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What Is the Future of Augmented Reality in Science Teaching and Learning? An Exploratory Study on Primary and Pre-School Teacher Students' Views

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Abstract: While extensive research has explored the impact of Augmented Reality (AR) on student perspectives, experiences, and outcomes, there remains a significant gap in empirical studies focusing on teachers' viewpoints, particularly within Science Education. Given that uncovering teachers' viewpoints is crucial for leveraging AR technology's potential in education since teachers decide whether to integrate it into their classrooms, the research question guiding this exploratory study is as follows: How do primary and pre-school teacher students perceive the integration of AR into Science teaching and learning following their engagement with pertinent university courses? Following a mixed-method approach, the data were collected via written questionnaires from 69 teacher students and focus group discussions involving 12 participants. Subsequent descriptive statistical and thematic analyses revealed that teacher students hold positive stances towards the integration of AR in Science Education. They emphasized that AR could significantly enhance motivational and cognitive outcomes for their future students while also improving accessibility and inclusion. Furthermore, their involvement in creating AR-enhanced materials not only increased course engagement and interest but also broadened their knowledge and fostered a sense of innovation, with the AR platform and application used being perceived as easy to use. Finally, challenges associated with classroom implementation were also highlighted.

Keywords: science education; augmented reality; teacher students views; primary education; pre-school education; university students; AR experience; formal education; non-formal education; augmented reality in higher education

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1. Introduction

In the current digital age, the landscape of education is facing changes fueled by technological progress. New emerging technologies, such as Augmented Reality, Virtual Reality, and Artificial Intelligence, can transform teaching by offering immersive educational experiences that transcend the limitations of users' real-world sensory perceptions, as well as the personalized and adaptable content creation, providing real-time assistance for students [1,2].

While extensive research has explored the impact of AR tools on student perspectives, experiences, and outcomes [3–5], there remains a significant gap in empirical studies focusing on teachers' viewpoints, particularly within Science Education [6]. Notably, research addressing the perceptions of primary and preschool teacher students towards AR integration is exceptionally scarce. Given that uncovering teachers' viewpoints is crucial for leveraging AR technology's potential in education since teachers decide whether to integrate it into their classrooms [6,7], this paper aims to investigate teacher students' views on AR integration in Science topics. The central research question guiding this investigation is as follows: How do primary and pre-school teacher students perceive the integration of AR into Science teaching and learning following their engagement with pertinent university courses?

To address this question, the study employs a mixed-method research approach. This method combines quantitative data and qualitative insights to provide a comprehensive understanding of teacher students' views on integrating AR in Science Education.

2. Literature Review

Augmented reality (AR) is a system or visualization technique that enhances the natural environment by integrating virtual objects that seem to share the same physical space as the real world [8,9]. AR provides the potential for designing effective learning experiences, combining virtual and real objects, providing real-time interaction, and presenting 3D objects, resulting in students having a sense of reality in an individual learning environment [10,11].

The widespread use of smartphones and tablets makes mobile AR technologies easily accessible for all learners. Using the smartphone camera view and object markers, such as QR codes and AR markers printed on paper (e.g., leaflets, cards, and maps) or GPS sensors in locations of significant cultural, historical, and educational value, users are able to superimpose layers of virtual information on the physical world [11–16]. Such applications are user-friendly and provide teachers with the opportunity to create their own augmented experiences, aiming to engage students in immersive and interactive educational environments [16,17].

2.1. AR in Education

Akçayır and Akçayır [3], in a literature review of 68 papers, found that the majority of research on AR in education has been conducted with K-12 students, followed by university students. Only a small number of papers addressed teachers. The authors identified the advantages of AR in education, as well as the challenges. Concerning advantages, the researchers acknowledged benefits related to learner outcomes. For instance, they identified that AR could enhance learning achievement, motivation, understanding, and positive attitudes while also providing satisfaction, decreasing cognitive load, and enhancing confidence and spatial ability. Additionally, pedagogical benefits were emphasized, such as increased enjoyment, engagement, interest, and collaboration opportunities. AR also facilitates communication, promotes self-learning, combines the physical and virtual worlds, allows learners to learn by doing, enables multi-sensory learning, and enables learners to receive information quickly. Furthermore, it offers the opportunity to visualize invisible objects, events, and abstract concepts while being perceived by students as easy to use. In terms of challenges, the review pointed out that AR applications need well-designed interfaces to prevent usability issues that could undermine educational effectiveness. Moreover, AR requires more time to be used in the classroom compared to traditional lecturing. Technical issues were also evident, such as low sensitivity in triggering recognition and GPS errors. Additionally, some studies suggested that AR might be less effective for large group instruction and could potentially distract students [3].

Pedaste et al. [4] conducted a literature review of 15 studies on the use of AR in inquiry-based learning from primary to high school levels. They found that AR was primarily used to achieve cognitive learning and motivational goals. However, when examining the five phases of the inquiry cycle—namely, Orientation, Conceptualization, Investigation, Conclusion, and Discussion [18]—they noted that AR was applied on a limited basis, most commonly in the Conceptualization phase, followed by the Investigation phase. The majority of studies indicated that AR could be easily utilized to facilitate learning about objects or processes relevant to the subject matter being taught. Concerning the effects of AR in inquiry-based learning, most of the studies revealed that AR had a positive effect on learning outcomes related to knowledge and conceptual understanding, as well as on students' attention, attitudes, satisfaction, and engagement.

In a recent literature review, Gopalan et al. [5], analyzing 90 papers, identified three critical success factors for AR in Science learning. Specifically, incorporating AR into Science Education provides a rich learning experience characterized by heightened interest, enjoyment, engagement, fun, and deep immersion. Furthermore, AR leads to improved outcomes, notably in motivation, conceptual understanding, and practical skills. This approach also boosts effectiveness, aids in knowledge retention, and sustains attention. Furthermore, it adds to learners' relevance, concentration, and overall satisfaction. In addition, the authors concluded that the inherent characteristics of AR lead to effective Science learning environments, specifically the usability, visualization, interactivity, cognitive load, acceptance, and realism of AR [5]. Similarly, a meta-analysis [19] encompassing 28 studies demonstrated that students exhibit significantly more favorable attitudes toward AR-assisted education than those without AR support. Furthermore, learning outcomes enhanced by AR education were significantly higher than those attained with non-AR educational approaches.

