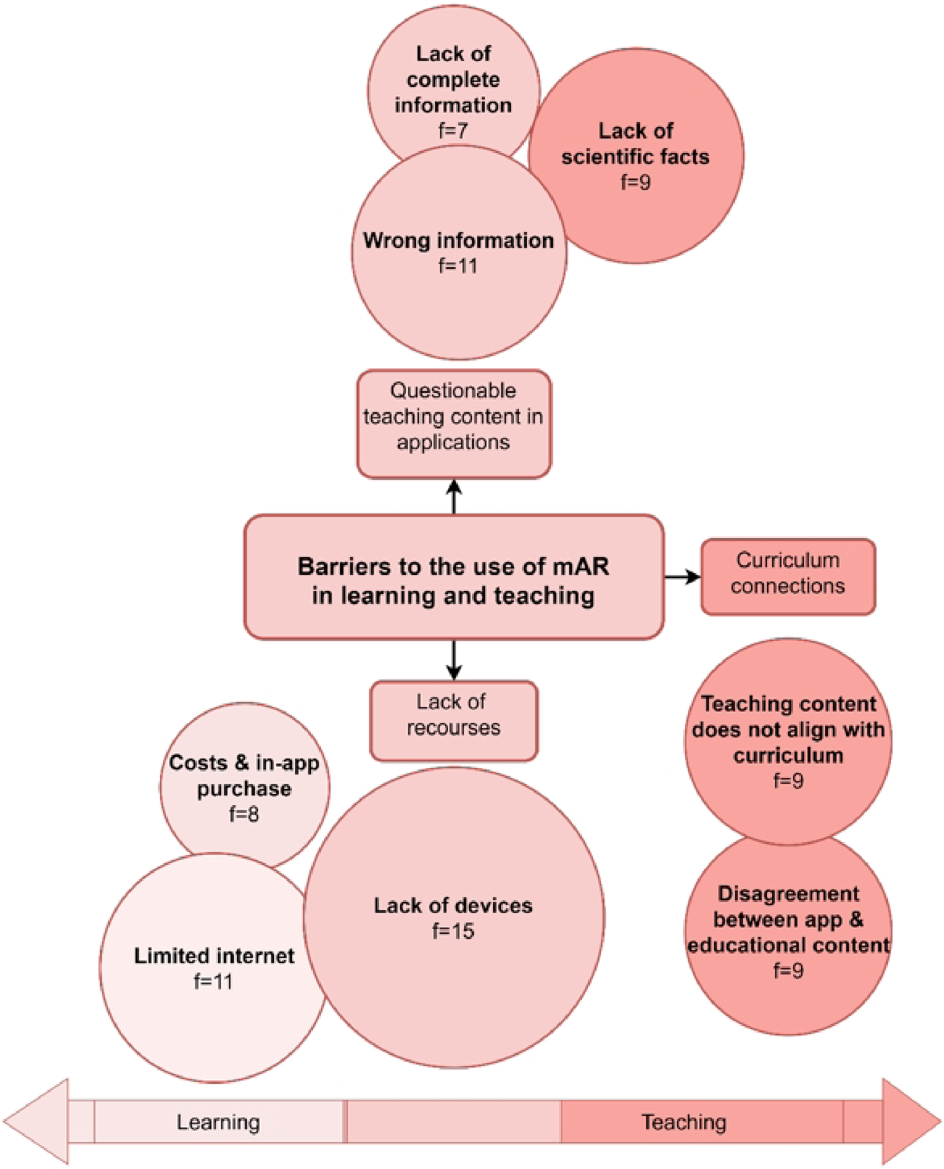

Figure 9: Example of codes within the core phenomenon "Challenges" barriers to the use of mAR in learning and teaching (I need). The frequency per participant is shown in a bubble (the larger/smaller bubble according to the frequency of mention), and the subcategory in which they are classified are given

