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Teachers' Views on Integrating Augmented Reality in Education: Needs, Opportunities, Challenges and Recommendations

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Abstract: The integration of augmented reality (AR) in education is promising since it enhances teaching and offers more engaging and appealing learning experiences. Teachers can have a catalytic role towards the adoption of AR in education; therefore, their perspectives with regard to AR in teaching and learning are very important. The current study explores teachers' views on the integration of AR in education through an open-ended questionnaire that has been answered by 93 educators worldwide. A set of digital skills that can support student-centered pedagogies in an appropriate infrastructure are the main requirement for effective teaching with AR. Among the perceived benefits and opportunities are interactive teaching and learning, increased interest and engagement, better understanding of complex concepts. As barriers, participants reported the lack of AR educational applications, the cost of buying and maintaining AR equipment and resources, the lack of teachers' and students' digital skills, classroom management issues, and security and ethical issues. Moreover, survey participants highlighted the need for raising teachers' awareness for the added value of AR in education and the need for teachers' continuous professional development. Implications and future research recommendations on the integration of AR in education are discussed.

Keywords: augmented reality; augmented reality in education; augmented reality in teaching; teachers' perceptions; teachers' skills; teachers' training

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1. Introduction

Augmented reality (AR) enables users to view and sense an augmented environment with superimposed virtual objects [1,2]. In this way, the users can visualize abstract and complex concepts as well as additional information [3]. In addition, the users can interact with both the real and the virtual objects in real time.

AR has been applied in many fields including education [3–6], mostly in Natural Sciences and Mathematics for undergraduate students [3,5]. Literature reviews have shown that AR increases the students' content understanding, motivation, interaction, and collaboration [3,5,7]. More specifically, AR has a medium effect on the learning gains of students and is more effective than using other multimedia resources, traditional lectures, or traditional pedagogical resources (e.g., labs, games) [4,5].

While many studies exist that explore the educational advantages of AR, not many studies exist that investigate teachers views on the integration of AR in educational practice. Teachers are catalysts in the educational process. So, they should be involved in any educational intervention including technological ones. AR is a new technology that has not yet been introduced in the educational system except from some sporadic experimental cases. Teachers would become the early adopters of AR in order to transfer and infuse their AR knowledge and skills into their teaching. Thus, it is important to understand the teachers' views about integrating AR in education (ARinE). However, previous

studies [8–10] point out that there is limited research on teachers' perspectives with regard to AR in school teaching and learning.

The current study is aiming to increase the understanding of the teachers' perceived opportunities and challenges regarding the integration of AR in education as well as to capture teachers' needs and their recommendations to effectively integrate AR into their professional practice. Thus, the study will try to shed light to the following research questions (RQ):

RQ1: What do teachers think about the level of their AR competences?
RQ2: What do teachers think are the important digital skills for integrating AR in education?
RQ3: How easy do teachers find AR educational resources?
RQ4: What do teachers think are the safety, security, and ethical issues that are associated with using AR in education?
RQ5: What pedagogical and teaching methods would teachers use for integrating AR in their teaching?
RQ6: What do teachers think are the benefits and opportunities that AR can offer to education?
RQ7: What do teachers think are the obstacles and challenges that may prevent AR to be integrated in education?
RQ8: What recommendations do teachers propose to overcome these obstacles?

The following Section 2 presents previous studies on teachers' views with regard to the integration of ARinE. Section 3 describes the research methodology followed by the current study and Section 4 presents the results. Finally, Section 5 presents the main conclusions of this study and Section 6 suggests future research directions.

2. Previous Studies on Teachers' Views about AR in Education

Although there are many studies that investigate AR educational applications as well as the students' views, experiences, and results of using ARinE [3–5,9,11–15], few studies analyze the teachers' points of view. This is an important factor to be considered in order to maximize the capacity of this technology in education.

In general, teachers show a positive attitude towards using ARinE [16,17]. They think that AR increases quality of teaching, autonomous and collaborative learning [17] and promotes students' exploratory behavior [8]. It can also promote student interactions and the interactions between students and learning material [17]. They believe that AR enables visualization of abstract concepts making them more understandable, facilitates students to understand learning content better, increases knowledge retention and thus improves learning [9,17–19]. Additionally, they recognize that AR increases students' positive attitude, enjoyment, interest, motivation, curiosity, and knowledge durability [8,9,17,19]. Teachers reported that AR can increase learning interest, it has the potential to enhance learning motivation [8,9], promotes a positive attitude, enhances satisfaction, and can raise engagement [17,19].

However, most teachers do not have any experience on AR [10,20]. More specifically, they do not have appropriate technological and pedagogical skills [16,21] such as programming skills and using 3D design software [22] as well as practical knowledge on AR content creation and integration in education [17]. Furthermore, they believe that a number of constraints prevent the wide adoption of ARinE. Such constraints include the AR cost [10,17,19], the lack of quality AR resources [9,10,21], the lack of time [10,18,19,22], the lack of digital infrastructure ([8,16,18], and the lack of institutional support [21].

