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Comparison and evaluation of augmented reality technologies for designing interactive materials

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Abstract
Although there has been a growing interest in the use and adoption of augmented reality (AR) technology in educational institutions recently, there is limited research dwelling on pre-service teachers' technical and pedagogical preparation for AR technology. This study investigated teacher candidates' perceptions concerning their learning and immersive experiences of different AR tools and compared these tools on seven dimensions, i.e., intention to use, multimedia, satisfaction, usefulness, self-efficacy, effectiveness, and system quality. A mixed method approach was adopted to analyze qualitative and quantitative data gathered from 55 pre-service teachers who attended a five-day online seminar program about AR tools. The findings showed that teachers developed positive views for all AR tools but some tools like CoSpaces, Fectar, and Blippar were found to be significantly superior in all dimensions to Wikitude, UniteAR, and Unity & Vuforia. The findings also revealed that AR tools presented both affordances and challenges for instructional learning environments. While affordances included materializing and visualizing the abstract concepts, providing permanent learning, and catching interest, challenges consisted of unaffordable applications, limited educational content, internet connectivity issues, and limited access to devices. Overall, the findings of the current study have offered significant implications for designing and preparing AR-enhanced interactive course materials.

Keywords Augmented reality · Pre-service teachers · Perceptions · Teacher training program · AR tools

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1 Introduction

Technology infuses almost all aspects of the sectors, and the education sector is not an exception. Educational institutions target at the optimum use of technology to equip students with theoretical and practical knowledge so that they can exploit it in their work lives. The Horizon Reports estimate that the effect of emerging technologies on higher education would even increase more in the following decades (Becker et al., 2017, 2018). For that reason, the European Commission's (2020) digital education action plan for the period between 2021 and 2027 has called for implementing initiatives like teacher training programs to boost future teachers' skills in educational technology and digital environments.

Educational environments have always been an eligible space for different learning technologies, considering the vast number of studies on technology adoption (Granić, 2022). Mixed reality is one of the new and immersive technologies with a great potential impact on education. A recent Horizon Report highlighted that higher education institutions would increasingly adopt mixed reality technology in the forthcoming years (Pelletier et al., 2022). Studies examining the instructional opportunities provided by technology have expanded in education and other fields (Bower et al., 2014). Mixed reality is a combination of different technologies, including both virtual reality (VR) and augmented reality (AR), that allows digital and physical objects coexist simultaneously in the same place. Although they have similarities, AR and VR are two different technologies in that they offer different experiences to users (Rauschnabel et al., 2022). AR is supported by several electronic devices, such as smartphones, laptops, tablets, and computers. It has become widely used in educational organizations, and its adoption is predicted to be intensified in the upcoming years (Statista, 2020). The main reason for the widespread use of AR applications in education is attributed to their potential affordances(Bacca et al., 2014) and the widespread use of portable electronic devices. In other words, the proliferation of mobile devices has led to a rapid escalation of AR tools as a learning medium in different educational fields (Hadi et al., 2022). Likewise, the rise in the availability of low-cost handheld devices and the use of digital technologies among students, especially mobile devices and computers (Diacopoulos & Crompton, 2020; Goundar & Kumar, 2022), has made AR technology more preferable and acceptable in educational settings (Ibáñez & Delgado-Kloos, 2018).

AR is defined as a technology that "supplements the real world with virtual (computer generated) objects that appear to coexist in the same space as the real world" (Azuma et al., 2001, p.34). The term augmented reality (AR) was first coined by Tom Caudell and David Mizell in 1990. AR is an immersive and interactive technology combining virtual and real-life elements (Wu et al., 2013). More specifically, it allows individuals to put virtual objects, materials, and contents of various types into the real world and interact with them without losing contact with the real world (Dunleavy et al., 2009). With its distinctive and compelling characteristics, AR technology can transcend traditional learning experiences and bring it into a different dimension (3D and 2D) where it becomes possible to cover, manipulate, and interact with the subjects/concepts/conditions that are either difficult or impossible to deal with in real-world situations (Hamilton et al., 2021). In addition, researchers can create immersive and collaborative learning laboratories based on AR systems to let their students remotely perform their work without any restraint during emergency conditions (Chu, 2022).

Teachers are the gatekeepers of the integration and acceptance of technology in schools. However, it is still debated whether teachers are appropriately trained and well-prepared to create engaging and exciting learning and teaching environments that can support 21st -century skills(Pitsikalis et al., 2022; Sari et al., 2022) and most particularly AR technology (Akçayır et al., 2016; Salleh et al., 2021). Pre-service teachers are believed to be digital natives who are expected to possess considerable technology skills and "move beyond being computer literate to technology competent" (Smarkola, 2008, p.1197). Previous research has shown that pre-service teachers not only have a high intention and are quite willing to use technology in their future lesson practices (Yilmaz & Baydas, 2016), but they also have a high motivation for constructing the teaching materials promoted after developing their materials with AR technology (Chookaew et al., 2017). Besides, research highlights that teachers who implement AR technology in a teacher training course develop positive technology implementation beliefs and positive attitudes toward the pedagogical values of AR (Nikimaleki & Rahimi, 2022). Although pre-service teachers are eager and highly motivated to use AR applications in their classes (Nikimaleki & Rahimi, 2022), they lack knowledge and skills regarding how to use them efficiently (Uygur et al., 2018). In this regard, this study is significant, and it has important contributions to the literature on pre-service teachers' experiences of popular AR tools and how they view the pedagogical and challenging aspects of these technologies in the educational context.