When it comes to the teaching content presented in these applications, teachers believe that they may contain erroneous information (*f* = 11), as well as information that is not focused on scientific facts (*f* = 9): Respondent 6, female teacher, 24: '*Results are often false, and the students need to be able to think critically in addition to enjoying the use of AR apps. Quite often the correct answer is not the first search result.*'. As one of the obstacles to the use of these applications, the teachers mentioned the lack of connection between the curriculum and applications (*f* = 11), as well as the disagreement between mAR and educational activities recommended in the curriculum (*f* = 9). In addition to the problems with the curriculum, there was also a lack of knowledge about the efficient utilization and where to find mAR apps mentioned by some participants:
Respondent 6: female teacher, 31: '*There is a lack of information about which mAR apps are available and how to find them. In addition, for which topics they can be used. Some apps are rather suitable for the lower secondary level, as the appropriate apps are sometimes missing for the upper secondary school. It needs an overview, adapted to the curriculum, on which topic you can use a certain app*'.

According to the opinion of the teachers who participated in this research, the lack of devices, the accuracy of the information found in the applications for mAR and the inconsistency of the curriculum with the applications are the most common obstacles to the use of this technology in biology education. In addition, some of the teachers believed that the high price and partial information are additional obstacles to the application of mAR in biology education.

DISCUSSION

This paper gave an overview of AR and mAR technology as well as some current mAR examples of mobile applications, frequently used by 35 Austrian biology teachers, with different approaches and contexts in biology education. The aim was to show and describe the perceptions of Austrian secondary school biology teachers on the utilization of mAR apps in their teaching. The purpose of the review and the study was to possibly increase the efficient and responsible applicability and the impact of mAR apps in biology education. Furthermore, to show the problems and obstacles of mAR in Austrian secondary schools, and examine the barriers, which are perceived by the questioned teachers. The results of this study can serve as an approach for further research to solve the problems mentioned in the future.

Regarding the impact of mAR on the learning and teaching process, and in which part of the lesson mAR can be used, research findings show that mAR could contribute beneficially to teaching and students' learning processes. Further, according to the surveyed Austrian teachers, mAR-based teaching materials can be suitable for the development of student activities and tasks, especially for the determination of living beings. In addition, mAR can be utilized for the realization of students' homework, outdoor learning (e.g., fieldwork), the exchange of ideas (e.g., brainstorming), as well as supporting the organization of classes, in any part of the lecture. However, some participating teachers emphasized that the implementation of mAR depends on the respective teachers and their (mobile) abilities. In theory, according to the surveyed biology teachers, it is possible that mAR could be employed in the lecture anytime. However, if the teachers are not familiar with the app or its AR functions, or do not deal with it sufficiently, some educators may generally refuse to use it in the classroom at all. In the future, there will be a need for guidelines and assistance on how to motivate and help biology teachers to employ mAR in their classrooms despite reservations.

Concerning the mAR-based teaching approaches and methodology teaching, the participating teachers felt that mAR is possibly suitable for discovery learning, students' project approaches, collaborative learning, and even modeling. Regarding the presentation of teaching science content to the students, the findings demonstrate that mAR can be useful for a clearer and better presentation of teaching content, such as human anatomy and morphology, for depicting different types of organisms, and for presenting processes in biology teaching. Furthermore, mAR can be used as teaching media for the development of materials by students, according to the participating teachers. Concerning the contribution of mAR to the development of students' and teachers' skills, this research results indicate that the utilization of mAR can be beneficial for students, according to the teachers, by using smartphones for educational purposes, improving digital skills, as well as learning safe Internet use. Moreover, the data indicate that mAR contributes to teachers' skills to use smartphones in teaching as well as improving their digital skills, according to the participants. In this study, it must be emphasized that most respondents probably have a possible positive attitude towards AR and/or mobile learning, perhaps because of their age.

According to the teachers' perceptions of the impact of mAR on learning science and interests in science-based content, the findings showed that most of the participating teachers in this study believe that mAR positively influences students' interest in learning science-related content and that mAR helps them to get more interested in biology lectures. These results are congruent with a recent study in 2021 (Dakeev et al., 2021), where incorporating AR tools into STEM lessons increased primary school students' enthusiasm for learning.

