TechTrends
https://doi.org/10.1007/s11528-024-01014-4

ORIGINAL PAPER

Exploring Teachers' Competences to Integrate Augmented Reality in Education: Results from an International Study

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Accepted: 24 October 2024

Abstract
Augmented Reality (AR) can enhance learning experiences offering many benefits to students. However, its integration in educational practice is rather limited due to several obstacles. One of these obstacles is the absence of AR digital competencies among instructors. Limited research exists about teachers'competence areas in integrating AR in teaching and learning. The current study utilizes the validated Teachers' AR Competences (TARC) framework to investigate teachers' self-perceived competences in creating, using, and managing AR resources. Furthermore, it investigates educators' attitudes towards integrating AR in education. An online survey received responses from 150 educators worldwide. Quantitative results indicated that while teachers have positive attitudes towards educational AR, they do not feel confident in creating, using, or managing AR resources and experiences. All TARC subscales found to be significantly correlated to attitudes towards AR. No significant differences were found across all competence areas in regard to gender, age, and teaching level. However, statistically significant differences were found across all competence areas with respect to the teaching subject, general digital skills level, and previous class use of AR. Among the main practice and policy implications discussed, we suggest the need for training teachers in instructional design that deploys AR experiences.

Keywords Augmented reality · Attitude · Digital education · TARC · Teachers · Teachers' competence · Teachers' skills

Introduction

Augmented reality (AR) refers to technologies where digital objects are superimposed on the real word so users can interact with both (Cuendet et al., 2013). UNESCO has acknowledged AR as an emerging digital technology that can transform and enrich education by providing new educational experiences and opportunities (Miao et al., 2022). This emerging technology has been exploited in different areas of education such as mathematics, physics, biology, health, languages, and more (Garzón et al., 2019).

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Research has shown that AR can enhance the learning process. It enables the visualization of theoretical and abstract concepts and situations (Arici et al., 2021; Da Silva et al., 2019), enhances collaborative learning (Chang & Hwang, 2018;) as well as experiential (Mystakidis et al., 2022) and situated learning (Cai et al., 2022). Moreover, AR can offer various benefits to students. Studies have shown that AR can increase students' interest (Alalwan et al., 2020; Belda-Medina & Calvo-Ferrer, 2022), motivation (Belda-Medina & Calvo-Ferrer, 2022; Chang & Hwang, 2018), enjoyment (Alalwan et al., 2020).

However, there are several barriers that prevent the wide adoption of AR in education. These barriers are related to the technology, the students, the schools, and the teachers. Previous studies reported that one main challenge in AR adoption is that AR is "difficult for students to use" (Akçayir, & Akçayir, 2017). Usability is an important technical factor (Chang et al., 2014) and students either do not always have the digital skills to use AR or the skills to overcome usability or possible technical issues (Perifanou et al., 2023). Moreover, from a pedagogical integration perspective, AR may often distract students' attention (Alalwan et al., 2020;

Published online: 08 November 2024

Ibáñez & Delgado-Kloos, 2018). In addition, schools may not support AR (Barroso-Osuna et al., 2019), may have policies (such as the BYOD policy restrictions) that prohibit AR adoption (Alalwan et al., 2020; Perifanou et al., 2023), and lack both budget (Heintz et al., 2021) and appropriate digital infrastructure (Alalwan et al., 2020; Alkhattabi, 2017). Moreover, there is limited availability of quality AR material and resources that teachers can use in the classroom (Arici et al., 2021; Barroso-Osuna et al., 2019) and in addition, teaching time to experiment with AR is often limited (Heintz et al., 2021; Tzima et al., 2019). Therefore, most in-service teachers do not utilize AR applications in the classroom and have never created any AR application (Tzima et al., 2019).

Finally, another main obstacle is the teachers' lack of appropriate digital competences (Perifanou et al., 2023; Tzima et al., 2019). For example, only 39% of teachers in the European Union feel well prepared for using digital technologies in their daily work (OECD, 2019). While various digital skills such as computer programming, 3D modelling and animation software are required for the development of AR applications, most teachers do not have these skills (Belda-Medina & Calvo-Ferrer, 2022; Perifanou et al., 2023; Tzima et al., 2019). Even young future teachers (students) lack the skills necessary to develop AR apps and incorporate them into actual classroom instruction (Belda-Medina & Calvo-Ferrer, 2022). In addition to the lack of advanced digital skills for creating AR applications, teachers also lack pedagogical and technological knowledge as well as skills for implementing and integrating AR in class (da Silva et al., 2019; Belda-Medina & Calvo-Ferrer, 2022). Since teachers are key actors in the educational process, policies internationally prioritize the development of teachers' digital competence (European Union, 2022; OECD, 2019).