2.2. Teachers' Views on AR Integration

Alkhattabi [7] explored the level to which primary school teachers (n = 200) accept integrating AR applications within an e-learning context in Saudi Arabia through a Likert-scale questionnaire. The findings revealed a broad familiarity with AR technology among the teachers, who expressed a willingness to integrate AR tools into their instructional practices, believing that such tools would enhance student engagement and learning outcomes. Regarding obstacles teachers face in AR use in schools, they agreed with the lack of information technology skills and infrastructure and resistance to change.

Tzima et al. [20] investigated views of 20 secondary teachers (divergent discipline teaching) focusing on factors that can affect the use of AR in classrooms in Greece. The researchers found that AR technology use was limited in the classroom. The teachers demonstrated a positive attitude towards training; however, it was observed that such training sessions seldom lead to practical application, which is crucial for consolidating the knowledge gained. Furthermore, most of the teachers were unfamiliar with designing or utilizing digital 3D models in teaching, elements that could be integrated into AR applications. Nonetheless, they emphasized their eagerness to undergo training in this area.

Buchner and Zumbach [21] implemented a training program for in-service teachers on AR integration. They contend that the teachers perceived this training as motivating. Most teachers expressed intentions to utilize AR in their classrooms following the program. The teachers highlighted that integrating movement and learning in the classroom was a significant motivator for utilizing AR, emphasizing its capability to "bringing pictures to life" [21]. Teachers also expressed concerns related to technological challenges, such as unstable Internet connections, planning considerations, including the substantial time required to develop AR educational materials, and the necessity for additional training to implement AR for specific curriculum topics effectively. The authors conclude that training for AR classroom implementation should extend beyond the technology alone and should take into account the Technological Pedagogical Content Knowledge (TPACK).

Arici et al. [22] employed semi-structured interviews to investigate the views of secondary Science teachers (n = 10) who possessed knowledge of AR applications and had practical experience in incorporating these technologies into the classroom. Concerning teachers' views about learning with AR apps, the researchers found that teachers think that visualizations and 3D structures in AR apps help concretize abstract knowledge, making the Science content more understandable. Moreover, AR can contribute to avoiding unsafe conditions by visually demonstrating dangerous situations in the classroom. In addition, they think that this can increase students' motivation toward the lesson, engage multiple senses, and ensure permanence. Concerning the role of AR applications on students' interest, the teachers mentioned that this technology can attract students' attention, is enjoyable, prevents boredom, enhances curiosity, and is exciting to use it. Challenges were also reported by the teachers, such as insufficient numbers of tablets/phones for students, limited AR applications suitable for the curriculum, and the fact that several AR apps are not free. Moreover, AR apps need an Internet connection, and schools do not have sufficient Internet infrastructure.

Heintz et al. [23] investigated the perspectives of 65 teachers from several different countries, predominantly from primary and secondary STEM subjects, on integrating AR in the classroom. The researchers found that teachers recognized the educational value of AR tools, highlighting the enhanced interactivity and visualization capabilities. However, in attempting to identify the teachers' needs to facilitate the increased use of AR in classrooms, the researchers found that teachers face financial constraints, notably the scarcity of relevant school equipment. Moreover, they highlighted the teachers' need for training in AR integration and the limited availability of AR applications featuring high-quality materials that support teaching. Teachers also suggested that a repository of AR applications tailored to the specific topics of each country's curriculum would be beneficial. The researchers concluded that providing teachers with authoring tools, which would enable them to create AR-enhanced teaching materials, could be particularly valuable.

Perifanou et al. [6] explored teachers' perspectives on integrating AR into education by utilizing an open-ended online questionnaire answered by 93 teachers. The majority of participants were educators in tertiary education, although the sample also included teachers from secondary and primary levels. The researchers identified that teachers believe digital competencies, such as programming and 3D modeling, are essential for educators in the AR domain. In addition, they think that several student-centered pedagogical approaches could be used to integrate AR in class, such as situated learning, game-based learning, project-based learning, and collaborative learning. Affordances of AI were referred to the potential to visualize recourses that could not be physically present in the classroom, such as planets and molecular structures. Moreover, the augmentation, i.e., adding layers of information and interactivity, were identified in the teachers' answers. Concerning the benefits, they highlighted the enhancement of students' understanding of complex concepts, enabled experiences that were previously not possible, and facilitated increased interaction, interest, engagement, and motivation. Lastly, the teachers expressed concerns regarding security and privacy, e.g., noting that not all AR applications are designed for educational purposes, which, consequently, raises privacy issues.

Koutromanos and Jimoyiannis (2022) investigated teachers' views concerning the benefits, affordances, and challenges of AR integration in teaching and learning. The teacher participated in a training program aiming to develop their TPACK in order to be able to create AR applications related to school topics, focusing on books and printed materials that the AR application would enhance. Interviews with ten in-service primary and secondary teachers who participated in the program revealed that they recognized (a) the educational benefits of AR, e.g., increased learning motivation and interest, and enhanced understanding of the subject content, (b) the affordances of AR, e.g., including the combination of printed and digital-virtual materials, efficient visual representations, and immediate access to AR resources; and (c) teachers' challenges and concerns such as the lack of digital infrastructure, the cost of AR platforms, increased workload, the need for teacher training, and the necessity of a supportive educational environment.