Furthermore, in regard to the opinion of the impact of mAR on the learning process and learning success, in this research, most of the biology teachers had a positive opinion towards the contribution of mAR to the student's learning process and learning success. The majority of the participants' opinions were that mAR helps students with their learning and that the students prefer to learn with mAR rather than with the textbook. However, a significant number of teachers were indecisive about whether mAR positively impacts the students' learning success. This result is interesting, because although many young teachers in this study like to use the mAR apps frequently in their classrooms, they are not quite sure whether the applications increase the students' learning success in the long term. These findings differ slightly from the results of previous studies (Wahyu et al, 2020; Ajit et al, 2021). Their research indicated that mAR-assisted learning improved the learning outcome in STEM subjects, and further, mAR could lead to superior students' science literacy and science learning achievements compared to conventional learning strategies. After comparing the findings with other studies, the authors assume that the surveyed biology teachers in this research have a lack of scientific evidence that mAR enhances learning, a lack of knowledge about the apps themselves and that some of the participating teachers, especially older ones, never use or are hesitant to use mAR in class.

In terms of the positive effect of mAR on motivation and collaboration, by questioning the biology teachers, it became evident in this study that most of them believe that mAR positively affects students' motivation to learn science, and furthermore, collaborate with their peers throughout the learning process. These assumptions can be confirmed by a study by Ke and Hsu (2015), where the findings indicated that AR increased participants' ability to problem-solve, cooperate, and communicate with peers in class. In addition, in a study by Hsu et al. (2017), AR-enhanced lessons also positively affected students' motivation. These results can also be found in the study of Celik et al. (2020), where the authors noticed a positive change in the student learning environment, which was considered a result of increased motivation. Throughout these results, it can be assumed that mAR positively impacts the student's motivation and collaboration in biology classes.

Within this research, it was also ascertained what the teachers' opinion about the main features that mAR offers in biology lessons was. The results of the descriptive methods in this research demonstrate that the majority of the teachers think that the most important contribution was creativity in the lesson structure to design a creative biology course unit. Besides creativity, the importance of innovation in biology lectures was also mentioned. Huang (2017) reached similar results through the application of an experimental research study. He concludes that mAR technologies and creative learning applications can help teachers to better understand the growing research on the role of AR in learning. Assumptions for these findings of this research are that the Austrian biology teachers may think that a creative design course unit and teaching in an innovative way provides variety and reduces student boredom, increases classroom enjoyment and learning outcomes, and further, surprises themselves and students.

In addition to innovation and creativity, the participating biology teachers' perceptions were that creating a sense of enjoyment in biology learning was also important for teaching. Many studies, such as Akçayr and Akçayr (2017), have found that the utilization of AR brings fun into the classroom. These quantitative results indicate that teachers think that AR-based learning creates enjoyment in biology lectures. Moreover, the authors assume that students prefer learning (science) with fun rather than under pressure, to increase their interest in the subject and students' engagement, and motivate the teachers themselves, as seen in other studies (Irwansyah et al., 2019; Berry and Wintl, 2009).

Furthermore, analyzing the quantitative data, it was shown that the questioned Austrian teachers in this study also agreed that particularly important characteristics that mAR provides in their biology teaching were visualization and enabling learning with the use of smartphones. The result regarding the utilization of smartphones in the classroom probably indicates that the participating biology teachers are aware of the importance of teaching the correct, meaningful, and safe use of smartphones in school. Concerning the visualization, in addition to the results of this teacher survey, other studies like Saidin et al. (2015) show that the visualization of scientific abstract concepts or objects can help students to learn science.

Regarding the barriers to the use of mAR in learning and teaching, the findings of this study show that the lack of devices is one of the main obstacles, according to the surveyed teachers. Furthermore, also limited Internet access. These results correlate with many other studies about this topic (Uluyol and Eryılmaz, 2014; Yapıcı and Karakoyun, 2021; Ajit et al., 2021). Research by Ajit et al., (2021) and Müller (2014), indicate that the selection of quality technical devices is very important for the successful implementation of mAR in the teaching process and that the lack of adequate technical devices is one of the most frequent obstacles to the use of this technology in education. This information can be of particular importance to policymakers in education systems, which should consider these obstacles when developing strategic plans for implementing mAR in education.