However, a main question is in which specific areas teachers lack digital competencies. Previous studies (Alalwan et al., 2020; Arici et al., 2021; Heintz et al., 2021) point out that there is limited research with regard to teachers' competences in incorporating augmented reality into instruction. Moreover, limited studies exist to investigate the impact of other variables (e.g., age, teaching level and experience, teaching subject, etc.) on teachers' attitudes towards AR integration and their perceived competences in integrating AR in teaching and learning (Heintz et al., 2021).

Thus, the current study will try to answer the following research questions:

1. *What are teachers' attitudes on integrating AR in education?*
2. *What are the teachers' self-perceived skills on creating, using, and managing AR resources?*
3. *How teachers' attitudes towards integrating AR in education correlate with their competences to create, use, and manage AR resources?*
4. *How teachers' AR attitudes and self-perceived skill levels differ across gender, age, teaching level, teaching experience, teaching subject, general digital skills level, and previous class use of AR?*

Literature Review

According to Alalwan et al. (2020), Arici et al. (2021), and Heintz et al. (2021) there is limited research with regard to teachers' competences in integrating AR in teaching and learning. Moreover, few studies exist to investigate the impact of other teachers' characteristics (e.g., age, teaching level and experience, teaching subject, etc.) on their attitudes towards AR and their perceived competences in integrating AR in teaching and learning (Heintz et al., 2021). Previous studies found that teachers are not proficient in creating AR applications (Belda-Medina & Calvo-Ferrer, 2022; Perifanou et al., 2023; Tzima et al., 2019). For example, Tzima et al. (2019) found that the majority of educators never developed an augmented reality application and did not use it in their instruction. In addition, based on the technological, pedagogical, and content knowledge (TPACK) framework, Belda-Medina and Calvo-Ferrer (2022) found that pre-service language teachers (students) lacked the skills necessary to develop AR apps and incorporate them into actual classroom instruction.

Teachers' attitudes toward incorporating AR into educational settings have become a subject of growing interest due to the potential transformative impact of AR on pedagogy. Most studies found that in-service and preservice teachers generally hold positive attitudes towards AR's potential to enhance teaching and learning (Ashley-Welbeck & Vlachopoulos, 2020; Belda-Medina & Calvo-Ferrer, 2022; Hervás-Gómez et al., 2017. AR helps to visualize tangible or intangible resources, provide extra layers of information and facilitates interactivity (Marín-Marín et al., 2023; Perifanou et al., 2023).

Several studies employed the Technology Acceptance Model (TAM) as a theoretical framework to understand teachers' inclinations toward adopting AR in education. Jang et al. (2021) found that teachers' favorable views of AR and VR-enabled education affect their continuous use in the classroom. In addition, Asiri (2022) discovered that perceived ease-of-use affects teachers' attitude to use AR in teaching. However, a study of mathematics teachers using an AR geometry tutorial system revealed no direct effect of perceived ease-of-use on attitude (Iblili et al., 2019). Similarly, based on TAM, Mikropoulos et al. (2022) and Koutromanos et al. (2023) found that perceived ease-of-use does not affect Greek teachers' attitude towards using AR in their teaching. On the other hand, perceived usefulness and perceived enjoyment affect teachers' attitude. In turn, attitude affects intention to use AR in teaching. Finally, Marín-Marín et al. (2023) showed that Spanish secondary education teachers had a positive attitude towards developing and applying AR in teaching. Similar studies on teachers' self-perceived competences have been based on various frameworks such as TAM (Koutromanos et al., 2023) or TPACK (Belda-Medina & Calvo-Ferrer, 2022).