Regarding students' attention there are contradictory results: some teachers state that students lose attention to the AR app because they use their devices for other reasons [8], while other teachers argue that AR captures students' attention and can increase students' cognitive load [9]. In addition, teachers believe their students lack appropriate skills and they require long time to become able to run AR apps [8], therefore the overhead required

to overcome these usability issues is not usually desirable. Finally, several previous studies urge for teachers' training on using ARinE [10,17,18,21,22].

3. Methodology

In order to capture teachers' opinions and perspectives about the integration of ARinE, an online questionnaire with open-ended questions was developed by the researchers, aiming to record teachers' views on the required digital skills, pedagogical aspects, AR resources, safety/security and ethical issues for integrating AR in education.

Once ethical approval was granted by the University of Strathclyde ethics committee, researchers disseminated the questionnaire internationally through teachers' social media channels (e.g., Facebook and Linkedin teachers' professional groups) and teachers associations' discussion email lists, during the period from May to June 2022. All communication channels used were related to the teaching profession (primary, secondary, tertiary, and life-long learning education).

The first page of the online questionnaire informed participants about the aim and context of the research study, their confidential, anonymous, and voluntarily answering of the questionnaire, as well as their right to withdraw at any time. After signing the consent form, a participant could answer the online questionnaire. The questionnaire had two parts. The first part included a series of socio-demographic and teaching related questions namely: gender, age, country of teaching, general digital skills level (basic, intermediate, advance), level and subject of teaching as well as previous experience with AR. The second part included four open-ended questions as follows:

(1) "What digital skills do you think are most important for integrating AR in teaching and what aspects of your digital skills do you think need to be improved in order to use AR in your teaching?"
(2) "How would you integrate AR in the subjects that you are teaching? (Any example?) and what pedagogical aspects would you consider in organizing an AR lesson?"
(3) "How easy can you find AR resources (from existing open source or commercial AR repositories) and judge their accuracy and relevance?"
(4) "What safety/security/ethical factors do you think that are associated with the use of AR in teaching?"

A total of 93 responses were collected via Qualtrics. Participants were 52% female, 44% male, 2% preferred to self-describe, while 2% preferred not to say. Their distribution in terms of their age was, 41–50 years old (37%), 51–60 years old (20%), 61–70 years old (18%), 31–40 years old (13%), and 21–30 years old (12%). Participants were from USA (15%), UK (14%), Greece (12%), Malta (7%), Australia (5%), India (5%), Malaysia (5%), Portugal (3%), and 34% from other countries with lower participation. In terms of their general digital skills level, 8% of the participants had basic digital skills (use of a basic range of software such as office; and devices such as computer, tablet), 40% had intermediate digital skills (use of a big variety of software such as Screencastify, Audacity; and devices such as smart interactive whiteboards), and 52% had advanced digital skills (use of highly innovative and complex digital and communication technologies such as programming, software development, network management).

Most of the participants were teaching in tertiary education (56%) with the secondary education (22%) and primary education (12%) to follow, while 10% of the participants described the education level they were teaching as other. Their teaching experience in years was varied with 23% to have 6–10 years teaching experience, 21% to have 16–20 years teaching experience, 15% with 21–25 years, 12% with 1–5 years, 10% with 31–35 years, 10% with 11–15 years, and 9% with 26–30 years. The distribution of the participants in terms of the subject they were teaching was Informatics/Engineering/Technology 54%, Science (Math, Physics, Chemistry, Biology) 22%, Languages/Literature 10%), Economics/Social Sciences 4%, and other 10%. Finally, regarding the previous use of AR in class, 36% replied that they had used AR in class before while 64% said they had not. The

respondents' socio-demographic and teaching related characteristics are presented in Tables 1 and 2, respectively.

Table 1. Participants' socio-demographic characteristics (*N* = 93).

Gender	%	Age (Years Old)	%	Country	%	General Digital Skills Level	%
Female	52	21–30	12	USA	15	Basic	8
Male	44	31–40	13	UK	14	Intermediate	40
Prefer to self-describe	2	41–50	37	Greece	12	Advanced	52
Preferred not to say	2	51–60	20	Malta	7		
		61–70	18	India	5		
				Australia	5		
				Malaysia	5		
				Portugal	3		
				Other	34		

Table 2. Participants' teaching related characteristics (*N* = 93).

Teaching Level	%	Teaching Experience (#In Years)	%	Teaching Subject/ Discipline	%	Previous AR Use in Class	%
Primary	12	1–5	12	Science (Math, Physics, Chemistry, Biology)	22	Yes	36
Secondary	22	6–10	23	Informatics/Engineering/Technology	54	No	64
Tertiary	56	11–15	10	Economics/Social Sciences	4		
Other	10	16–20	21	Languages/Literature	10		
		21–25	15	Other	10		
		26–30	9				
		31–35	10				

In total 93 responses were received. Data in the participants' answers to the open questions were analyzed using content analysis [23]. Content analysis is a continuous repeated process of coding the raw data, categorizing the codes, and then returning to the raw data to reflect on the previous steps. In content analysis, the researchers not only identify and count words, but also interpret the context associated with the use of the words and explore the range of meaning that a word can have [23]. The data were coded by two researchers experienced in content analysis. Each researcher repeatedly read all data to understand deeply the data and get an idea of the whole. Then, each researcher read again word by word and highlighted specific words or phrases that seemed to capture important perceptions, viewpoints or concepts. Next, each researcher assigned code names to the words or phrases and repeated the process. Then, the researchers discussed their assigned codes, and they came to a consensus regarding the coding scheme. Afterwards, they categorized the codes into categories that contain related codes. They repeated the whole process until they agreed that all codes were properly categorized. A third researcher discussed with them and concluded on the final coding scheme and categorization. Finally, they counted the frequency of codes and selected examples for each code.