The utilization of modern and new technologies is anchored in the curriculum of Austrian secondary schools, as required by the ministry. Regarding efficiency and responsibility in Austrian biology education, the teachers, therefore, have the responsibility to prepare their students for dealing with mobile educational applications such as mAR in their lessons. Due to the mentioned and already known issues with mAR, the students need teachers who are very familiar with the apps and their AR functions, and ideally who have completed teacher training, to efficiently prepare their students for the lessons, regarding content, smartphone, and AR utilization, not only in biology classes. Therefore, if the teachers are not properly trained or only have little information about the correct applicability, the teachers and students can have bad experiences in education or with the app or device, and the lessons cannot run smoothly. These impressions can also lead to the teachers and/or students refusing to use mAR or other technologies at all.

This research also demonstrates another very important issue to the use of mAR, which is related to the teaching content presented in those applications, (partly) false information, information that is not focused on scientific facts, lack of connection between the biology curriculum and mAR, as well as a disagreement between mAR and educational activities recommended in the curriculum, are mentioned. This study agrees with previous research (Radu, 2012; Urban et al., 2022; Kuleto and Paun, 2022), which indicates that mAR applications sometimes neglect the scientific accuracy of the content due to the desire to present the content in an attractive way. It was further emphasized by the questioned biology teachers that there is often uncertainty about where to find good mAR or science-based apps and how to properly connect them to the curriculum. It was also mentioned that there is a lack of suitable mAR apps for higher secondary school students. Based on this data, recommendations can be made for developers of mAR applications, who should, when creating applications, take into special consideration the scientific accuracy of facts as well as compliance with curricula in order to increase the applicability of these applications in teaching. There should also be a larger selection of suitable mAR apps for all age groups, as well as guidelines on how to use them correctly.

Limitations and Further Research

The main limitations of this study are the sample size of participating teachers (n = 35) and the imbalance regarding age as well as gender. These facts may affect the results because most of the participants were in their twenties or thirties and female, which is why in the future, more research with larger numbers of balanced participants will have to explore this topic in more detail, in order to be able to make a more precise statement with general plausibility about the perceptions on mAR of Austrian biology teachers.

Although the questionnaire was posted online and sent to six different Austrian schools, it was mainly filled out by very young teachers, who are persuaded that mAR positively influences students' interests in learning science-related content. Therefore, it can be assumed that either older teachers have inhibitions against mobile learning, apps, or AR in general, or have problems with or no time filling out an online questionnaire. Another study with Austrian biology teachers, analyzing interviews, should clarify what inhibitions they have against mobile AR apps in biology lessons. In addition, these interviews are intended to shed more light on the advantages and disadvantages of mAR implementation in Austrian biology lessons. Moreover, it could help to clarify whether this questionnaire was only completed by biology teachers who have had positive experiences with AR or learning apps in general. After further studies with teacher interviews, all collected results are used in upcoming teacher training courses to reduce possible reservations against mAR in biology education and to increase their implementation in class.

Regarding the aim of the Austrian biology curriculum, that new media such as mAR should be used in the classroom and that students should be educated to deal with them critically, further research is needed to what extent this is already being implemented by Austrian biology teachers. Furthermore, additional studies by the authors will take place on the perceptions of students on the implementation of mAR applications and science-based educational applications in Austrian biology lectures.

CONCLUSION

In summary, after surveying and analyzing 35 Austrian biology teachers' opinions on mAR in biology lectures, it can be assumed that the participating biology teachers think the utilization of mAR in their classroom is innovative, creative, and changes the design of the learning unit. Moreover, the surveyed teachers likely use mAR apps to teach human anatomy or for the determination of plants, fungi, or animals. In addition, the participating teachers' perception of mAR is that these applications are good for visualization, proper smartphone usage, modeling, and enjoyment. Further, according to the teachers, mAR apps may possibly increase students' learning outcomes and success, collaboration, and interest in learning and science. This study collected already known problems with augmented reality, such as technical requirements (e.g., missing devices and Internet).

In addition, according to the participating teachers, mAR currently still has incorrect scientific content, there are not enough choices for teachers for all age groups, and some mentioned mAR apps are not yet linked to the biology curriculum. The teachers also need assistance and guidelines on where and how to find suitable mAR apps, and how to utilize them correctly and efficiently in their biology education. In order to confirm these assumptions and to reduce possible mentioned limitations, further research with a larger and more balanced sample size needs to be done on this topic in the future for general significance.