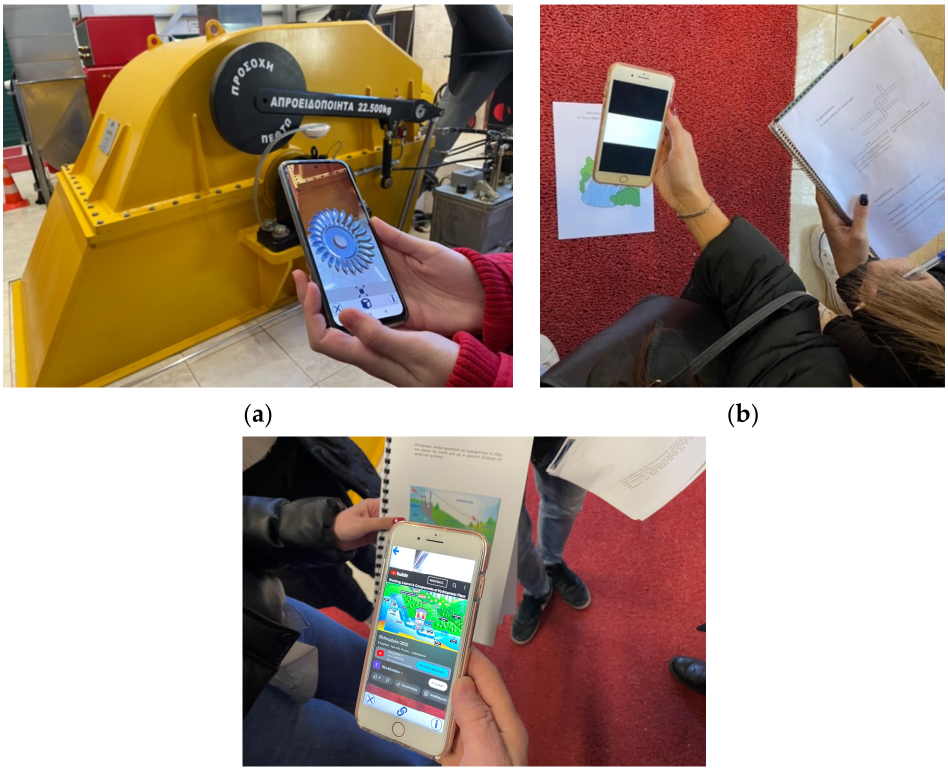
In a study conducted in Greece by Sofianidis [24], the perspectives of prospective pre-school teachers (n = 51) were explored. This research was focused on students' experiences with AR quizzes, which were integrated for formative self-assessment purposes within a university Science Education course. Based on questionary and focus group discussions, the researcher concluded that teacher students believe that AR quizzes aided in identifying their areas of understanding and misunderstanding regarding the course material. For instance, the feedback provided by the AR quizzes leads teachers to identify their misunderstandings and search for clarification of the learning material. Moreover, the teacher students mentioned that AR quizzes were an easier way to learn, supported different learning styles, and were helpful in the most challenging topics. The design characteristics of the AR quizzes, such as repetition, feedback, and multimodality (e.g., sound, images, and cartoon), were identified as contributing positively to the students' attitudes towards the AR quizzes. Moreover, the teacher students found the AR quizzes interesting, engaging, and easy to use. In parallel, they mentioned that the AR quizzes "became part of their physical world, which created a sense of personal communication and a feeling of real-world interaction" [24] (p. 18).

3. Materials and Methods

3.1. The Context

The research was conducted in the context of two university courses focused on Science Education within the Departments of Primary Education and Early Childhood Education. Both courses aimed to train teacher students in developing inquiry-based teaching materials for formal or non-formal Science Education settings. The lecturers of the courses (i.e., the authors of this paper) proposed AR technologies as a tool for designing modern teaching materials. Students from both courses participated in a single training session, lasting three hours, on the utilization of the ARTutor platform [https://artutor.ihu.gr (accessed on 25 April 2024], a free AR authoring tool accessible to both teachers and students [16,25].

The course within the Primary Education Department was dedicated to designing, developing, and implementing educational activities in non-formal settings, such as techno-science centers. Teacher students were acquainted with concepts pertinent to non-formal Science Education, such as the goals of non-formal Science Education, as well as the development of activities before, during, and after the school visits to techno-science centers in order to offer their students a meaningful experience [26,27]. Furthermore, they were introduced to AR technologies to create AR-enhanced materials for non-formal educational activities [28]. The students were tasked with designing a school visit to a hydroelectric power plant for their future students. They were also required to develop inquiry-based activities and related worksheets for students, to be utilized before, during, and after the visit to the hydroelectric power plant. In the specific activities designed for use during the hydroelectric power plant visit, students were tasked with creating AR-enhanced materials utilizing the ARTutor platform. Figure 1 illustrates teacher students testing the AR-enhanced materials at the hydroelectric power plant, utilizing the ARTutor to visualize a 3D model of the water turbine (Figure 1a) and to access video content necessary to complete a student worksheet (Figure 1b,c).



(**a**) (**b**)

(**c**)

Figure 1. Pictures of the teacher students testing the AR-enhanced materials at the hydroelectric power plant: (**a**) a 3D model of a water turbine; and (**b**,**c**) videos about the hydroelectric power plant.

The course within the Department of Early Childhood Education focuses on using experiments in teaching and learning Science in pre-school formal educational settings. First, students were introduced to the role of experiments in Science and Science Education and the use of experiments within inquiry-based activities [18]. Then, students formed teams of 4 persons and participated in inquiry-based activities concerning several topics of Science, such as States of Matter and Units of Measurement, Floating and Sinking, Temperature and Thermal Energy, Magnets and Magnetism, and Introduction to the use of an Optical Microscope. After each lesson, one of the teams formed was assigned to create videos for each phase of the inquiry following the activities' worksheet of the lessons' topic to create an augmented worksheet of the lesson. These augmented worksheets were uploaded to a shared folder to be available for all students who participated in the course. Additionally, the students were asked to design an activity for pre-school students using AR based on the activities they participated in during the course as a final assignment. Each team presented the augmented worksheet (Figure 2) of the course and their activity and received feedback from the lecturer and their colleagues.

(**a**) (**b**)

(**c**)

Figure 2. Pictures of the augmented worksheets of courses concerning (**a**,**b**) Temperature and Thermal Energy and (**c**) States of Matter and Units of Measurement captured by the ARTutor application.

3.2. Participants

Sixty-nine students participated in the study (78.3% females, 18.8% males, and 2.9% non-binary). Among these participants, 50.7% were enrolled in a university's Department of Early Childhood Education, while the remaining 49.3% attended a Primary Education Department in Greece. Furthermore, 49.3% of the participants were fourth-grade students, 26.1% were third-grade students, and 24.6% were second-grade students. Regarding age, 82.6% were between 17 and 23 years old, 5.8% fell into the 24 to 30 age range, and 11.6% were 30 years old or older. Twelve of the participants (nine females and three males) attended the two focus groups conducted. Seven were university students in the Department of Primary Education, while five attended in the Department of Early Childhood Education.