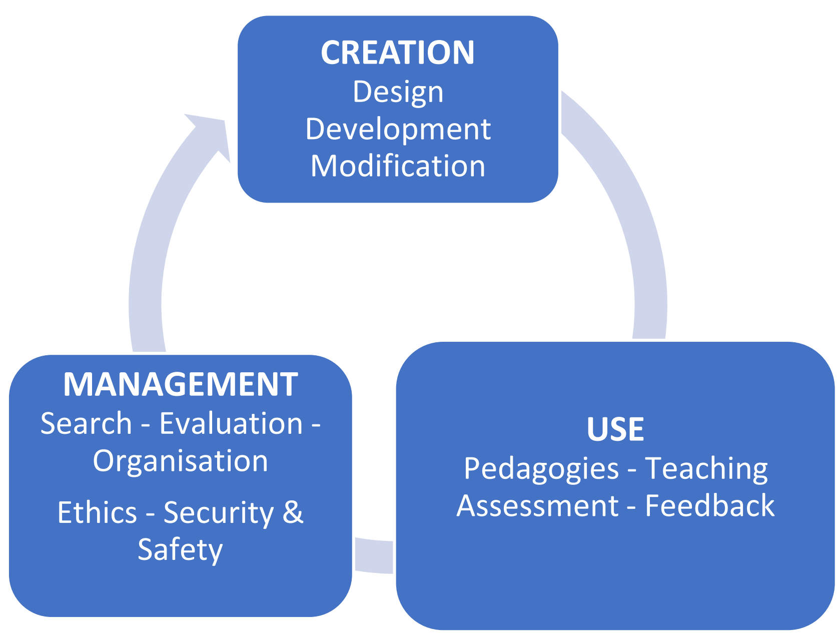
Our study is novel because it is the first one that uses the validated TARC model (Nikou et al., 2023) which focuses exclusively on AR-specific competences. The current study examines all specific AR competence subscales instead of an overall AR competence level. Furthermore, very few studies investigated both constructs (teachers' AR skills and teachers' attitudes toward AR in education) together. Ripsam and Nerdel (2024) investigated teachers' attitudes and self-efficacy toward AR in chemistry education and they found only a weak correlation between self- efficacy regarding digital media and acceptance. The authors urged for future research to examine relationships between digital skills, attitude and acceptance. So, the current study will further investigate this issue.

Finally, very few studies investigated the teachers' AR attitudes and AR competences across their personal characteristics. Jwaifell (2019) found the years of teaching experience had no impact on a teacher's readiness for AR, and that female teachers were more prepared than male teachers to embrace AR. Marín-Marín et al. (2023) found that teachers' age and teaching experience influence their attitude toward using AR. Nikou et al. (2023) found significant differences of teachers' AR competences with respect to teaching subject, general digital skills and previous AR class experience. However, there were not any significant associations of AR competences with respect to gender and age. Compared to secondary and primary levels, educators in higher education institutions self-reported having a higher competency level for creating, changing, and designing augmented reality resources.

Theoretical Background

The study uses the Teachers' Augmented Reality Competences (TARC) framework proposed by (Nikou et al., 2022) as its theoretical background. TARC defines three AR competence subscales for teachers, namely: *Create*, *Use*, *and Manage* AR learning resources (Fig. 1) and can help educators to self-assess their AR competencies in order to integrate AR in their practice. *Creation* refers to the capacity to design, develop, and modify augmented reality learning resources and experiences. *Use* refers to the capacity to employ various pedagogies and teach using AR, design and deploy assessment and provide feedback using in AR. *Management* refers to the capacity to find, organise/classify, and evaluate augmented reality learning resources as well as taking into account concerns about security, safety, and ethics while incorporating augmented reality into instruction. The framework deemed appropriate to inform the current study because it addresses all the challenges involved on the integration of AR into teaching. TARC has been successfully used to frame other prior studies (Nikou et al., 2024a, b; Nikou et al., 2024b). The main instrument of the current study is based on the TARC framework, and it is described in the methods section.

Fig. 1 Teachers' AR competencies (TARC) framework



Methods

The study employed a quantitative research design relying on collection and analysis of numerical data, a frequently used strategy in social and psychological research (Singleton & Straits, 2009). Specifically, the study followed a non-experimental descriptive design employing a survey. The chosen research design is a descriptive method defined as "the collection of information from a sample of individuals through their responses to questions" (Check & Schutt, 2012, p. 160) aiming to describe characteristics of a group or population (Fraenkel et al., 2012). We have chosen this design with the intention of "simply study the phenomenon of interest as it exists naturally" without any attempt to "manipulate the individuals, conditions or events" (Mertler, 2016, p. 111). Among the several data collection modes, we have chosen a web-based survey as it is a convenient and cost-effective method. For our worldwide survey we have used convenience sampling as a feasible method to collect data from multiple regions and demographics. Furthermore, since there is not much research on teachers' competences to integrate Augmented Reality in education, convenience sampling provides a practical and quick means to gather initial data and gain insights that can inform future, more large-scale studies.