2 Literature review

AR technology has begun to permeate nearly all academic grades, from K-12 (Chiang et al., 2014) to the university level (Akçayır et al., 2016) as it allows teachers to create immersive and interactive 3D spaces for different learning environments. Research on AR technology has revealed both benefits and challenges associated with its use in educational settings (Akçayır & Akçayır, 2017; Bacca et al., 2014; Radu, 2014). There is a great deal of evidence proving that there are interactive, social, affective, and cognitive benefits gained from utilizing augmented reality learning applications (Arici & Yilmaz, 2022; Baabdullah et al., 2022; Çetin & Ulusoy, 2022). Besides, AR technology has been reported to have a positive effect on students' English speaking performance (Sally Wu & Alan Hung, 2022), learning gain and motivation for learning (Chen & Tsai, 2012; Chin & Wang, 2021; Garzón & Acevedo, 2019; Laurens-Arredondo, 2022), help them understand abstract concepts (Faridi et al., 2021), increase their interest and readiness for the subject (Cakir & Korkmaz, 2019), allow them to examine human anatomy rigorously (Gregorčič & Torkar, 2022), and provide them with opportunities to run virtual experiments or simulations on complex subjects that are either too costly or very dangerous to make the same test in real life (Cai et al., 2014).

Apart from the benefits, teachers using AR tools in their courses are prone to face challenges. According to Chiang et al. (2014), the most difficult job for teachers benefiting from AR was to promote students' sensory experience so that their learning motivation could increase. Besides, students could find AR applications challenging to use (Chang et al., 2014), and these applications might put a burden on cognition (Dunleavy et al., 2009) and take more time than the existing course time (Furió et al., 2013).

It is the responsibility of higher education institutions to prepare future teachers. In that respect, training programs are essential initiatives for future teachers to be aware of and learn how to use educational technologies effectively in their teaching practices. Research-based evidence on the effectiveness of AR technology as a classroom learning tool in education motivated researchers to examine pre-service teachers' use, readiness, and acceptance of this technology in their teaching practices (Salleh et al., 2021). For instance, in a recent study, pre-service teachers developed AR-based projects in teams using three different SDKs i.e., Zapworks, Aumentaty and Roar to teach English to young learners. Results of the study showed that pre-service teachers lacked practical knowledge and experience in how to create and implement AR-based content in education appropriately (Belda-Medina & Calvo-Ferrer, 2022). In another study, pre-service teachers were trained for the educational use of AR technology in bilingual and ESL education. During the training, teachers first explored some AR applications such as Quiver, JigSpace, Metaverse, Augment, StoryFab, and PhotoMath and then reflected on their strengths and limitations. The strengths the teachers referred to in the study included an increase in engagement and motivation whereas the challenges consisted of limited access to Mobil devices and internet, and unfamiliarity with AR technology education (Nikimaleki & Rahimi, 2022). In addition, in her study, Okumuş (2021) trained pre-service teachers on how to use an AR tool, Blippar. After preparing AR-enhanced activities for two weeks, the pre-service teachers reported that they had a high acceptance rate of AR, but they also underlined several AR-linked challenges for educators: complicated interface, high technology hardware cost, and lack of teachers' competency to employ and prepare AR-based activities.

The need for new digital settings and continuing development in digital technologies have triggered the introduction of promising AR technologies with different capabilities and features. The web gives teachers easy and direct access to various AR tools with and without software development kits (SDKs). The great thing about these tools is that they are available for teachers' disposal. The tools shown in Table 1 are some of the well-known immersive AR technologies considered and examined in this study. As shown in the table, these tools come up with different characteristics. Even if they appear to share similar features, every tool is exclusively different from the others in terms of its unique capabilities.

Teachers are content creators and educators who are supposed to be familiar with how to create AR-enhanced content and integrate it into their classroom practices. Therefore, training pre-service teachers to utilize AR technologies in their instructional practices is highly valued (Belda-Medina & Calvo-Ferrer, 2022). Although it has previously been reported that AR technology motivated pre-service teachers in developing their teaching materials (Chookaew et al., 2017), limited research was

Table 1 The characteristics of pervasive and immersive AR Tools

Name	AR & VR	Educational Resources	SDK	Web Studio	Phone & Web	Free	Founded Date	Web Address
Blippar	Both	No	Yes	Yes	Both	Limited	2011	https://www.blippar.com/
Co-Spaces	Both	Yes	No	Yes	Both	Limited	2012	https://cospaces.io/edu/
Fectar	Both	Yes	No	Yes	Both	Limited	2020	https://www.fectar.com/
Quiver	AR	Yes	No	No	Phone	Limited	2013	https://quivervision.com/
UniteAR	AR	No	No	Yes	Phone	Limited	2018	https://www.unitear.com/
Unity& Vuforia	Both	No	Yes	Yes	Both	Full	2008	https://library.vuforia.com/
Wikitude	AR	Yes	Yes	No	Phone	Limited	2008	https://www.wikitude.com/

conducted on pre-service teachers, as also noted by Belda-Medina and Calvo-Ferrer (2022), rather a bulk of research focused on students (Turhan et al., 2022). It has also been stressed that pre-and in-service teachers' lack of knowledge and experience of AR tools(Akçayır & Akçayır, 2017; Belda-Medina & Calvo-Ferrer, 2022) is a barrier to their integration into teaching practices (Kerr & Lawson, 2020). Therefore, pre-service teachers' technical and pedagogical preparation for AR technology is an important area to explore more. Delving more into preservice teachers' experiences for AR applications and the comparison of these applications could inform pre-and-in-service teachers about the type of tools they could benefit from and use in their teaching practices. In this regard, this study's findings would fill a significant research gap in the accumulative literature on AR use in education because the current study extensively zooms in on teachers' five-days experiences of the widely utilized emerging AR applications (see Table 1) and it compares these tools based on their potential benefits on the seven dimensions: intention to use, multimedia, satisfaction, usefulness, self-efficacy, effectiveness, and system quality. Consequently, the current study addressed the following research questions:

1. What are the pre-service teachers' views on using AR tools as part of educational materials considering seven dimensions i.e., intention to use, multimedia, satisfaction, usefulness, self-efficacy, effectiveness, and system quality?
2. What are the perceived advantages of using AR tools as part of educational materials?
3. What are the perceived disadvantages of using AR tools as part of educational materials?
4. Is there a significant difference between AR tools based on seven aspects: intention to use, multimedia, usefulness, self-efficacy, effectiveness, and system quality?

3 Methodology

3.1 Study design

This study employed a concurrent mixed-method research design, deploying quantitative and qualitative research strategies (Creswell, 2013a). Quantitative data were triangulated with qualitative data to understand further pre-service teachers' views and experiences regarding AR tools (Creswell, 2013b). Quantitative and qualitative data were equally important, but the priority was given to quantitative methods. Qualitative data were used to support the results drawn from quantitative data.

3.2 Context of the study

A five-day program was prepared to introduce AR tools to pre-service teachers. Ten faculty members from eight universities organized the program and took part as an instructor. Table 2 shows the program schedule and the activities implemented on each day of the program. A website (http://boteprojeleri.kku.edu.tr/agegitimi2021/) was prepared to present the program content and activities. The program was imple-

Table 2 The flow of the program on preparing interactive teaching materials with augmented reality

Day	Activities
Day 1: Introduction	Use of Technology in Education
	Features of Augmented Reality Technologies
	Lunch Break
	Introduction of QR Code Applications
	Preparing Instructional Materials with QR Code
Day 2: Blippar and Wikitude	Introduction of Blippar Application
	Preparing Teaching Material with Blippar
	Lunch Break
	Introduction of Wikitude Application
	Preparing Teaching Materials with Wikitude
Day 3: Fectar and UniteAR	Introduction of Fectar Application
	Preparing Teaching Materials with Fectar
	Lunch Break
	Introduction of UniteAR Application
	Preparing Teaching Materials with UniteAR
Day 4: CoSpaces and Quiver	Introduction of CoSpaces Application
	Preparing Teaching Materials with CoSpaces
	Lunch Break
	Introduction of Quiver Application
	Preparing Teaching Materials with Quiver
Day 5: Unity & Vuforia and Material Development	Introduction of Unity & Vuforia Application
	Preparing Teaching Materials with Unity & Vuforia
	Lunch Break
	Preparing Your Teaching Material

Table 3 Demographics for participants

	Year		Gender	
Department	3	4	Female	Male
Mathematics Education	11	3	12	2
Science Education	9	9	15	3
Computer Education and Instructional Technology	3	8	4	7
Classroom Teacher Education	9	3	11	1
Total	23	32	42	13

mented in an online seminar using Zoom, a synchronous video-conferencing application. Each workshop day started at 9:00 AM and ended at 5:45 PM.

The program's first day covered the general information regarding the use of technology in education, characteristics of AR technology, QR code applications, and their potential implication for developing interactive instructional materials. On the second day and the following days, the instructors gave thorough theoretical and pedagogical information about the relevant AR tool and then showed participants how to use it with the phone for educational purposes. Furthermore, the instructor devoted much effort to monitoring participants throughout the day and ensuring that every participant interacted with the course content. On the last day of the program, participants developed their interactive teaching materials or activities using the knowledge and experiences they acquired throughout the program. Two research assistants with previous experience with AR tools supported the seminar and facilitated critical teaching stages. Participants were trained on how to use specific AR tools while preparing particular educational materials. The seminar emphasized AR applications and the associated pedagogical knowledge and skill.

3.3 Sample

The sample of this study comprised 55 pre-service teachers who attended a five-day online seminar program. They were undergraduate students from 31 universities in four different departments (see Table 3). While 76,4% of them were female, 23,6% were male. Their grade point averages were in the range of 2.54 to 3.90. In addition, 32 participants were in 4th grade, and 23 were in 3rd grade.

3.4 Data collection tools

A survey was used to determine participants' opinions and experiences regarding seven different AR tools introduced in the program (Appendix 1). The survey was adapted from a previous study by Kucuk et al. (2015). In their research, they prepared a series of survey items based on the review of the relevant literature to reveal how medical faculty students view the use of mobile augmented reality technology in anatomy learning. The researchers in this study slightly reworded survey items to ensure the survey's reliability and validity for the current study. For instance, an item in the original survey, "MAR (Mobile Augmented Reality) applications created a sense of reality," was changed to "Implementation of THIS AR (Augmented Reality) TOOL created a sense of reality." As indicated in Table 4, the survey included 23 items grouped by seven dimensions: intention to use, satisfaction, multimedia,