Section 4 presents the results of the content analysis.

4. Results

4.1. Teachers' Digital Skills for Integrating ARinE

Regarding the double open question "What digital skills do you think are most important for integrating AR in teaching and what aspects of your digital skills do you think need to be improved in order to use AR in your teaching?", most participants recognized programming to be the most important digital skill for integrating AR in teaching and they need to improve it (Table 3). Many participants suggested as important that they also needed to improve the advanced AR skills such as 3D modeling, design, and development as well as 3D animation, while others the basic AR skills. In addition, some participants regarded as important other advanced digital skills such as game programming, simulations, user interface design, video and photo processing or even basic digital skills such as digital and information literacy, e-learning skills, and using hardware.

Table 3. Important teachers' digital skills in order to integrate AR in teaching.

Digital Skills	Frequency	Example
Programming	20	*For Vuforia or Arcore apps (with Unity for example), a strong programming background is necessary.*
Advanced AR skills and 3D modeling, design, animation, developing	16	*Three-dimensional animation and modeling skills.*
Basic AR skills	11	*Understanding of how to use AR technology.*
Innovative Pedagogy and Instructional Design	10	*Immersive storytelling pedagogy.*
Soft skills for the digital society	9	*Adaptability and openness to new ways of teaching and learning.*
Advanced digital skills	7	*Game programming.*
Basic digital skills	4	*Being able to operate different digital platforms and tools, knowing how such platforms function overall.*

Emphasis was also given to innovative pedagogical and instructional design skills such as matching technology to educational goals, immersive storytelling pedagogy, and technological pedagogical content knowledge. Finally, teachers also mentioned other important soft skills such as problem solving, creativity, presentation skills, communication skills, the desire to learn new things, adaptability and openness to new ways of teaching and learning, and the willingness to take risks. On the other hand, one teacher expressed doubts about the usefulness of AR in class.

Previous studies confirm that in general teachers do not have the programming and 3D modeling skills that are required for designing and developing AR experiences [3,5,11,12,17,21,22,24–26]. Therefore, they would like to receive training on using AR in their teaching practice [10,12,20–22,24,27].

4.2. Pedagogical Approaches and Teaching Methods for Integrating ARinE

Regarding the double open question "How would you integrate AR in the subjects that you are teaching? (Any example?) and what pedagogical aspects would you consider in organizing an AR lesson?", participants suggested a variety of student-centered instructional/ teaching methods to be used in integrating AR in class to support teaching and learning (Table 4). Most of them thought that AR fits well with situated/ place-based learning. Some participants also mentioned game-based learning, collaborative learning, project-based, interactive learning, virtual labs, inquiry-based learning, student makers, problem-based learning, storytelling, and more. However, one participant stated that he would not integrate any of it.

Table 4. Student-centered instructional/teaching methods for integrating ARinE.

Student-Centered Instructional/Teaching Methods	Frequency	Example
Situated/Place-based learning	8	*Scenarios for leadership development where they can test their real skills on various responses to a situation.*
Game-based learning	5	*Use of avatars and games in teaching.*
Project-based learning	4	*Project-based pedagogical methods.*
Collaborative learning	4	*This would let pupils experience how museums and galleries work as well as having to collaborate with others.*
Interactive learning	4	*Students can use their avatars and interact with each other.*
Virtual labs	4	*Immersive experiments in the laboratory.*
Inquiry-based learning	3	*POGIL (Process Oriented Guided Inquiry Learning).*

Previous studies recognize that collaborative learning using AR educational resources is the most beneficial teaching method for students [3,11,24,28–31]. Similarly, previous studies found that situated-based learning is the most common AR-based pedagogical approach [3,15,28,32,33]. Other suggested teaching methods include game-based learning [3,15,25,32], project-based learning [14], interactive learning [3,24,30,34], virtual labs [12,14,35], and inquiry-based learning [8,15,32,33,36].

The participants emphasized particularly the affordance of AR to visualize tangible or intangible resources (e.g., information, abstract concept, idea, process, real or imaginary object) that are not physically there in the real world (Table 5). For example, they suggested using AR in order to visualize planets, molecules, organs, animals, remote places, galleries, mathematical concepts, physics and chemistry experiments, dynamic processes, and more. Previous studies also point out the AR affordance to visualize abstract concepts or unobservable phenomena, such as electron movements or magnetic fields [6,37,38].