During their high school years, 71% of the participants did not have Science as a major discipline. However, 71% declared that they like Science and 8.7% that they like Science a lot, 18.8% stated that they do not like Science, and 1.4% that they do not like Science at all. Concerning their stances on technology, 43.5% of the participants reported that they typically adopt new technologies once they become mainstream among their acquaintances. In comparison, 29% indicated they like new technologies and tend to use them before most of their peers. Furthermore, 11.6% of the participants expressed enthusiasm for new technologies, stating that they are usually among the first to adopt new Internet technologies. Conversely, 8.7% mentioned they are generally among the last in their social circle to adopt new technologies, and 7.2% described themselves as cautious, only using new technologies when necessary. Almost half of the participants (49.3%) had used AR applications before the course. In comparison, only 8.7% had used the specific application that was used in the lessons, i.e., the ARTutor, as a user and 5.2% as an author; that is, they had created augmentations.

3.3. Data Collection

The research followed a mixed-method approach. The data were collected through a 4-point Likert written questionnaire (e.g., "definitely not", "probably not", "probably yes", and "definitely yes") designed by the authors to explore the participants' stances on the AR integration in Science topics. Data collection took place at the end of the spring semester of 2022–2023. Students were asked to complete a written questionnaire and were invited to participate on a voluntary basis in upcoming focus groups. The questionnaire concentrated on their perspectives, firstly, as teacher students, with questions like, "How much do you think that the process of enriching the teaching material with augmented reality helped you engage more in the educational process?" and, secondly, as prospective teachers, with inquiries such as, "Do you think that the use of augmented learning materials would make the lesson more fun for your future students?". A focus group protocol was also developed to gather in-depth qualitative data, further exploring participants' views.

Informed consent was obtained from all the participants after providing information about the aim of the research, data handling, and privacy protection rights. Moreover, they were informed that participation was voluntary and would not affect their grades. All the data were handled appropriately to protect the participants' anonymity. The research design followed ethical standards and was compliant with the Research Ethics Committee of the University of Western Macedonia (approval number: 35/19-12-2022).

3.4. Data Analysis

Concerning the quantitative data derived from the written questionnaire, a descriptive statistical analysis was conducted using IBM SPSS Statistics 29. As regards qualitative data, students' verbal commentary during the focus group were initially transcribed from audio to text form. Subsequently, the data were analyzed using thematic analysis. The authors familiarized themselves with the data through repeated review of the transcripts and collaborated to identify categories and subcategories. They then searched for and identified themes, guided by the idea that "a theme captures something important about the data in relation to the research question and represents some level of patterned response or meaning within the data set" [29]. Atlas.ti was utilized for the analysis of the qualitative data and 20 codes were created. Four major themes emerged from these codes: (a) teacher students' views as prospective teachers, (b) teacher students' views as learners, (c) ease of use, and (d) challenges.

4. Results

4.1. Teacher Students' Views as Prospective Teachers

The first theme concerns teacher students' views as prospective teachers. Their views seem to have a significant value for exploring their stances towards AR in Science Education since, based on the quantitative results (Figure 3), most of them would use AR applications to provide their future students with AR-enhanced learning materials. The teacher students' views as prospective teachers were grouped into three categories: (i) the benefits for students; (ii) the prerequisites for utilizing AR in the classroom; and (iii) the differences between primary school and pre-school education in AR integration.

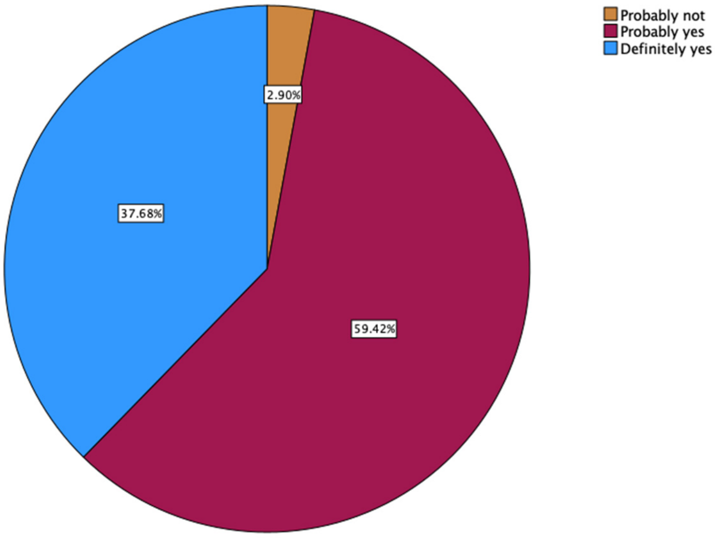


Figure 3. Percentages (%) of teacher students' responses to the questionnaire: "As future teachers, would you use ARTutor (or similar software) to provide your students with augmented learning materials?".

4.1.1. Benefits for Students

This category encompasses the benefits that teacher students associate with integrating AR-enhanced materials into Science lessons for students. We found four subcategories that are presented below.

a. Students' interest.

A great majority of teacher students (Figure 4) think that their future students would like the use of AR-enhanced materials, making the lesson more fun for them (Figure 5).

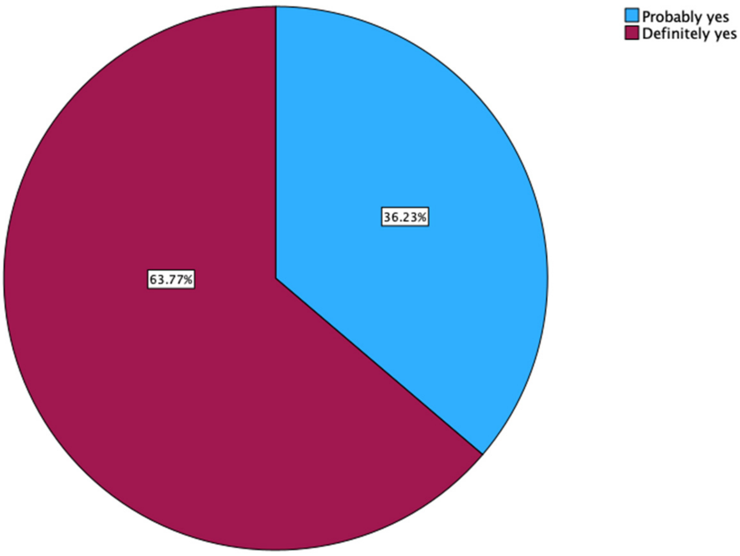


Figure 4. Percentages (%) of teacher students' responses to the questionnaire: "Do you think that your future students would like the use of augmented learning material?".