Table 4 The characteristics of each dimension in the survey

Dimension	Items	Description
Intention to Use	3	This dimension measures the degree of possibility that pre-service teachers will utilize the corresponding AR tool and integrate it into learning materials.
Satisfaction	3	This dimension measures the degree of satisfaction pre-service teachers perceive regarding their interaction with the corresponding AR tool's materials and applications.
Multimedia	3	This dimension measures the degree to which pre-service teachers are satisfied with using sound, pictures, and 3D animations in the relevant AR tool.
Usefulness	5	This dimension measures the capabilities of the relevant AR tool in creating a sense of reality, making the subject concrete, bringing benefits to individual works, and providing an accessible and flexible learning environment.
Self-Efficacy	3	This dimension measures pre-service teachers' beliefs about their ability to utilize and manage technical features (special software/applications) required for the relevant AR tool.
Effectiveness	3	This dimension measures the degree of pre-service teachers' beliefs about the effect of the relevant AR tool on motivation, effective and fruitful learning, and motivation for learning.
System Quality	3	This dimension measures the degree to which the relevant AR tool satisfies pre-service teachers concerning an internet connection, software features, and the software's ability to interact with course content.

usefulness, self-efficacy, effectiveness, and system quality. Pre-service teachers' responses to survey items were measured on a 5-point Likert scale ranging from strongly disagree to strongly agree.

A demographic form was also attached to the survey to gather participants' demographic characteristics such as sex, age, grade level, grade point average (GPA), and department. Besides, the survey was accompanied by four open-ended questions to get rich data about pre-service teachers' opinions on using VR tools as part of educational material. The open-ended questions were "What advantages do you think this AR tool has?", "What kind of materials can be prepared with this AR tool" "What kind of shortcomings do you think this AR tool has?" and "Which tool or tools covered in this training program do you prefer to develop AR materials?".

3.5 Data collection and analysis process

The current study included both quantitative and qualitative data. Both data types were collected at the end of the 5-days program using an online survey. One-way repeated measures ANOVA, descriptive statistics, and thematic analysis were performed to investigate the gathered data.

First, the items in data collection tools were rigorously transferred from paper-based to online form. After the program, the form link was sent to each participant, and they were asked to respond to each of the questions in the form objectively and honestly. In addition, an online consent form was placed at the top of the online survey, informing participants that participation in the survey was voluntary and confidential.

Second, once the data collection was completed, the researchers transferred quantitative data to the SPSS program. First of all, the data were screened to identify missing values and outliers. Since no missing data was detected, the researchers used the skewness and kurtosis statistical tests to detect potential outliers. The variables with skewness values out of the range of ± 3 and kurtosis values out of the range of ± 10 were considered to be problematic. Therefore, the researchers applied a monotonic transformation to the variables that failed to meet these threshold values (Kline, 2016). As described by Kline, this type of transformation method is useful for dealing with univariate normality. Secondly, the assumptions required for one-way repeated measures ANOVA were checked: independent observation, normality, and sphericity. The tests indicated no violation of assumptions. After ensuring no assumption was violated, the researchers conducted quantitative analysis tests to investigate evidence addressing the study's research questions.

Besides, for each dimension of the survey, reliability score was estimated with Cronbach's alpha. The reliability score was 0.874 for intention to use, 0.877 for multimedia, 0.833 for satisfaction, 0.909 for usefulness, 0.879 for self-efficacy, 0.873 for effectiveness, and 0.792 for system quality.

Third, teachers' written responses to open-ended questions were collected and transferred to MAXQDA programs. Two researchers independently analyzed the qualitative data to ensure that the results attained were consistent and reliable (Marshall & Rossman, 2011). In the inspection process, the researchers followed the qualitative data analysis steps suggested in the literature (Creswell, 2013a). Each researcher examined the first teacher's written responses sentence by sentence to find meaningful patterns and create codes. In the second teacher's responses and the responses that followed, the researchers used the codes built previously and created new codes if required. The corresponding codes were then grouped into categories and sub-categories. Once the researchers finished the coding process, they compared their codes and the piece of statement linked to them. The parts upon which the researchers disagreed were revisited and revised once they reached a mutual agreement.

4 Results

A one-way repeated measures ANOVA was conducted to compare AR tools concerning seven dimensions. As shown in Table 5, there was a significant main effect for a training intervention for each AR dimension. Follow-up posthoc tests with a Bonferroni adjustment were conducted to identify how each AR tool differentiated across seven dimensions at the significant level of 0.05. The posthoc results are reported below. The p values given next to the AR tools below indicate the significant level at which the tools compared are significant on the relevant dimensions.

For the *intention to use*, the score of CoSpaces was statistically significantly larger than Blippar (p=.009), Wikitude (p=.000), UniteAR (p=.000), Quiver (p=.000), and Unity & Vuforia (p=.000). In addition, the score for Fectar was statistically significantly larger than Wikitude (p=.003), Quiver (p=.024), and Unity & Vuforia (p=.013).

For the *multimedia*, the score for CoSpaces was statistically significantly larger than Blippar (p=.005), Wikitude (p=.000), UniteAR (p=.003), and Unity & Vuforia (p=.003). Besides, the score for Fectar was statistically significantly higher than Wikitude (p=.015).

For the *satisfaction*, the score for CoSpaces was statistically significantly higher than Blippar (p=.002), Wikitude (p=.000), Fectar (p=.035), UniteAR (p=.000), Quiver (p=.003), and Unity & Vuforia (p=.000). Additionally, the score for Blippar was statistically significantly higher than Unity & Vuforia (p=.047).

For the *usefulness*, the score for CoSpaces was statistically significantly higher than Blippar (p=.001), Wikitude (p=.011), UniteAR (p=.013), and Unity & Vuforia (p=.004).