REFERENCES

Agency for Education and Internationalization (OeAD) (2021) *Learning App*, [Online], Available: https://www.oead.at [8 Aug 2022].

Ajit, G., Lucas, T., Kanyan, R. (2021) 'A Systematic Review of Augmented Reality in STEM Education', *Studies of Applied Economics*, Vol. 39, No. 1, pp.1–22. https://doi.org/10.25115/eea.v39i1.4280

Akçayır, M. and Akçayır, G. (2017) 'Advantages and challenges associated with augmented reality for education: A systematic review of the literature', *Educational Research Review*, Vol. 20, pp. 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Anđić, B., Cvjetićanin, S., Maričić, M. and Stešević, D. (2021) 'Sensory perception and descriptions of morphological characteristics of vegetative plant organs by the blind: Implementation in teaching', *Journal of Biological Education*, Vol. 55, No. 3, pp. 321–339. https://doi.org/10.1080/00219266.2019.1687107

Anđić, B., Kadic, S., Grujicic, R. and Malidžan, D. (2018) 'A Comparative Analysis of the Attitudes of Primary School Students and Teachers Regarding the Use of Games in Teaching', *IAFOR Journal of Education*, Vol. 6, No. 22, pp. 5–16. https://doi.org/10.22492/ije.6.2.01

Anđić, B., Šorgo, A., Stešević, D., and Lavicza, Z. (2022) The factors which influence the continuance intention of teachers in using the interactive digital identification key for trees in elementary school science education, *EURASIA Journal of Mathematics, Science and Technology Education*, Vol. 18, No. 8, em2140. https://doi.org/10.29333/ejmste/12239

Arena, F., Collotta, M., Pau, G. and Termine, F. (2022) 'An Overview of Augmented Reality', *Computers*, Vol. 11, No. 2, 28. https://doi.org/10.3390/computers11020028

Barrow, J., Sands, A. and Hurst, W. (2019) 'Augmented Reality for Enhancing Life Science Education', Proceedings of the *fourth International Conference on Applications and Systems of Visual Paradigms (VISUAL 2019)*, [Online], Available: https://www.iaria.org/conferences2019/VISUAL19.html [8 Aug 2022].

Bahng, E. and Lee, M. (2017) 'Learning Experiences and Practices of Elementary Teacher Candidates on the Use of Emerging Technology: A Grounded Theory Approach', *International Electronic Journal of Elementary Education*, Vol. 10, No. 2, pp. 225–241. https://doi.org/10.26822/iejee.2017236118

Berry, A.M. and Wintle, S.E. (2009) 'Using Laptops to Facilitate Middle School Science Learning: The Results of Hard Fun', *Maine Education Policy Research Institute*, Vol. 115.

Bogomolova, K., van der Ham, I. J., Dankbaar, M. E., van den Broek, W. W., Hovius, S. E., van der Hage, J. A. and Hierck, B. P. (2020) 'The effect of stereoscopic augmented reality visualization on learning anatomy and the modifying effect of visual-spatial abilities: A double-center randomized controlled trial', *Anatomical sciences education*, Vol. 13, No. 5, pp. 558–567. https://doi.org/10.1002/ase.1941

Bowers, A. W. and Creamer, E. G. (2021) 'A grounded theory systematic review of environmental education for secondary students in the United States', *International Research in Geographical and Environmental Education*, Vol. 30, No. 3, pp. 184–201. https://doi.org/10.1080/10382046.2020.1770446

Çakır, N. G., Gokhan and Çelik, C. (2021) 'Integration of mobile augmented reality (MAR) applications into the 5E learning model in Biology teaching', *International Journal of Technology in Education (IJTE)*, Vol. 4, No. 1, pp. 93–112. https://doi.org/10.46328/ijte.82

Celik, C., Guven, G. and Cakir, N. K. (2020) 'Integration of mobile augmented reality (MAR) applications into biology laboratory: Anatomic structure of the heart. *Research in Learning Technology*, Vol. 28, No. 2 pp. 1–11. https://doi.org/10.25304/rlt.v28.2355

Cohen, L., Manion, L. and Morrison, K. (2002) *Research methods in education*, London: Routledge.