Table 5. Affordances of AR.

AR Affordances	Frequency	Example
Visualization and Virtualization	24	*Visualize a difficult concept, visualize planets, animals, part of the body, visualize abstract mathematical concepts, virtual labs structures in biology, and atomic and molecular structures in chemistry.*
Augmentation	6	*Some added layers of information.*
Interactivity	4	*For tasks that require interactive actions with annotated guidelines is very useful.*

Furthermore, in line with previous studies participants appreciated the augmentation (e.g., added layers of info, annotated guidelines, audio attached to object) and interactivity (e.g., person to virtual object, person to person using avatars) affordances of AR [24,30,34].

Finally, the participants suggested that AR can be integrated in various educational subjects such as Medicine, Biology, Physics, Chemistry, Mathematics, Languages, Arts, and Social Science (Table 6).

Table 6. Educational subjects (disciplines, fields) for integrating ARinE.

AR Application in Subject/Discipline/Field	Frequency	Example
Medicine	6	*We have used AR to turn lifeless resuscitation dummies into bleeding patients for paramedic training.*
Biology	3	*Visualize animals.*
Physics	2	*Visualize planets.*
Chemistry	2	*Atomic and molecular structures in chemistry.*
Mathematics	2	*To visualize abstract mathematical concepts.*
Languages	2	*Incorporated into digital storytelling in literacy/languages.*
Arts	2	*Gallery visits, artworks up close.*
Social Science	2	*Things that could be integrated in social studies or art and other humanities where we can have students experience things that they cannot travel to go and see.*

AR has been applied in various educational subjects (disciplines, fields) such as science, engineering, and social sciences [4,5,9,11,15]. Most AR applications were applied in science, as well as in humanities and Arts [3]. Actually, AR has a very large effect on students' learning in engineering, manufacturing, and construction and a large effect in arts and humanities [4]. It has a medium effect in the disciplines of social sciences, journalism and information, natural sciences, mathematics and statistics, as well as health and welfare [4]. However, it has a small effect in the disciplines of information and communication technologies as well as education [4].

4.3. Easiness to Find and Evaluate Educational AR Resources

Regarding the question "How easy can you find AR resources (from existing open source or commercial AR repositories) and judge their accuracy and relevance?", participants' opinions were almost evenly distributed between easy and difficult to find AR resources (Table 7). The few previous studies that investigated the easiness to find AR resources [9,39] concluded that it is difficult to find AR resources or that the AR resources do not match educators' requirements. So, it is possible that some participants in the survey overestimated the availability of subject-specific AR educational resources, or they were thinking only about AR authoring tools.

Table 7. Easiness to find educational AR resources for integrating ARinE.

Easiness to Find Educational AR Resources	Frequency	Example
Easy to find	15	*Nowadays many free sources are available if it comes to objects, models.* *It is quite easy to find simple AR resources from specific AR platforms/ apps.*
Difficult to find	16	*It's not easy to find quality resources.* *I don't find easy AR resources for schools, there are some games or videos with no really educational content.*

The participants also expressed worries about the AR resources' cost, sustainability, relevance, and accuracy issues (Table 8).

Table 8. Evaluating educational AR resources.

AR Resources' Evaluation Issues	Frequency	Example
Cost issues	4	*Some cool models are quite costly unfortunately.*
Sustainability issues	1	*Difficult to find anything that is affordable and has sustained presence in the market.*
Relevance issues	1	*Ready-made resources most of them are at a high price and not always relevant.*
Accuracy issues	1	*However, judgement of accuracy and relevancy are always challenging in these aspects.*

Similarly, previous studies also highlighted the AR high costs as well as various AR sustainability issues [14,24,26,40–43]. Furthermore, other studies investigated AR relevance [41] and accuracy issues [29].

4.4. Security, Safety, Privacy, and Ethical issues of integrating ARinE

Regarding the question "What safety/security/ethical factors do you think that are associated with the use of AR in teaching?", participants conveyed concerns regarding AR security, ethics, privacy, physical safety, and accessibility (Table 9). Security and privacy are the major challenges in AR applications [44] while security leaks can cause serious problems such as personal data theft and identity hacking [45]. [46] found that AR may threaten other people's privacy but not the privacy of the AR users. However, [47] found that users of AR applications worried whether sensitive resources on their smartphone are accessed by the AR applications.

Table 9. Security and ethical issues in integrating ARinE.

Security and Ethical Issues	Frequency	Example
Security	6	*More control of what the students can view in case of HMD (Head Mount Displays).* *Password securing the participant entrance to the AR application.*
Ethics	5	*Ethical aspects are of greatest importance of course, specifically in the presence of synthetic human-like embodiments.*
Privacy	3	*Reading privacy policies is hard.* *A lot of them are not designed for educational use; therefore, issues such as privacy and adherence to the standards is difficult.*
Physical safety	2	*Safety issues are mostly around distraction when moving in a physical space.*
Accessibility	1	*Accessibility is another important issue.*

In addition, AR applications may cause ethical problems with regard to superrealism, confusion between real and virtual, psychological and social issues [45]. Correspondingly, AR users exhibit low situation awareness and thus learners are exposed to risks such as pedestrian-vehicle accidents [48]. Finally, only a few AR applications consider users with special needs [3,5,12].