For the *perceived self-efficacy*, the score for Unity & Vuforia was statistically significantly lower than (p=.000), Wikitude (p=.016), Fectar (p=.000), UniteAR (p=.023), CoSpaces (p=.000), and Quiver (p=.000).

For the *effectiveness*, the score for CoSpaces was statistically significantly higher Blippar (p=.036), Wikitude (p=.006), Fectar (p=.012), UniteAR (p=.003), and Unity & Vuforia (p=.000).

For the *system quality*, the score for CoSpaces was statistically significantly higher than Blippar (p=.015), Wikitude (p=.003), UniteAR (p=.006), and Unity & Vuforia (p=.000). Furthermore, score for Unity & Vuforia was statistically significantly lower than the scores for Blippar (p=.005), Fectar (p=.001), and Quiver (p=.018).

As a result, after participants' one-week exposure to six augmented reality tools, CoSpaces was regarded as superior in all dimensions, followed by other less favorable tools, Fectar and Blippar, respectively. On the other hand, Wikitude, UniteAR, and Unity & Vuforia were perceived to be inferior in most dimensions. In other words, participants had a strong inclination toward using CoSpaces and Fectar and strongly favored these tools over the others for their diverse usage capability in various multimedia channels. Qualitative results substantiated these findings. For example, in the following quote from one participant's writing response, it was clear that teachers found some AR tools, particularly CoSpaces, Blippar, and Fectar, more promising for preparing immersive educational materials.

Table 5 Mean and Standard Deviation for Augmented Reality Tools by Different Dimensions

	Blippar		Wikitude		Fectar		UniteAR		CoSpaces		Quiver		Unity& Vuforia					
Dimension	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*df*	*F*	*p*	η_p^2
Intention to use	4,50	0,50	4,18	0,77	4,62	0,55	4,27	0,77	4,78	0,43	4,33	0,74	4,21	0,79	6, 49	10.06	<0.001	0.552
Multimedia	4,55	0,44	4,30	0,75	4,61	0,50	4,49	0,55	4,74	0,41	4,53	0,55	4,38	0,63	6, 49	6.50	<0.001	0.443
Satisfaction	4,69	0,38	4,45	0,71	**4,68**	0,55	4,48	0,71	**4,91**	0,24	4,59	0,58	4,38	0,71	6, 49	11.95	<0.001	0.594
Usefulness	4,49	0,48	4,40	0,67	4,59	0,54	4,47	0,55	4,71	0,40	4,57	0,46	4,42	0,55	6, 49	6.79	<0.001	0.454
Self-efficacy	4,58	0,55	4,47	0,73	4,66	0,57	4,45	0,66	4,70	0,47	4,64	0,58	3,99	0,89	6, 49	6.49	<0.001	0.443
Effectiveness	**4,73**	0,40	**4,56**	0,67	**4,68**	0,53	**4,64**	0,51	**4,91**	0,23	**4,67**	0,57	**4,55**	0,53	6, 49	6.14	<0.001	0.429
System Quality	4,51	0,55	4,39	0,67	4,60	0,50	4,41	0,64	4,77	0,40	4,52	0,65	4,08	0,76	6, 49	8.84	<0.001	0.520
Total	4,58	0,32	4,39	0,62	4,64	0,45	4,46	0,53	4,79	0,26	4,55	0,45	4,29	0,55				

Note. Bold indicates the highest mean score in the column, N=55

> I can say that I will often prefer Blippar and Fectar applications. Blippar provides convenience in terms of implementation and is also the tool I find the most successful in the trigger reading/detection part. I found Fectar successful in terms of interface since it is designed just like a social media platform. I will especially prefer the CoSpaces application for virtual reality applications. I think coding knowledge and virtual reality are successfully combined in the CoSpaces application. For this reason, CoSpaces was my favorite among the tools in education.

In addition, participants gained significant satisfaction in utilizing CoSpaces and Blippar. CoSpaces was the only tool they considered potentially more fruitful and effective. Besides, compared to other AR tools, participants reported significantly lower beliefs in their capabilities to utilize Unity & Vuforia. The qualitative evidence supporting these results could be seen in the following excerpt from one participant's written response.

> Cospaces and Blippar have a more straightforward structure. I think they are more comprehensive in terms of content. Especially Cospaces appeals to creativity. It is a comprehensive and sophisticated application that allows you to intervene even in minor situations.

As shown in Table 5, all seven AR tools had the highest mean score in the effectiveness dimension. The other highest mean score was measured on the dimension of satisfaction for both Fectar and CoSpaces. In addition, almost all AR tools got a mean score larger than 4.50 on every dimension. However, the mean score of Unity& Vuforia on each dimension was found to be comparatively low. These results indicated that, despite the significant difference observed in the ANOVA results, most teachers thought that all these seven AR tools had a decent quality of being sufficient and meeting their needs on the seven dimensions.

Qualitative data were collected to provide evidence of what drives teachers' responses regarding the quality of relevant AR tools in different aspects. Inductive analysis of qualitative data revealed both advantages (see Table 6) and challenges (see Table 7) associated with using AR tools in educational settings. As for the benefits, while choosing an AR tool for educational material, participants focused mainly on pedagogical, technical, and student considerations. In other words, participants saw AR tools as complementary apparatus to learning materials mainly due to their ability to enhance learners' interest, promote active learning, and attract their attention. According to participants, permeant learning was the most likely outcome one could get through using AR tools, followed by increased motivation and development of creativity and spatial abilities. The following excerpt from participants' written responses provides evidence of these findings.