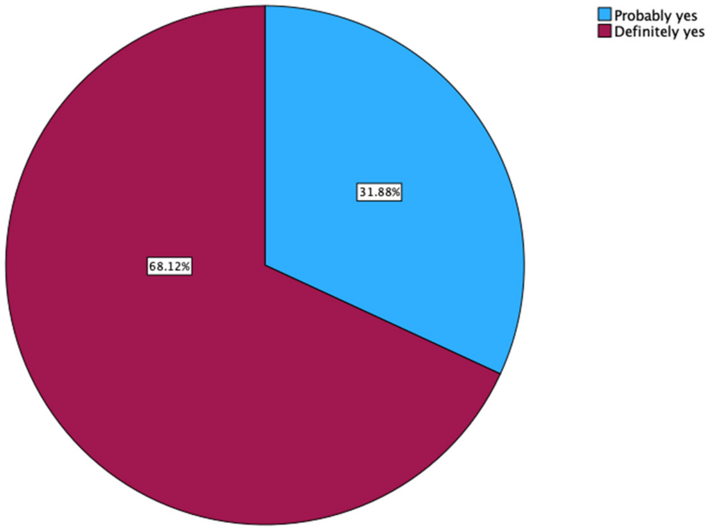


Figure 5. Percentages (%) of teacher students' responses to the questionnaire: "Do you think that the use of augmented learning materials would make the lesson more fun for your future students?".

Examples of teacher students' quotes are presented below, highlighting the focus on leveraging students' interest:

1:19 I believe that children these days, in pre-school and primary school, are very familiar with technologies. Technology is evolving, and it will be more interesting for the children if the lessons are conducted in this way.

2:33 Personally, I had never used it before, neither in elementary school nor up until now. It's very interesting and offers tremendous possibilities. The fact that we could see things we couldn't see with our naked eyes is unprecedented and very impressive. And I believe that younger children, let's say, are extremely excited, and it makes the entire educational process attractive and joyful.

b. Active engagement.

Based on the questionnaire results, all teacher students believe that AR teaching materials could enhance students' motivation to participate in educational activities (Probably yes: 53.6%, and Definitely yes: 46.4%) and, consequently, lead to more active participation in the lessons (Probably yes: 49.3%, and Definitely yes: 49.3%). Based on the focus group discussions, it is evident that teacher students recognize the potential of AR technologies to support students' active engagement in an inquiry-based learning environment, fostering a sense of autonomy. Quotes from teacher students' discussions are presented below:

1:66 I believe that it helps a lot in how to learn. It provides students direct representations, enable them to be researchers by themselves so that they can achieve a result. Therefore… I would choose it because the students essentially research to be able to complete [worksheets], to use new technologies, so they become like researchers and find the way they will learn and receive the information. They don't get it ready from us [the teachers].

2:65 An additional function is that children assume a more active role in the educational process… They might also take more initiatives…

2:75 Again, it appears to me that the students take on roles, they have autonomy… they use their hands, they scan [to collect information], they engage in a process. They are not passive recipients of information.

c. Support learning: use of representations and interactivity.

This category encompasses teacher students' perceptions of the potential of AR-enhanced materials to support learning. These materials offer the opportunity to utilize 3D models for visualizing invisible objects and abstract concepts. The incorporation of videos, images, and recordings, along with opportunities for interactive experiences, is crucial for teachers in aiding students to grasp Science concepts. Examples of teacher students' quotes are provided below:

2:23 We take an image and incorporate it into the program, showing something, we cannot see with the naked eye. For instance, should I mention the example with the turbine? We couldn't see the turbine; we were looking at a box. We couldn't understand what was inside the box... we couldn't see it. Therefore, we used a 3D model to show students what it's like, and thus, through the AR program, we saw how it the turbine works etc. That's what I was referring to when I mentioned the visualization of spaces and objects.

2:74 I want to add something too. With the ARTutor, there's the possibility of using a 3D model. Now, let's talk about the turbine. We had scanned it, and I remember in the classroom, we added a turbine [3D model], and we could move it around by touching the phone and place it on any surface within the space. The children could walk around it and interact with it... something that isn't possible with just a video or a picture. With AR, it's almost like being there; it's like the object is actual reality, just in digital form.

2:71 We can use it to explore the microworld and the objects within it, helping the students gain greater familiarity with these elements in the future.

1:27 I would like to comment that it was very interesting how, during the augmentation, we could add sound, video, an image, and 3D models. It's not just about adding, let's say, sound. There are so many elements you can incorporate, and this variety helps children understand the concept better.

d. Accessibility/Inclusion.

In this category, we include teacher students' responses that address the enhanced accessibility and inclusion of students through the use of AR technologies. The teachers acknowledged the multimodal opportunities of knowledge presentation for students with disabilities and/or diverse educational needs. Indicative examples are presented below:

1:70 I believe it could play an important role depending on a student's difficulties. For example, if a student has dyslexia, I think such an AR application would be very helpful, allowing them to engage with the material without being overwhelmed solely by writing or reading. It provides the opportunity to avoid materials that are challenging for them. They have the opportunity to use images and videos to better comprehend what they see, compared to only seeing written text on the board. Seeing the content, for instance, in a video or an image can help the child, because it moves away from what challenges them.

1:72 Through the utilization of audiovisual resources, students with challenges like visual impairments can benefit from audio features. Similarly, students with hearing impairments can effectively learn about specific subjects using visual aids. Therefore, I believe this approach enhances our capabilities, particularly in the context of special education for students.

2:5 I want to emphasize accessibility, catering to all the needs of the students... Essentially, it's about ensuring ease of use and access for everyone.

2:19 I talk a lot about the pre-school where there are many children who may not know how to read, for example, and we use the ARTutor to assist them in understanding the activity, or there might be a child who cannot see well. With the ARTutor, we help them to engage with the activity and have the opportunity to follow the class. So, AR can support children with disabilities and help ensure they are able to understand and participate.