4.5. Benefits and Opportunities of Integrating ARinE

Regarding the open question "What benefits and opportunities do you think that AR can offer to education?", participants believed that ARinE offers a variety of benefits and opportunities for students and teaching. More specifically, they mentioned that AR can increase students' interest, engagement and commitment, motivation and enthusiasm, fun and enjoyment, thinking skills, creativity, and inclusiveness (Table 10). Using 3D visualization, AR can facilitate students' understanding, exploration and explanation (e.g., complex concepts), interaction, and presentation of their ideas. Finally, AR can enable students' experiences that previously were impossible to live (e.g., from the past, from the future, dangerous experiences, expensive experiences, microcosmos, outer space).

Table 10. Students' benefits and opportunities of integrating ARinE.

AR Benefits and Opportunities for the Students	Frequency	Example
Increase students' interest	8	*Can spark the students' interest.*
Increase students' engagement	8	*Increase student engagement in content.*
Increase students' motivation	5	*Raises students' motivation.*
Increase students' commitment	1	*Increase the commitment and interest of students for the subject studied.*
Increase students' enthusiasm	1	*For students to be more enthusiastic about learning.*
Increase students' fun and enjoyment	4	*Fun of learning would increase.*
Increase students' thinking skills	1	*Improve students thinking skills.*
Increase students' creativity	1	*Promote creativity thinking.*
Increase students' inclusiveness	3	*AR can be used to engage different types of learners.* *This technology is fitting to lifestyle and mentality of new generations/students; inclusivity (in terms of students' mental and physical capacities).*
Facilitate students' presentation of their own ideas	1	*Can offer learners ways to present their own ideas in previously unavailable ways.*
Facilitate students' interaction	10	*You can interact with 3d objects.* *Virtual manipulation of objects.*
Facilitate students' understanding, exploration and explanation (e.g., complex concepts)	12	*making concepts and topics be easily understood by learners;* *Good for visualizing complex concepts.* *It brings something uncommon and unusual as well as not easily to be seen or explained for students, improving understanding of space and concepts that are difficult to see (e.g., in physics, chemistry, medicine).* *Student can learn more detailed by examining the AR object.*
Enable students' experiences previously not possible (e.g., from the past, from the future, dangerous experiences, expensive experiences, microcosmos, outer space)	10	*It can also allow students to experience things which happened in the past/ might happen in the future/ are too expensive or dangerous to happen in real life.* *Allowing you to see or do things that are not*

available or might be dangerous if done in real life.

Many previous studies confirm that AR fosters students' interest and motivation [3,5,11,12,24,41,49]. Additionally, several previous studies found that AR increases students' interest [8,12], engagement [3,12,24,50], fun and enjoyment [3,8,11,12,25,43], problem solving and critical thinking [12,13,36], and creativity [5,24,31,40,41,49].

Furthermore, the augmentation of real environments with virtual objects enables students to experience phenomena that would not be possible in the real world [6,38]. In this way, the AR visualization of complex relationships and abstract concepts facilitates the students' comprehension [3,5,6,9,11,30]. Finally, AR enables interaction opportunities [3,34].

Regarding teaching, participants believed that AR can facilitate interactive learning, experiential learning, authentic learning, situated learning, anyplace anytime learning, problem solving learning, collaborative learning, innovative and alternative teaching methods (e.g., context-informed learning, immersive learning, sense-based learning, affective learning, movement-based learning, visual-spatial learning) (Table 11). They also mentioned that AR can facilitate teaching topics that previously were not possible to be taught as well as visualization of complex concepts, abstract processes, mathematics, problems, space, real world objects, etc.) and reduction in teaching costs (e.g., expensive laboratory equipment).

Table 11. Teaching's benefits and opportunities of integrating ARinE.

AR Benefits and Opportunities for the Teaching	Frequency	Example
facilitate interactive learning	10	*Enables the possibility of interacting with objects/ beings which are not possible in real life.*
facilitate experiential learning	10	*AR can lead to experiential learning.*
facilitate authentic learning	5	*Ensuring more authenticity;* *Authentic experiences;*
facilitate situated learning	2	*Getting students to experience as close to real life situation as possible.*
facilitate anytime anyplace learning	2	*AR can also be employed away from the class without the use of any specific equipment, for instance, microscopes to study small structures.*
facilitate problem solving learning	1	*AR can promote problem-solving activities.*
facilitate collaborative learning	1	*Collaborative opportunities.*
facilitate innovative and alternative teaching methods (e.g., context-informed learning, immersive learning, sense-based learning, affective learning, movement-based learning, visual-spatial learning)	8	*AR can make learning more immersive;* *Context-informed. Employing senses, emotions and understanding affective states;*
facilitate teaching topics previously not possible	9	*Experiences previously not possible within the classroom;* *See things that are not able to see in a normal lesson;* *Bring risky real-world experiences in to safe classroom spaces;*