Dakeev, U., Pecen, R., Yildiz, F. and Clint, E. (2021) 'Effect of an Augmented Reality Tool in Early Student Motivation and Engagement', Proceedings of the *2020 CIEC*, https://doi.org/10.18260/1-2-370-38705

Elmqaddem, N. (2019) 'Augmented reality and virtual reality in education. Myth or reality?', *International journal of emerging technologies in learning*, Vol. 14, No. 3. pp. 234–242. https://doi.org/10.3991/ijet.v14i03.9289

Fan, W. and Yan, Z. (2010) Factors Affecting Response Rates of the Web Survey: A Systematic Review, *Computers in Human Behavior*, Vol. 26, No. 2, pp. 132–139. http://dx.doi.org/10.1016/j.chb.2009.10.015

Federal Ministry of Education, Science, and Research (2019) *Curriculum*, [Online], Available: https://www.bmbwf.gv.at [8 Sep 2022].

Federal Ministry of Education, Science, and Research (2021) *Seal of Quality for Learning Apps*, [Online], Available: https://www.bmbwf.gv.at/Ministerium/staatspreise-auszeichnungen/praz_b/lernapps.html [7 Aug 2022].

Fernandez, M. (2017) 'Augmented-Virtual Reality: How to improve education systems', *Higher Learning Research Communications*, Vol 7, No. 1, pp 1–15. http://dx.doi.org/10.18870/hlrc.v7i1.373

Fuchsova, M. and 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*, Vol. 8, No. 1, pp. 92–102. http://dx.doi.org/10.13187/ejced.2019.1.92

Garcia-Bonete, M. J., Jensen, M. and Katona, G. (2019) 'A practical guide to developing virtual and augmented reality exercises for teaching structural biology', *Biochemistry and Molecular Biology Education*, Vol. 47, No. 1, pp. 16–24. https://doi.org/10.1002/bmb.21188

Godoy Jr., C. H. (2021) 'Augmented Reality for Education: A Review', *International Journal of Innovative Science and Research Technology*, Vol. 5, No. 6, pp. 39–45. https://doi.org/10.38124/IJISRT20JUN256

Huang, T. C. (2017) 'Seeing creativity in an augmented experiential learning environment', *Universal Access in the Information Society*, Vol. 18, pp. 301–313. https://doi.org/10.1007/s10209-017-0592-2

Hsu, Y. S., Lin, Y. H. and Yang, B. (2017) 'Impact of augmented reality lessons on students' STEM interest', *Research and practice in technology enhanced learning*, Vol. 12, No. 1, pp. 1–14. https://doi.org/10.1186/s41039-016-0039-z

Ibáñez, M. B. and Delgado-Kloos, C. (2018) 'Augmented reality for STEM learning: A systematic review', *Computers & Education*, Vol. 123, pp. 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

İpek, Z., Atik, A. D., Tan, S. and Erkoç, F. (2020) 'Opinions of Biology Teachers about Nanoscience and Nanotechnology Education in Turkey', *International Journal of Progressive Education*, Vol. 16, No. 1, pp. 205–222. https://doi.org/10.29329/ijpe.2020.228.15

Irwansyah F. S., Yusuf, Y. M., Sugilar, H., Nasrudin, D., Ramdhani, M. A. and Salamah, U. (2019) 'Implementation of fun science learning to increase elementary school students' skill in science and technology', *Journal of Physics: Conference Series*, 1318. https://doi.org/10.1088/1742-6596/1318/1/012063

Jang, J., Ko, Y., Shin, W. S. and Han, I. (2021) 'Augmented reality and virtual reality for learning: An examination using an extended technology acceptance model', *IEEE Access*, Vol. 9, pp. 6798–6809. https://doi.org/10.1109/ACCESS.2020.3048708

Jumani, A. K., Siddique, W. A., Laghari, A. A., Ahad, A. and Abdullah. A. K. (2022) *Virtual Reality and Augmented Reality for Education*, Boca Raton: CRC Press. https://doi.org/10.1201/9781003196686-9

Karacan, C. G. and Akoglu, K. (2021) 'Educational Augmented Reality Technology for Language Learning and Teaching: A Comprehensive Review', *Shanlax International Journal of Education*, Vol. 9, No. 2, pp. 68–79. https://doi.org/10.34293/education.v9i2.3715

Krippendorff, K. (2013) *Content Analysis: An Introduction to Its Methodology*, 3rd edition, California, CA: Sage.