4.1.2. Prerequisites for Utilizing AR in the Classroom

This category pertains to the prerequisites that teacher students believe are necessary for utilizing AR-enhanced materials in the classroom. Three subcategories were identified.

a. Teachers' role.

The teacher students believe that effectively integrating AR into the classroom requires a change in the teacher's role. Instead of traditional, teacher-directed instruction, the approach should be more student-directed, with the teacher acting as a facilitator.

2:60 It's the role of the teacher. The key point is that if students learn to work in small groups and collaborate, they won't lose sight of the educational objectives. For example, the teacher could say, "Now we are doing this activity in order to uncover something hidden behind it" to stimulate students' curiosity and guide them.

b. Students' worksheets.

In this subcategory, we included teacher students' responses that highlighted the need for the use and development of student worksheets. They believe that these worksheets should guide students' inquiry using AR-enhanced materials.

2:61 Additionally, shouldn't there also be a worksheet to guide the students on how to proceed? I believe that if it's only the AR application, the main point might be lost. Therefore, with a worksheet, there could be a guided process. The worksheet should outline steps or activities that the children need to follow in order to collect data by scanning [using the AR application], then answer questions, scan again, and answer again.

c. Differences between primary school and pre-school education in AR integration.

Given that the focus groups included both primary and pre-school teacher students, this subcategory encompasses their perspectives on the differences they identify in AR integration between primary school and pre-school education. The teacher students emphasized the need for AR-enhanced materials to be aligned with the appropriate content for different levels of education based on the curriculum. Moreover, they believe that a major difference is that the use of AR in pre-school should aim to elevate students' interest, while, in primary school, it should focus on both interest and content comprehension.

1:84 I believe there will be a significant difference in content. That is, we will present different subjects in primary school and different subjects in pre-school. But I think that even within elementary school, there is a difference in what we will present. That is, as a teacher, I would aim to achieve different educational objectives for 1st grade students compared to 6th grade students. It depends on what I would want to help students learn and gain from the AR experience.

1:87 Maybe in pre-school, we try to approach it more simply and not focus on content understanding. Perhaps we aim to enhance their interest so they pay attention and then explore something, rather than explicitly teaching them something. Whereas in elementary school, based on the ideas mentioned, such as learning about the circulatory system, I imagine the children need to learn about it.

4.2. Teacher Students' Views as Learners

The second theme refers to teacher students' views on how they perceived, as learners, the process of developing AR-enhanced materials during the lessons. Three categories were identified under this theme: enhanced interest and engagement of teacher students, and enrichment of teacher students' knowledge, as well as perceiving a sense of innovation.

4.2.1. Enhanced Interest and Engagement of Teacher Students

Drawing from the quantitative data, a significant majority of educators expressed a favorable viewpoint toward the integration of AR elements into teaching materials. Specifically, 53.6% of respondents deemed the process to be very interesting, while an additional 43.5% rated it as interesting to a great extent. Additionally, the majority of teacher students think that this process helped them a lot (50.8%) or to a great extent (40.6%) to engage more actively in the educational process during the lessons. In line with these quantitative results, several statements from teacher students based on the focus group discussions reveal their interest and engagement.

2:27 I found the process very interesting because there was a lot of freedom. I mean, I had many ideas on how to develop, let's say, a worksheet, how to enrich it.

1:40 What I want to convey is that we essentially engaged very interactively with the subject as students. On one hand, you provided us with the basic knowledge and guidelines on how the AR application works, as well as what steps to follow... On the other hand, we had to provide the answers... I mean, to create our own material, search for information, and enrich the material with AR elements. It wasn't just you conveying information using a PowerPoint or a board. We were the ones who drove the lesson based on what we found and recorded.

1:44 What I want to say is that, in essence, to add material to the ARTutor, we first had to study extensively to find the appropriate material and definitely we had to participate more in the lesson, to be more active. In other words, to create all this [the AR enhanced material], it's not just about opening the ARTutor and inserting anything without thought. It requires study and research behind it. Personally, I remember before starting to do it, I would study the PowerPoint presentations you uploaded to get an idea of how to approach the whole topic from the beginning. This allowed us to more easily and comfortably engage in the enriching process and participation in the classroom.

4.2.2. Enrichment of Teacher Students' Knowledge

Based on the quantitative data, the majority of teacher students answered that the process of enriching the teaching material with AR elements helped them to better understand the subject matter (A lot: 52.2%; To a Great extent: 37.7%; and Not really 10.1%). Based on the qualitative results, this category included teacher students' statements that confirm the quantitative results, by referring to the contribution of the AR enrichment process to the understanding of the subject matter by the teacher students. Indicative statements were as follows:

2:44 We searched for information about the parts of the hydroelectric power plant, we found images. We tried to find the best possible images that were available and the best information that we could be included in the material, in order to be understandable for the children. So, I think it helped us better understand the subject.

1:36 It was also very beneficial for us, as we created videos that presented experiments, we conducted, which we would then teach to the children [the videos were part of the AR-enhanced material]. Reviewing and editing these was very helpful for us enhancing our understanding of the experiments.

Teacher students, also, highlight the enhancement of their technological knowledge. For example, a teacher student mentioned the following:

1:38 Also, through this process, we learn other applications. That is, we learn how to use an application to edit a video and then use it to create an augmentation to include in the book we are making. This also involved learning how to upload videos to YouTube and utilize in the AR application. Thus, we learned several things.

4.2.3. Sense of Innovation

Teacher students underscored that the AR enrichment process elicited a sense of working on something innovative.

1:20 Students don't receive as much exposure to new technologies in school as they should, despite significant technological advancements. From my perspective, drawing on my personal experiences as a primary student and my role as a university teacher student, there's a substantial gap between the potential of technology and what schools currently implement; there's a lack of alignment. The unique aspect of this application, for me, is it something different, something innovative, it a technology that typically is not used in the classroom.

4.3. Easy to Use

The third theme concerns teacher students' statements that were referred to the AR technology as easy to use. This theme included two subcategories: easy to use by the students and easy to use by the teachers.

4.3.1. Easy to Use by the Students

This category comprises three sub-categories: students as readers, students as creators, and students as co-creators.

a. Students as readers.