		Experience things which happened in the past/ might happen in the future; *Are too expensive, or dangerous to happen in real life;*
facilitate Visualization	7	*3D-visualizations and interactions could actually help learners to understand complex problems.* *It also enables visualization of processes which are too abstract for students;*
reduce teaching cost	2	*Instead of seeing something in 2D because you cannot access it due to time/location/financial constraints, you can see it in front of you in 3D;* *Without the use of any specific equipment, for instance, microscopes to study small structures;*

Previous studies also agree that AR supports and fits well with interactive learning [3,24], authentic and experiential learning [3,6,14,26,50], situated learning [3,15,32,33,40], problem-based learning [13,14,28,32,36], and collaborative learning [3,6,14,15,24,28,30,33]. AR also enables visualization [3,5,6,9,37]

4.6. Obstacles and Challenges in Integrating AR in Education

Regarding the open question "What are the obstacles/challenges of AR in education?", participants perceived that there are several obstacles and challenges that prevent the integration of ARinE. These obstacles and challenges are related to the AR technology itself and the AR educational resources, the students, the teachers, the teaching practices, and the schools. According to several participants, the cost of buying and maintaining AR equipment and resources as well as the lack of AR educational content and resources (in various languages, educational subjects, levels, objectives, etc.) impede the wide adoption of ARinE (Table 12).

Table 12. AR technology and educational resources obstacles and challenges in integrating ARinE.

AR Technology and Educational Resources Obstacles and Challenges	Frequency	Example
Cost of buying and maintaining AR equipment and resources	10	*This kind of technology is too expensive;* *Currently AR is often very expensive;*
Lack of AR educational content and resources (in various languages, educational subjects, levels, objectives, etc.)	10	*The obstacle is AR-based learning facilities which are still limited in their existence according to the subject matter and student characteristics;*
Lack of AR tools, immature technology	4	*The main problem is getting access to good tools;* *technological glitches;*
Complexity and difficulty to use AR	3	*Complexity of using the new technologies;*
Security concerns regarding AR	3	*Security concerns;*

Safety concerns regarding AR devices	1	*Students will not (be) harm(ed) from any devices;*

Few participants worried about the immaturity of AR technology and the lack of AR tools, the complexity and difficulty to use AR as well as the security and safety problems with AR.

Previous studies confirm the AR cost [14,24,26,40–43], the lack of AR educational material [21,40], the AR complexity [5,7,11,24,26,35], and the students' difficulty in using AR [11,24,51] may prevent the wide adoption of ARinE. In line with previous studies, there are also serious concerns with regard to the security [45,44] and safety [48].

Moreover, few participants considered that the lack of students' AR awareness and skills prevent the integration of ARinE while AR disables students' imagination and distracts students' attention (Table 13).

Table 13. Students' obstacles and challenges in integrating ARinE.

Students' Obstacles and Challenges	Frequency	Example
Lack of students' AR awareness and skills	2	*The challenge is the awareness of users is still low on using AR on their daily life;*
AR disables students' imagination	1	*Reduce the imagination of students;*
AR distracts students' attention	1	*AR … not contribute anything to learning apart from a bit of distraction;*

Previous studies recognized the students' need to be trained on AR [8,12,24] as well as the students' attention distraction because AR applications demand too much attention [5,8,12,24].

In addition, some participants recognized as obstacles to the adoption of ARinE the teachers' lack of knowledge and skills regarding ARinE, lack of general digital skills as well as the teachers' lack of time to find, learn, develop, and teach using AR resources (Table 14). Furthermore, the negative teachers' attitude towards ARinE contribute to block the integration of ARinE.

Table 14. Teachers' obstacles and challenges in integrating ARinE.

Teachers' Obstacles and Challenges	Frequency	Example
Lack of teachers' knowledge and skills regarding AR in education	13	*The ability and skills of teachers in using AR technology are also still limited;*
Lack of teachers' digital skills	3	*Teachers' training and confidence with the technology is also a major concern;*
Lack of teachers' time to find, learn, develop, and teach using AR resources	9	*The obvious obstacles and challenges are time, efforts, and required skills;* *Time it takes to find and learn how to use AR, fit within curriculum;* *Time to develop and integrate the AR in the lessons;*
Negative teachers' attitude towards AR in education	9	*Teachers' unwillingness, lack of motivation, disbelief in the potential of new technologies;*

	Teachers are reluctant to learn new technologies;

Previous studies agree that the lack of teachers' knowledge about AR [5,11,12,21,24,25] as well as the lack of teachers' training on ICT [17,21,22,24,40] prevent the integration of ARinE. Furthermore, the development of AR applications is time consuming [13] and there is resistance from teachers with respect to using AR in teaching [5,6,11].

According to participants, time constraints in class, the difficulty of assessment using AR, and the AR mismatch to learning objectives impede the adoption of ARinE (Table 15).

Table 15. Teaching's obstacles and challenges in integrating ARinE.