Kuleto, V. and Paun, D. (2022) '"New Perspectives on Virtual and Augmented Reality: Finding New Ways to Teach in a Transformed Learning Environment", Edited by Linda Daniela, Routledge, Book Review', *EdTech journal*, Vol. 2, No. 1, pp. 81–88. https://doi.org/10.18485/edtech.2022.2.1.6

Ke, F. and Hsu, Y.C. (2015) 'Mobile augmented-reality artifact creation as a component of mobile computer-supported collaborative learning', *The Internet and Higher Education*, Vol. 26, pp. 33–41. https://doi.org/10.1016/j.iheduc.2015.04.003

Maloney, K. M. (2005) 'Adventuring: A grounded theory discovered through the analysis of science teaching and learning', *The Grounded Theory Review: An international journal*, Vol. 4, No. 3.

Mikropoulos, T. A., Katsikis, A., Nikolou, E. and Tsakalis, P. (2003) 'Virtual environments in biology teaching', *Journal of Biological Education*, Vol. 37, No. 4, pp. 176–181. https://doi.org/10.1080/00219266.2003.9655879

Miles, M.B., Huberman, A.M., Saldana, J. (2014) *Qualitative Data Analysis*, Thousand Oaks: SAGE

Mystakidis, S., Christopoulos, A. and Pellas, N. (2022) 'A Systematic Mapping Review of Augmented Reality Applications to support STEM Learning in Higher Education', *Education and Information Technologies*, Vol. 29, pp. 1883–1927. https://doi.org/10.1007/s10639-021-10682-1

Osadchyi, V. V., Valko, N. V. and Kuzmich, L. V. (2021) 'Using augmented reality technologies for STEM education organization', *Journal of Physics: Conference Series*, 1840. https://doi.org/10.1088/1742-6596/1840/1/012027

Omurtak, E. and Zeybek, G. (2022) 'The effect of augmented reality applications in biology lesson on academic achievement and motivation', *Journal of Education in Science, Environment and Health (JESEH)*, Vol. 8, No. 1, pp. 55–74. https://doi.org/10.21891/jeseh.1059283

Radu, I. (2012) 'Why should my students use AR? A comparative review of the educational impacts of augmented-reality', Proceedings of the *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 313–314. https://doi.org/10.1109/ISMAR.2012.6402590

Petrov, P. D. and Atanasova, T. V. (2020) 'The Effect of augmented reality on students' learning performance in stem education', *Information*, Vol. 11, No. 4, 209. https://doi.org/10.3390/info11040209

Restivo, T., Chouzal, F., Rodrigues, J., Menezes, P. and Lopes, J. B. (2014) Augmented reality to improve STEM motivation. Proceedings of the *2014 IEEE global engineering education conference (EDUCON)*, pp. 803–806. https://doi.org/10.1109/EDUCON.2014.6826187

Saidin, N., Abd Halim, N. D. and Yahaya, N. (2015) 'A Review of Research on Augmented Reality in Education: Advantages and Applications, *International Education Studies*, Vol. 8. No. 13, https://doi.org/10.5539/ies.v8n13p1

Shapley, K., Sheehan, D., Maloney, C. and Caranikas-Walker, F. (2011) 'Effects of technology Immersion on Middle School students' Learning Opportunities and Achievement', *The Journal Educational Research*, Vol. 104, No. 5, pp. 299–315. http://dx.doi.org/10.1080/00220671003767615

Sırakaya, M. and Alsancak Sırakaya, D. (2020) 'Augmented reality in STEM education: A systematic review', *Interactive Learning Environments*, Vol. 30, No. 8, pp. 1556–1569. http://dx.doi.org/10.1080/10494820.2020.1722713

Strauss, A. and Corbin, J. (1990) *Basics of qualitative research: Grounded theory procedures and techniques*, Newbury Park, Calif: SAGE.