Based on the quantitative results, Figure 6 shows that the majority of the teacher students believe that their future students could easily use the AR teaching material as simple users, i.e., readers.

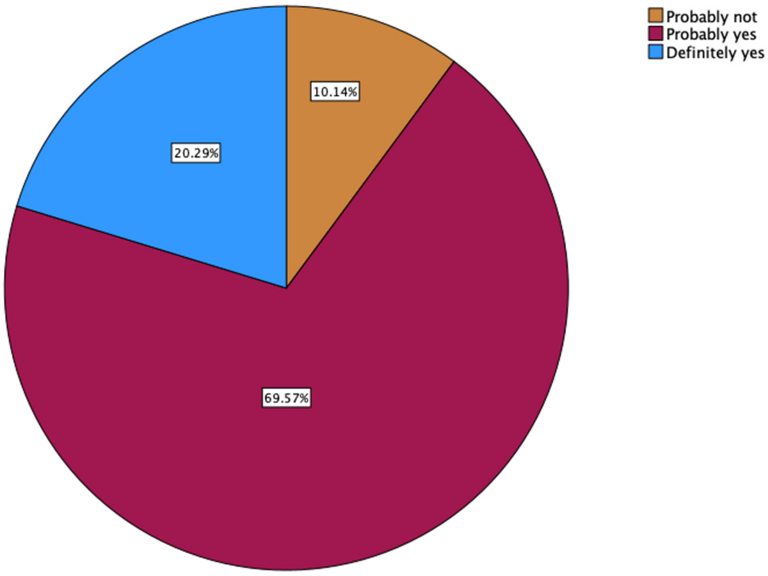


Figure 6. Percentages (%) of teacher students' responses to the questionnaire: "Do you think that the use of augmented teaching material would be easy from your future students' point of view (use as simple users/readers)?".

Based on focus group discussions, teacher students indicated that they believe the AR-enhanced material is easy to use for both primary and pre-school students, acting as readers. Indicative examples are presented below:

> *1:53 They will definitely be able to use it... children are familiar with the technology... they could scan something.*

> *1:55 I also believe that it is very easy for the children to use it. Now we see even small kids grabbing a phone, turning it on, and using it. Certainly, in primary school, it is much easier for them to use it.*

b. Students as creators.

The teacher students believe that, based on appropriate guidance, upper primary school students could create AR-enhanced materials. Some examples are as follows:

> *2:51 A 5th or 6th grade student, I believe could do it. However, a pre-school child or a child from the lower grades of primary school, I think would struggle a bit to do it. But a child from the upper grades of primary school, I believe, would be able to do it. They could manage it.*

> *1:57 The students themselves could create an ARTutor book with, of course, the guidance of the teacher.*

c. Students as co-creators.

Some teachers identified that, even if students find it difficult to create AR-enhanced materials, both in primary and in pre-school education, the students could contribute to the enrichment process in several ways. For instance, they could choose or create images, videos, and recordings with relevant information pertaining to the subject matter.

1:61 The students could think and decide which of all turbines would like to add as an augmentation. Moreover, they could choose the mode of the augmentation: a video, a recording? And why? Then, together with the teacher, by accessing the Internet, they search information and create the final augmentation.

1:63 The students could create drawings, and we could turn them into augmentations.

4.3.2. Easy to Use by the Teacher Students

Based on the quantitative results, the majority of teacher students found it easy to use the ARTutor to create their own augmented teaching materials (Figure 7). This argument is also evident in focus group discussions. Some examples are as follows:

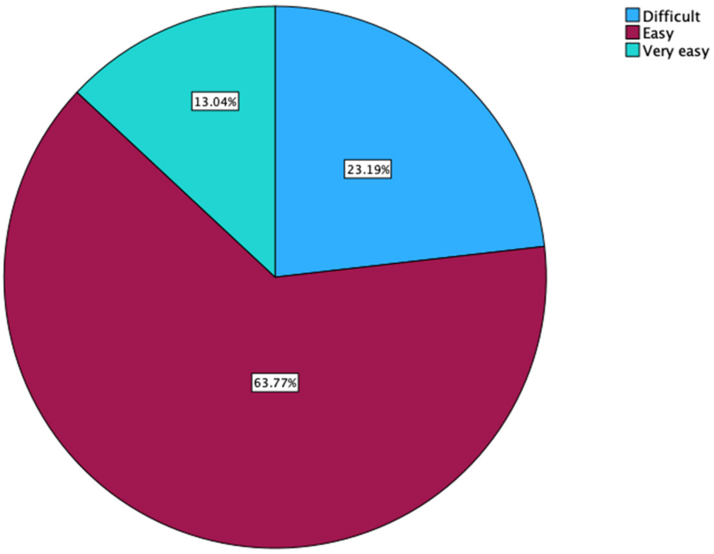


Figure 7. Percentages (%) of teacher students' responses to the questionnaire: "How difficult or easy did you find it to use ARTutor to create your own augmented learning material?".

1:29 As a teacher, I believe that creating AR materials would be very easy.

2:50 Personally, I didn't find it particularly difficult. Because I was already familiar with the computer and simply followed the steps and did it.

4.4. Challenges

The fourth theme encompasses the challenges that teacher students perceive in creating AR-enhanced materials or using them in classroom. This theme includes three categories.

4.4.1. Technical Difficulties

In this category, teacher students' responses that referred to technical difficulties encountered during the use of the ARTutor authoring tool for developing the AR-enhanced materials are included. These difficulties addressed the distinction between QR codes, trigger images, and augmentations, as well as the compatibility of files that could be used, such as 3D augmentations or audio files.

1:37 I recall the first instance I attempted to create augmentations... having never attempted it before, I encountered mistakes that were imprudent, and due to this, it appeared challenging to me. For instance, despite having created the augmentations, in order to see them with the cell phone application, you conduct a scan of a QR code and *then move over the [trigger] image, and the augmentation appears. I had neglected that basic step; I hadn't initially scanned the QR code. That elementary step was not clear to me.*

4.4.2. Substantial Time

Students emphasized the need for substantial time in the creation of AR-enhanced materials, as depicted in the following teacher student quote:

2:46 If you are not familiar with it [the process of enriching the educational material with AR elements], I consider it is challenging. I mean, it requires time. You need to investigate how it works. If you have an image and you also you are familiar with computers, perhaps things might go a bit easier. But okay, if you dedicate the right amount of time, it' s not so difficult.