Procedure

The survey was conducted from May to June 2022, after ethical approval was granted by the University Ethics Committee. Researchers disseminated at international level a web-based questionnaire through teachers' social media channels and teachers' associations' discussion email lists. Social media channels and associations specifically for teachers ensure that the survey reaches the intended demographic directly, helping to increase the representativeness of the resulting sample. Moreover, teachers who are members of these channels and associations are likely to be more engaged and interested in professional discussions, including surveys that pertain to their field. Participants were directed to a Qualtrics questionnaire through initial conduct via social media or emails. Participation in the study was completely voluntary and anonymous.

Materials

In order to avoid any misconceptions about AR, the questionnaire included in the beginning, a clear and concise definition of AR as well as a short video about AR in order to ensure all participants have a consistent understanding of the concept. So, all participants would be able to work from the same baseline definition, reducing variability in interpretation. Furthermore, the survey was pilot tested with a small diverse group of individuals to identify and address any ambiguities or misunderstandings regarding AR.

The questionnaire itself consisted of three sections. The first section focused on participants' socio-demographic and teaching related data. This section included multiple choice questions about participants' 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 section (questions A1-A4) focused on participants' attitudes towards integrating AR in education. The third section focused on teachers' self-perceptions on their skills to *create*, *use*, *and manage* AR educational resources and has been adopted from the TARC framework questionnaire. The TARC questionnaire has been validated by (Nikou et al., 2023) through a confirmatory factor analysis that demonstrated valid results in terms of model fit criteria, factor loadings, validity, and reliability. This third section of the study questionnaire included three subscales namely teachers' beliefs on their skills to c*reate*, *use and manage* AR educational resources. The *AR creation* subscale incorporated aspects of designing, developing, and modifying AR resources and comprises questions C1-C3. The AR use subscale incorporated aspects of using pedagogical, instructional, assessment and feedback practices and comprises questions U1-U4. The *AR management* subscale incorporated aspects of searching, evaluating, organizing as well as ethical and safety issues and comprises questions M1-M5. The questions for the attitudes and AR competencies were 5-point Likert-type, ranging from "Strongly disagree (1) to "Strongly agree" (5).

Participants

A total of 176 responses were collected via Qualtrics. The final sample, however, consisted of 150 responses after a few were removed for being incomplete. Participants' demographic data and their teaching related characteristics are shown in Tables 1 and 2 respectively.

Findings and Data Analysis

The data collected through the Likert-type questionnaire comprise ordinal data (Sullivan & Artino, 2013) and due to its ordinalist interpretation, nonparametric tests were used (South et al., 2022) without any assumption for the normality or continuity of the data (Harpe, 2015). Therefore, the median, mode, and interquartile range (IQR) were used to present central tendency measures as being more appropriate (Jamieson, 2004; Sullivan & Artino, 2013). The Cronbach's alpha reliability coefficient of internal consistency

Table 1 Participants socio-demographic characteristics ($N=150$)

Demographic variables		Percentage
Gender	Female	49.9%
	Male	46.6%
	Prefer to self-describe	1.2%
	Preferred not to say	2.4%
Age	21–40 years old	28.5%
	41–60 years old	63.4%
	61–70 years old	5.4%
	other/prefer not to say	2.7%
Country	UK	17.5%
	Greece	16.2%
	Malta	12.3%
	USA	7.2%
	India	5.5%
	Portugal	3.8%
	Canada	2.5%
	Australia	2.5%
	38 other countries	32.5%
General digital skills level	Basic	9.7%
	Intermediate	43.0%
	Advanced	47.3%

for all scale items was calculate ensing that all Cronbach's α values are greater than 0.7 demonstrating the internal consistency of the questionnaire (Cronbach, 1951; Leung, 2011). Further analysis to determine the statistically significant differences in beliefs between the various teachers' groups was performed using the non-parametric criterion Kruskal-Wallis (Dancey & Reidy, 2017). Pairwise post hoc tests were then performed to evaluate pairwise differences among the groups, controlling for Type I error across tests by using the Bonferroni approach with the alpha-level set to 0.05 and the sample size 150. The post-hoc analysis considered the following effect sizes for the eta-squared estimates: $0.01 \leq \eta^2 < 0.06$ as small, $0.06 \leq \eta^2 < 0.14$ as moderate and $\eta^2 \geq 0.14$ as large (Tomczak & Tomczak, 2014; Perugini et al., 2018). Eta-squared calculates the percentage of the total variance in a dependent variable that is related to the membership of different groups defined by an independent variable (Richardson, 2011).