Tan, S. and Waugh, R. (2013) 'Use of virtual-reality in teaching and learning molecular biology', in Cai, Y. (ed.) *3D immersive and interactive learning*, pp. 17–43. Singapore: Springer. http://dx.doi.org/10.1007/978-981-4021-90-6_2

Tobinski, D. and Cyra, K. (2021) 'Digital Competence of Teachers - An Exploratory Study of Teachers' Usage of Digital (Educational) Technologies and Their Motivation Before the Sars-COV-2 Pandemic', *Proceedings of the INTED2021 Conference*. http://dx.doi.org/10.21125/inted.2021.1392

Urban, H., Pelikan, G. and Schranz, C. (2022) 'Augmented Reality in AEC Education: A Case Study, *Buildings*, Vol. 12, No. 4, 391. https://doi.org/10.3390/buildings12040391

Wahyu, Y., Suastra, I. W., Sadia, I. W. and Suarni, N. K. (2020) 'The Effectiveness of Mobile Augmented Reality Assisted Stem-Based Learning on Scientific Literacy and students' Achievement', *International Journal of Instruction*, Vol. 13, No. 3, pp. 343–356. https://doi.org/10.29333/iji.2020.13324a

Yapıcı, İ. Ü. and Karakoyun, F. (2021) 'Using augmented reality in biology teaching', *Malaysian Online Journal of Educational Technology*, Vol. 9, No. 3. pp. 40–51. https://doi.org/10.52380/mojet.2021.9.3.286

Zhou, R., Wang, X., Zhang, L. and Guo, H. (2017) Who tends to answer open-ended questions in an e-service survey? The contribution of closed-ended answers. *Behaviour & Information Technology*, Vol. 36, No. 12, pp. 1274–1284. https://doi.org/10.1080/0144929X.2017.1381165

APPENDIX

QUESTIONS FROM THE ONLINE QUESTIONNAIRE

- Demographic data: Age, Gender, Profession
- Which mAR apps have you already used, or are you currently using? Please list your apps
- How often do you use mobile AR apps in your biology lessons (*never, once a school year, once a semester, once or twice a month, several times a month, or weekly)*
- Why do you use mobile scientific AR apps in studies or in class? Please describe your answer
- How often do you use mobile AR apps in private (*never, once a school year, once a semester, once or twice a month, several times a month, or weekly)*
- Why do you use mobile scientific AR apps in private? Please describe your answer

Rate the following statements (*strongly agree, agree, neither nor, disagree, strongly disagree*):

- "AR apps are supporting students with their learning ability"
- "AR apps are helping students to be more prepared for biology exams"
- "I think AR apps in biology lectures are very motivating for students"
- "With the implementation of AR apps, students work and collaborate more in biology lectures"
- "AR apps are helping students to get more interested in learning in lectures"
- "AR apps are supporting students to get more interested in science"
- "AR apps break and loosen up traditional lessons' structure"
- "Students rather prefer to learn with AR apps than with an analog textbook"
- Please tick the appropriate box: What do you particularly like about the use of AR apps in science lessons/studies? Multiple answers possible:
  - ❒ Use and learn with the smartphone
  - ❒ Fun
  - ❒ Creativity in class or study
  - ❒ Learning success
  - ❒ Innovation in learning and teaching
  - ❒ Illustrations and representation of objects/objects (visualization)
  - ❒ Freedom to use the app anywhere
  - ❒ Utilization is easy and fast (user-friendly)
  - ❒ mAR App is free or inexpensive
  - ❒ Learning content is delivered quickly
  - ❒ Language and texts are easy to understand
- Please tick the appropriate box: How and where can AR apps be used creatively and innovatively in the classroom? Multiple answers possible:
  - ❒ Work order (groups, partner work)
  - ❒ Homework
  - ❒ Visualization of objects
  - ❒ Reading articles
  - ❒ Development of new and deepening of already learned content
  - ❒ Repetition of learning content
  - ❒ Quiz
  - ❒ Project
  - ❒ research-based learning
  - ❒ creative use of the smartphone
  - ❒ Station operation
- Describe how and in which part of the learning unit or lesson mAR can be used? Please justify and describe your answer
- What bothers you about scientific mAR apps and how can mAR applications be improved to be easier to use in the classroom/education? Please justify and describe your answer
- What are the main obstacles and problems to using mAR in teaching? Please justify and describe your answer