Teaching Obstacles and Challenges for the Teaching Practice	Frequency	Example
Time constraints in class	1	*Time constraints in the classroom;*
Difficulty of assessment using AR	1	*When it came for assessment, i think it will be difficult;*
AR mismatch to learning objectives	1	*That is not tied at all to learning objective;*

These results are also supported by previous studies that found that there is insufficient time in class for using AR applications [11,22,51] as well as lack of quality AR educational materials [10]. With regard to the AR-enhanced assessment, there are not many previous studies. However, AR has been used for assessment in various subjects such as medical student laparoscopic skill [52] and structural biology [53].

As far as the school is concerned, the participants considered that the adoption of ARinE is prevented by the lack of the school's digital infrastructure and equipment, funding, directors' awareness and interest about AR as well as by the school's restrictive regulation (Table 16).

Table 16. School's obstacles and challenges in integrating ARinE.

AR Obstacles and Challenges for the School	Frequency	Example
Lack of digital infrastructure and equipment	6	*The main obstacle is the lack of technological equipment at school;* *The lack of equipment and high speed internet connections in public schools hold its implementation in the educational process back;*
Lack of funding	3	*Not having enough funds leads to institutions not being able;*
Lack of directors' awareness about AR	1	*Stakeholders' awareness is a big issue;*
Lack of directors' interest about AR	1	*The obstacles are getting teacher and admin interest;*
Restrictive school's regulation	1	*Mobile devices are not allowed at the school premises;*

Previous studies confirm the lack of schools' digital infrastructure, equipment, and funding [8–11,16,40,54] as well as the lack of institutional support [21].

4.7. Recommendations for Overcoming Obstacles of Integrating ARinE

The final open question is "How would you overcome these obstacles?". In order to overcome the obstacles in integrating AR in class to support teaching and learning, participants proposed several actions with respect to teachers, the schools and state as well as the AR companies. More specifically, they strongly recommended teachers' training and professional development, but also collaboration, raising teachers' awareness and motivation as well as taking small steps towards the smooth integration of ARinE (Table 17).

Table 17. Recommendations for teachers.

Actions to Overcome Obstacles for Teachers	Frequency	Example
Training and Professional Development	12	*To overcome them, first and foremost there should be special funding and training opportunities;* *Offer necessary training and support;* *Webinars or professional workshops in different levels can help to prepare teachers before school year;*
Collaboration	4	*Work with a colleague or team to take a 'risky step' into the AR world;* *Work closely with IT department to overcome any issues;* *Involvement of stakeholders to help in the acquisition of AR;* *Well-designed open source and freeware developed collaboratively;*
Raising teachers' awareness and motivation	2	*Motivate teachers to adopt new technologies;* *need more awareness among educators;*
Small steps towards smoothly integrating AR in education	3	*While AR, MR or VR is more an more used in an educational context, we should be just really careful to not overstress use of digital content and in the same way also overstress the students/learners;* *Testing these equipment before use in the classrooms; being very well prepared and plan ahead;* *introduce such technology gradually;*

Previous studies widely recognized the teachers' need for both training on how to integrate ARinE [10,12,20–22,24] and cooperation with other teachers [18,22].

The participants also suggested that the schools and the state should allocate funds for AR in order to develop infrastructure, open-source tools, open educational resources, and repositories as well as to raise awareness on AR (Table 18).

Table 18. Recommendations for schools and state.

Actions to Overcome Obstacles for Schools and State	Frequency	Example
Funding	3	*To overcome them, first and foremost there should be special funding and training opportunities.*
Develop infrastructure	1	*Infrastructure.*
Develop open-source tools, open educational resources and repositories	2	*Department of education needs to … invested in creation of open source XR educational repositories.*

Raise awareness on AR	3	*Open days, preferably demonstrating the technology itself.* *To overcome the obstacle to start build awareness by making a lot of webinars and activities.* *Department of education needs to acknowledge the impact of XR in education;*

Previous studies found similarly that schools lack funding and digital infrastructure [8–10,16,40,53] implying that schools need to find and allocate funds in order to develop their digital infrastructure.

Finally, the proposed AR companies to design easier-to-use AR tools and make AR less expensive (Table 19).

Table 19. Recommendations for AR companies.

Actions to Overcome Obstacles for AR Companies	Frequency	Example
Design easier-to-use AR tools	1	*Better tools and UX design support.*
Make AR less expensive	1	*Become less expensive.*

Prior studies found that the AR cost [10,17,19] and the difficulty to use AR [5,11,24,26,51] may prevent the AR adoption in schools, implying that AR should become less expensive and easier-to-use [19].

Software developers should focus on eliminating the technical difficulties of AR pedagogical tools and on facilitating their usage, especially for people with low technological skills and people with disabilities [5].

5. Conclusions and Recommendations

It is widely acknowledged that AR can support teaching and learning. In order to effectively integrate AR in schools it is necessary to take into consideration the teachers' thoughts and views. Teachers' views and thoughts about the integration of AR in educational practice is of significant importance because teachers are usually the main ambassadors of any technology integration in instructional practice. Moreover, by addressing teachers' perceived challenges and needs we can maximize the potential of integrating AR in education. This study conducted a survey among teachers all over the world.