> As a science teacher candidate, there are many abstract concepts, and I think these technologies are very effective and efficient tools for concretizing these abstract concepts. In addition, I believe that students will be more enthusiastic

Table 6 The perceived advantages of AR tools in educational materials

Categories	Sub-categories	*f*
Technical affordances (*f*=80)	Helps make abstract concepts concrete	41
	Enables the visualization of expensive and inaccessible objects	11
	No technical challenges	9
	Enables the visualization of invisible matters (micro and macro)	6
	Easy to use	6
	Allows designing various instructional materials	6
	Enables simulating potentially dangerous experiments	1
Learner outcomes (*f*=43)	Enables permanent learning	13
	Increases motivation	6
	Develops creativity	6
	Makes learning fun and enjoyable	5
	Develops spatial abilities	4
	Develops digital literacy	4
	Helps to understand the subject	4
	Promotes meaningful learning	1
Pedagogical contributions (*f*=28)	Enhances interest	13
	Promotes active learning	7
	Gains attention	3
	Helps create interactive materials	2
	Decreases misconceptions	1
	Connects multiple subjects	1
	Allows designing simulations	1

> about the lesson. Therefore, efficient and permanent learning will take place by ensuring active participation.

In addition, participants favored AR tools in terms of their affordances to primarily visualize abstract concepts and provide access to science phenomena that are dangerous or very expensive to inspect in real life. Furthermore, some participants thought AR tools are easy to use and do not pose any challenges. Some participants reported that AR tools could penetrate and infuse miscellaneous instructional materials. These findings were reflected in one of the following quotes, emphasizing that AR tools had the potential for encouraging students in their learning and helping to teach abstract science concepts.

> Preparing materials with AR on abstract subjects will increase the quality of teaching. For example, materials can be prepared on planets, the solar system, elements, and systems. At the same time, I think that utilizing AR in subjects that contain much more verbal information and push more memorization can increase the retention of information. For example, creating a story on the concept of atoms from the past to the present through CoSpaces will attract stu-

dents' attention. In addition, the application already appeals to students in every aspect, such as sound, picture, and video. Such applications can increase the quality of teaching.

The study result showed that the challenges of exploiting AR tools in educational settings are grouped into usability, pedagogical, and technical issues. The prominent usability issues participants mentioned are bound to be the high cost of the relevant tool, scarcity of available resources, and unsupported language. The evidence supporting these results could be seen in the following excerpts from participants' written responses.

I think the first disadvantage is that AR applications are free for a certain period of time and then become paid. Apart from that, finding three-dimensional objects and uploading them to the application is often problematic.

The content of AR applications should be expanded because they are weak. In some applications, creative products are not produced except for certain structures. The scope of these AR tools should be increased to provide wider and more creative designs. Unlimited product design should be given. Since the Professional versions are paid, it also creates a problem in terms of cost.

Besides, several participants found AR tools challenging to use and complained about the lack of a proper level of trigger recognition. Only a few teachers emphasized that AR tools could deflect students' attention and create misconceptions. Participants also expressed their preferences regarding using AR tools in educational materials. Figure 1 demonstrates participants' preferences in using AR tools as educational materials. As shown in Figure, most teachers opted to use CoSpaces, Fectar,

Table 7 The perceived challenges of AR tools in educational materials

Categories	Sub-categories	*f*
Usability issues (*f*=37)	Expensive applications	8
	Limited content materials in the apps (3D objects, images)	7
	No support for the Turkish language	6
	Low sensitivity of trigger recognition	6
	Difficult to use	5
	Requires more preparation time	3
	Limited teacher knowledge	2
Technical issues (*f*=25)	Internet connectivity problems	12
	Limited access to devices	10
	Device incompatibility	3
Pedagogical issues (*f*=4)	Distracts students' attention	2
	Causes misconceptions	1
	It takes more time to use in the classroom	1

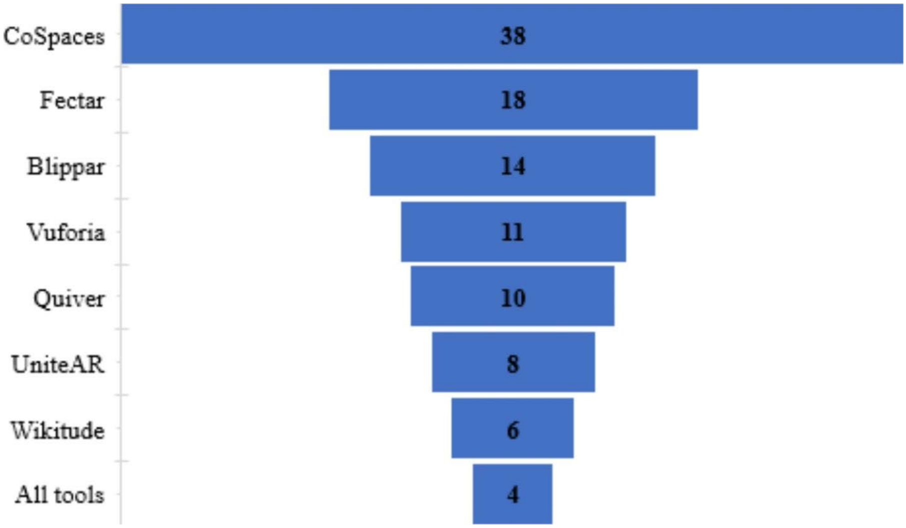

Fig. 1 Preferences for using AR tools in educational materials

and Blippar, whereas few expressed their preferences for Wikitude. The total number of the frequencies is greater than the sample size since some of the participants mentioned more than one preference.