4.4.3. Disturbs Students' Attention for the Learning Objective

This category reflects teacher students doubts on the potential of AR-enhanced materials for educational purposes. Specifically, a teacher student highlighted a concern that the AR technology might divert students focus from the learning objectives, leading them to use the materials solely for entertainment.

2:57 Nowadays, children as young as two begin interacting with technologies. Nonetheless, I have concerns about their ability to remain concentrated on the notion that "we are undertaking an activity to learn something substantive" as opposed to thinking, "oh, I'm just picking up the tablet to play".

5. Discussion

The aim of this study was to explore primary and pre-school teacher students' views on AR integration in Science Education after participating in university courses related to Science Education in formal and non-formal settings. Four main themes were identified: (a) teacher students' views as prospective teachers, (b) teacher students' views as learners, (c) ease of use, and (d) challenges. In what follows, the findings of this research will be discussed in conjunction with the existing literature to provide the reader with a more comprehensive understanding of these issues. This approach aims to contextualize our results within the broader academic discourse, thereby offering insights into their significance and implications for both theory and practice.

Firstly, teacher students revealed their perspectives on AR integration as prospective educators by acknowledging significant benefits for their future students, particularly highlighting the potential of AR-enhanced materials in Science classrooms to have positive motivational and cognitive effects. Specifically, teacher students believe that AR integration will boost their students' interest and active engagement. This finding is consistent with the previous literature, where researchers have reported that both in-service primary and secondary teachers agree that AR can enhance students' interest and engagement [6,7,22]. Furthermore, empirical studies have affirmed that the application of AR in Science Education can indeed amplify student interest and engagement [3–5]. In addition, teacher students, aligned with the literature [22,23], believe that AR integration could support student learning through the potentials offered by the use of representations. The incorporation of representations, such as 3D models in AR-enhanced materials, along with the opportunity to interact with them, enables students to view objects from various perspectives. This interactivity extends to exploring the interior of complex objects, facilitating observations of elements that are not visible to the naked eye, such as the structure of a cell. Consequently, this approach helps in concretizing abstract knowledge, thereby rendering the scientific content more comprehensible [4,22]. There is substantial research in Science Education literature supporting the use and creation of external models as representations of concepts, demonstrating their effectiveness in helping students comprehend abstract concepts [30,31]. We argue that the advent of AR applications seems to offer promising opportunities for using or creating models in digital forms for Science concepts. Furthermore, the teacher students believe that AR-enhanced materials can enhance accessibility and inclusion for all students. Indeed, the literature states that AR could eliminate the barriers that prevent students' active participation, e.g., by supporting students with special educational needs learn "in a real way what they cannot or have not been able to access. . ." [32] (p. 3). In addition, the teacher students referred to the prerequisites for utilizing AR in the classroom. They believe that integrating AR technologies into Science lessons teachers should implement student-centered instruction. In particular, they emphasize the importance of fostering collaboration among students in small groups and leveraging their curiosity. Additionally, they recommend providing students with worksheets to guide their learning process, such as those for data collection related to the investigation's objectives. This perception aligns with the inquiry-based learning approach, which is student-centered and fosters active participation by students in constructing knowledge [18,33].

Secondly, teacher students were found to recognize that their involvement in developing AR-enhanced materials not only heightened their interest and engagement in the course, but also broadened their knowledge and fostered a sense of innovation. Considering the limited empirical research focusing on teacher students as creators of AR-enhanced materials, this insight is significant. Teacher students identified common benefits for themselves and their future students, such as enhanced engagement and knowledge acquisition. This outcome is promising, as recognizing the effectiveness of the technology firsthand could encourage them to incorporate it into their teaching practices, since as Perifanou et al. [6] (p. 1) stated "Teachers are catalysts in the educational process" who decide whether to integrate a new technology into the classroom or not.

Thirdly, the teacher students perceived the ARTutor application, used to create the AR-enhanced materials, as easy to use for both themselves as creators and for their future students as readers. This finding is in line with the literature that states that ARTutor is easy to use for both teachers who can easily create augmentations and for students that can view the digital content using the mobile application [25]. Furthermore, the teacher students identified opportunities for their future students in utilizing ARTutor as creators—mostly in upper primary school—or co-creators. In the case of creators, they believe that, based on teachers' guidance, students can create AR-enhanced materials, while, as co-creators, students could collaborate with the teacher in the enrichment process, e.g., by choosing or creating images or videos for augmentations.

Fourthly, the teacher students identified challenges in AR integration in the classroom that are related to technical difficulties, and the substantial time for the creation of the AR-enhanced material, as well as the potential of such materials to divert students' attention from the learning objectives. Addressing these technical difficulties could involve enhancing the training courses that deal with these issues and providing more support to teachers in practice to help them overcome these challenges. The perspective that teacher students need substantial time to develop AR educational materials aligns with the teacher experiences documented in the literature [3,21]. The effective integration of AR in Science Education requires ongoing teacher training, practical applications, and feedback, while also collaborating with colleagues [6,20]. Additionally, Generative Artificial Intelligence offers promising applications that could help reduce teachers' workload [34], such as facilitating the rapid creation of instructional content [35] that could be used in augmentations. Furthermore, it is important to note that the existing literature has acknowledged the risk of AR technologies distracting students' attention [3], an issue that warrants further investigation in the Science Education field.

Despite the important findings of this study, it is crucial to highlight the limitations of the present research. This study was carried out in departments in which females make up 80% of the student population, a ratio that does not match the gender demographics seen in other academic departments. Additionally, the study utilized a particular platform, application, and AR environment. Future research could explore this method in varied educational settings and with alternative augmented realities.

6. Conclusions

The current study provides insights concerning teacher students' views on the use of AR in Science teaching and learning. The findings seem to highlight the potentials, the challenges, and the obstacles that teacher students project to their future practices; underscore their expectations on the impact of AR utilization on their future students; and reveal issues that should be addressed by teacher preparation programs. Despite the fruitful results of this research, further studies are required to explore students' views on the potentials of the utilization of AR technologies in Science teaching and learning by exploring the use of various AR environments, teaching strategies, and settings.

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