According to these teachers, the most important skills for integrating ARinE include technical, pedagogical, and soft skills. They also suggested the use of student-centered teaching methods. Teachers appreciated the visualization/ virtualization, augmentation, and interactivity affordances offered by AR for integrating ARinE. Some teachers thought that it is easy to find AR resources, while others thought that it is difficult. In evaluating AR resources, they were mainly concerned with the AR cost, security, and ethics.

Teachers believed that AR mainly increases students' interest and engagement as well as it facilitates students' interaction, understanding, exploration, explanation and experiences that previously were not possible. In addition, they considered that AR supports and facilitates interactive learning and experiential learning as well as visualization and teaching topics that previously were not possible.

On the other hand, these teachers believed that the cost of buying and maintaining AR equipment and resources as well as the lack of AR educational content and resources prevent the integration of ARinE.

In addition, they thought that the teachers' lack of knowledge and skills regarding ARinE, lack of time to find, learn, develop, and teach using AR resources and they have a negative attitude towards the integration of ARinE. Finally, they recommended that teachers should take training and professional development on integrating ARinE in their teaching practice.

In order to effectively integrate ARinE, teachers should become self-aware and reflect about their AR knowledge and skills, obtain training on ARinE, experiment with ARinE, and collaborate with colleagues. In parallel, educational institutes' administrators should learn about ARinE; promote and raise awareness among teachers, students, and parents about the opportunities and results of ARinE; organize and deliver teachers' training and support about ARinE; facilitate collaboration among teachers, trainers, educational content authors, curriculum designers, learners, alumni, employers, experts, and other schools (e.g., exchange experiences and best cases) about ARinE; find and allocate funds to ARinE; develop AR infrastructure and projects; encourage, support, and award experimentation, innovation, and creativity about ARinE.

Additionally, educational policy makers should develop policies, legislation, and regulation with regard to ARinE (e.g., design AR-related courses, allow more time for AR in class); allocate funding to ARinE (e.g., equip schools with AR hardware, software, educational resources); enable the design and development of open AR educational resources and repositories in various subjects and levels; enable the design and implementation of teachers' training, support, and awarding; encourage student-centered teaching methodologies; allow flexibility in teaching; promote innovation, creativity, openness, and inclusion in education.

Furthermore, AR companies should design and develop inexpensive, easy-to-use, secured, and accessible AR hardware, software, and educational resources. It is advisable that all interested stakeholders (e.g., instructional designers, educational content authors, teachers, trainers, students/learners, alumni, software developers, usability experts, psychologists, employers, subject-experts) be involved in the design of AR educational resources.

6. Limitations and Future Research

As usual with studies that are based on surveys, the thoughts of the participants may be different than their actual skills and behavior. Additionally, the participants express their perceptions at a given moment so they may have different expressions at a different moment. So, there is a need for longitudinal studies with regard to teachers' perceptions and behavior. In addition, the limited sample was not representative of all teachers worldwide. Future research may investigate larger samples worldwide or in specific countries, educational levels, and subjects. Another limitation of the study is that it did not consider the technology infrastructure where participating teachers work with, a factor that can affect their views towards the use of AR. Moreover, the distribution of the participants by country and teaching subject was somehow irregular. Future studies should take these limitations into consideration. Studies that correlate teachers' attitudes and beliefs with respect to the development level of countries and/or technical infrastructure might provide further insights.

This study investigated the teachers' perceptions with regard to ARinE. Future research may further analyze each one of the topics of this study. For example, it can scrutinize the teachers' required specific technical, pedagogical, and soft skills so that they can effectively apply ARinE in their teaching practice. Additionally, how AR can be effectively integrated in specific educational levels and subjects (disciplines, fields)? What are the most appropriate teaching methods for specific educational levels, settings, subjects and learning objectives? What mechanisms and methods facilitate teachers to find quality, relevant, accurate, and inclusive AR educational resources? Future research may also explicitly investigate trust, security, safety, privacy, and ethical issues with regard to ARinE. For

example, what measures should be taken to prevent bullying, harassment, snooping, and cyber-attacks during ARinE?

It can also compare various AR-based teaching methods with respect to learners' interest, engagement, motivation, enjoyment and other variables. Other research questions are related to the required AR infrastructure (e.g., AR-related hardware, software, educational resources) for schools, teachers, and learners as well as the cost structure of integrating ARinE (e.g., cost of buying, maintaining, adapting, replacing). How to efficiently design and develop easy-to-use, trusted, secured, safe, inclusive, ethical, and inexpensive AR tools and educational resources? What functionalities should be embedded on AR tools and educational resources? What features should an AR educational resource include in order to decrease learners' cognitive overload, distraction, misorientation, illusion, and confusion? What are the appropriate methods and practices for promoting ARinE and training teachers, learners, and others involved in ARinE? This is an evolving research area that for sure will bring in light many more interesting research findings that we aim to facilitate educators and students' teaching and learning experiences.

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