5 Conclusion and discussion

The current study investigated future teachers' experiences and opinions regarding well-known AR tools they were introduced to in a training program. The study also compared these tools on seven parameters: intention to use, multimedia, satisfaction, usefulness, self-efficacy, effectiveness, and system quality. First, this study has shown that pre-service teachers who participated in training programs developed a high and positive opinion of seven AR tools in all dimensions and gained insight into their potential values and strengths for education. These results support the previous studies reporting that AR technology motivated pre-service teachers to incorporate it into their instructional materials (Chookaew et al., 2017) and increased positive attitudes towards the science subject (Akçayır et al., 2016). The pre-service teachers' views and practices regarding AR tools in this study are important because different from previous studies that rely on pre-service teachers in a specific domain (Belda-Medina & Calvo-Ferrer, 2022), this study used a sample of pre-service teachers from four fields and examined both individual and collective pedagogical values of more AR tools.

Second, the current study has identified the significant differences between AR tools based on their relative strengths and values for possible educational use. CoSpaces was interestingly regarded as the most valued AR tool in all seven dimensions: intention to use, multimedia, satisfaction, usefulness, self-efficacy, effectiveness, and system quality. These results provide corroborative evidence suggesting that the CoSpaces platform is capable of increasing students' performance on grammar and lexical use (Sally Wu & Alan Hung, 2022) and creating a significant effect on emotional engagement (Wang & Sun, 2021). The other tools, Fectar and Blippar, followed CoSpaces in terms of having a significant superiority to Wikitude, UniteAR, and Unity & Vuforia. A part of these results reflects those of Okumuş (2021) who found that pre-service teachers developed a high acceptance of AR technology after preparing an educational activity using Blippar.

Furthermore, teachers expressed high preferences for incorporating CoSpaces, Fectar, and Blippar into their teaching practices in the future. The underlying reasons for their high preferences may derive from many factors known to influence teachers' acceptance of AR applications. Some of these factors are believed to be the usability of these tools, their perceived usefulness and enjoyment during the teaching and learning process, teachers' attitude towards those tools, innovativeness, and intention to use (Hadi et al., 2022; Rasimah et al., 2011). It is possible to hypothesize that an AR tool is less likely to be valued and accepted when teachers find it difficult to use and think they are not much useful. In addition, CoSpaces, Fectar, and Blippar seem solid options for teachers to employ in their teaching practices. In other words, this finding suggests that teachers who have a plan to enrich their educational materials with the use of AR technology can start with CoSpaces and then Fectar and Blippar.

There could be many other reasons driving teachers to have a high acceptance of particular AR tools. The qualitative data findings unveil the evidence of what some of these reasons could be and what kind of AR tools teachers could give a try in their forthcoming teaching profession. The findings of this study suggest that the affordances and challenges of an AR tool could be important determinants influencing teachers' dispositions towards using that tool in their instructional materials.

Third, in this study, pre-service teachers highlighted the potential benefits of using AR tools for educational purposes. These findings are echoed in previous research which showed that AR in different educational levels offer teaching and learning design enhancements to better capture attention, improve retention, promote motivation, arouse curiosity and learning interest, enhance learning performance, materialize the abstract concepts, make learning fun, enjoyable, and interactive, and develop creativity (Chang et al., 2016; Chin et al., 2020; Koçak et al., 2019; Kucuk et al., 2015; Nikimaleki & Rahimi, 2022; Sáez-López et al., 2020; Ustun et al., 2022). Despite the contradictory findings regarding the effect of AR on cognitive load (Buchner et al., 2022), in our research, the teachers noted that AR tools, not necessarily all AR tools, can also afford to develop spatial abilities and digital literacy and promote active learning. Using the capabilities of AR technology, teachers are able to create interactive and immersive teaching and learning materials. Therefore, the benefits AR technology can bring to the classroom are pervasive, but the main contribution of AR tools would be to disclose abstract concepts, make them clear, and turn them into understandable chunks. Besides, what makes AR technology a promising educational tool appears to be its featured ability to visualize and animate visible or invisible objects at micro and macro levels. However, as underlined before(Sáez-López et al., 2020), no benefit could be gained if teachers are denied a proper initial training for designing and applying AR-enhanced teaching practices.

Forth, in addition to the benefits of utilizing AR as a supporting tool in education, the current study found that AR tools imposed potential challenges for teachers while using them in their teaching practices. The major challenges teachers identified involve usability, technical, and pedagogical issues, which is consistent with prior review studies on AR used in educational settings (Akçayır & Akçayır, 2017; Wu et al., 2013). Relatively diverging from some studies(Belda-Medina & Calvo-Ferrer, 2022) which defined teachers' lack of AR technology knowledge as the main factor that constrained the adoption of AR technology in education, this study suggests that usability and pedagogical issues are as important as teachers' lack of ability to use AR tools. In other words, this study provides corroborative evidence that teachers could confront challenges of integrating AR tools into their instructional materials owing to their existing lack of competency in AR tools and the high cost of the tools (Okumuş, 2021), requiring more time to use in the classroom (Gavish et al., 2015), hindering attention, which is triggered by the split attention effect, (Chiang et al., 2014), internet connectivity problems (Chang et al., 2015), low sensitivity of trigger recognition and being difficult to use (Chang et al., 2014). It is suggested that technical problems can severely diminish users' engagement and experience with AR tools when combined with a complicated user interface and lack of a clear guideline regarding how to utilize AR.

This study revealed other significant problems that must be considered. For instance, teachers could have difficulty in creating an AR application because of limited or poor content (e.g., 3D objects, animations, images) available for the related AR tool, device compatibility issues, and limited access to the devices used to run the AR application. Besides, it would take more time for teachers to prepare AR-based activities or materials. Along with them, language might be another important issue for teachers to deal with since AR tools do not support all languages. It should be noted that more materials enhanced with multiple language options for teachers should be produced regarding how to use AR tools, especially for those novice teachers having no previous knowledge or experience with AR technology. Additionally, it seems that some of the issues inherent in AR for education might persist in the future and hinder teachers from integrating them into their courses.

It is concluded that knowing AR tools' potential value and strengths could provide teachers with valuable opportunities to exploit its features as instructional materials and then develop unique authentic learning applications for different educational purposes. Thus, AR tools would bring more pedagogical contributions to its users if teachers use them for creating special applications to teach abstract subjects. These subjects could involve experiments/activities that are dangerous or costly in terms of school resources.

6 Implications for practice

This study has important implications for education and future research. Previous studies primarily focused on implementing a specific AR technology developed by specialists to test its application for a particular field. However, pre-service teachers who are about to get into teaching practice and prepare learning materials for their courses are not sufficiently equipped with the experience of developing an AR tool. The best choice for them would be to use available AR tools. Even if they have access to ready-made AR applications, they may not know how to use them and incorporate them into their teaching and learning materials. Therefore, this study offers important findings regarding teachers' experience and thoughts about widespread AR tools along their strong and challenging aspects. More specifically, the results of this study inform teachers about which AR tools could be pedagogically more affordable, useful, and practical to help them attain the learning goals they aim to achieve in their lessons. Additionally, designers of AR learning environments and researchers can benefit from the study's findings and take them into consideration while designing their AR applications or learning environments.

The literature on AR technology lacked studies reporting findings related to comparing available AR tools that teachers could use to enrich their teaching materials and activities. In this respect, this study has important contributions to the accumulation of data on AR applications as well. First, CoSpaces and then Fectar and Blippar drew more positive responses from teachers compared to their counterparts, almost in all the investigated dimensions. This study presents tangible evidence as to which factors teachers could look for in an AR tool and includes important findings for the initiatives to educate teachers regarding these AR tools and their derivatives.

7 Limitations and recommendations

The co-creation technologies examined in this study are limited to seven AR tools. Therefore, a further investigation could expand the range of these tools to provide more comprehensive evidence for teachers' reflections on AR technology in educational settings. Besides, since the training program was conducted online, teachers' experiences of some AR tools could be remained limited, which might then influence their perceptions and views on those tools. Therefore, it would be better if a further study conducts the same program face-to-face. Along with it, the current study was designed to cover computer and mobile-based AR tools. More information on either computer or mobile augmented reality tools would help us establish a greater degree of accuracy on this matter.

The findings of the current study should be considered for the following presumed limitations: First, some participants could have previous knowledge and experiences with some of the AR tools or be better in terms of technological capabilities. Second, the faculty members who delivered the AR tools' training might be different in terms of subject knowledge, teaching styles, and previous experiences with AR tools. Third, all participants may not take the training under the same conditions like internet quality, computer performance, etc.

Appendix 1 Online Survey

	Definitely Disagree	Disagree	Uncertain	Agree	Definitely Agree
Intention to Use					
I would like textbooks to be supported with THIS AR TOOL in the future.					
I would like THIS AR TOOL to be implemented in our lessons in the future.					
In the future, I would like to use THIS AR TOOL application as an individual learning tool.					
Multimedia					
I like the use of sounds in THIS AR TOOL.					
I like the use of images in THIS AR TOOL.					
I liked the use of 3D animated videos in THIS AR TOOL.					
Satisfaction					
I am satisfied with the multimedia (image, audio, video) applications in THIS AR TOOL.					
I am satisfied with the use of materials created by THIS AR TOOL during class hours.					
I am pleased to work with the course materials created with THIS AR TOOL outside of class hours.					
Usefulness					
Implementation of THIS AR TOOL created a sense of reality.					
Implementation of THIS AR TOOL made the subject concrete.					
Implementation of THIS AR TOOL has been useful in my individual works.					
Implementation of THIS AR TOOL increased my interest in the course.					
Implementation of THIS AR TOOL provided a flexible (anytime, anywhere access) learning environment.					
Self-Efficacy					
I can easily use the particular software/applications required for THIS AR TOOL.					
It doesn't bother me to use THIS AR TOOL while studying.					
I can manage the technical features (custom applications, internet connection, etc.) required for THIS AR TOOL.					
Effectiveness					
I believe THIS AR TOOL has improved my learning performance.					
I believe THIS AR TOOL provides effective and efficient learning.					

	Definitely Disagree	Disagree	Uncertain	Agree	Definitely Agree
I believe THIS AR TOOL has increased my motivation to learn.					
System Quality					
I am satisfied with the interaction that THIS AR TOOL provides with the course content.					
I am satisfied with the features of the specific software/applications used for THIS AR TOOL.					
I had no problem with the internet connection while using THIS AR TOOL.					

Data availability The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest There is no conflict of interest to declare.

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