Techers' Attitudes Towards AR

Addressing the first research question "What are teachers' attitudes on integrating AR in education", participants were asked questions about their attitudes towards AR. The results of their answers are presented in Table 3. The Cronbach's alpha reliability coefficient is 0.949, which indicates a high level of internal consistency for our scale with this specific sample.

In terms of central tendency, teachers feel positive regarding the use of AR, they believe that it is good for teaching making it more interesting. In general, they have favourable attitudes toward using AR in teaching (median = 4, IQR = 1). This encouraging finding is essential for the successful integration of AR into education.

Teachers' Self-perceived Competences on Creating AR Resources

Addressing the section of the second research question that refers to the creation competences, "What are teachers' self-perceived skills on creating AR resources",

Table 2 Participants teaching related characteristics ($N=150$)

Teaching related characteristics		Percentage
Teaching level	Primary	9.3%
	Secondary	27.3%
	Tertiary	59.3%
	Other	4%
Teaching Experience	1–10 years	28%
	11–30 years	47.9%
	31–40 years	10.2%
	other/prefer not to say	3.2%
Teaching Subject/Discipline	Science (Math, Physics, Chemistry, Biology)	19.3%
	Informatics/Engineering/Technology	50.0%
	Economics/Social Sciences	4.8%
	Languages/Literature	6.7%
	Arts	3.2%
	Other	12.9%
Previous AR use in class	Yes	36.0%
	No	64.0%

Table 3 Teachers' response frequencies of Likert type questions about their attitudes towards AR ($N=150$)

	Likert Scale	1 Strongly Disagree	2 Disagree	3 Do not know	4 Agree	5 Strongly Agree	Median	Mode	IQR
A1	I feel positive regarding the use of AR in teaching.	5	2	25	57	61	4	5	1
A2	I believe it is a good idea to use AR in teaching.	4	0	23	61	62	4	5	1
A3	Using AR makes teaching more interesting.	4	1	22	55	68	4	5	1
A4	I have a generally favourable attitude toward using AR in teaching	5	1	20	68	56	4	4	1

participants were asked questions about their self-perceived skills on creating, namely designing (C1), developing (C2), and modifying (C3) AR resources.

Teachers' self-perceptions on their skills in creatin (designing, developing, and modifying AR resources) are presented in Table 4. The Cronbach's alpha reliability coefficient is 0.929, which indicates a high level of internal consistency for the subscale.

In terms of central tendency, teachers do not seem to be quite sure if they can create AR resources (median = 3) and in terms of the most frequent answer, teachers tended to respond, "I do not know". The percentage of teachers who believe that they cannot design AR resources ($n=60$, 40%) is greater than the percentage of the teachers who believe that they can ($n=49$, 32%). Teachers' beliefs for their ability to develop or modify AR resources seem to be divided. Many teachers responded that they could develop ($n=53$, 35%) and modify ($n=55$, 37%) AR resources but a roughly equal number indicated that they cannot develop ($n=51$, 34%) or modify ($n=57$, 38%) AR. Teachers' self-reported uncertainty regarding AR creation competences shows that a significant percentage of teachers (almost half) either have not had the opportunity to create AR or do not actually have this capacity.

Teachers' Self-perceived Competences on Using AR Resources to Teach

Addressing the section of the second research question that refers to the usage competences, "What are teachers' self-perceived skills on using AR resources in teaching", participants were asked questions about their self-perceived skills on using AR resources employing pedagogies (U1), teaching (U2), assessing (U3) and giving feedback (U4). Teachers' self-reported skills on using AR resources to teach (including pedagogies, teaching practices, assessment, scaffolding) are presented in Table 5. The Cronbach's alpha reliability coefficient is 0.961, which indicates a high level of internal consistency for the subscale.

In terms of central tendency, again neutrality has been recorded about teachers' beliefs regarding their ability to use AR for teaching (median = 3) and considering the mode, the most frequent answer was also "I do not know". From the teachers who gave a non-neutral answer, more teachers feel confident to teach with AR ($n=65$, 43%) compared to those who do not ($n=55$, 37%) while less teachers feel confident to assess using AR ($n=46$, 31%) compared to those who do not ($n=58$, 39%). Teachers' beliefs for their ability to employ pedagogies or provide feedback with AR seem to be divided. This uncertainty, considering the positive attitudes towards AR for the majority of teachers, evidence that while teachers would like to use AR, they struggle to use it.

Teachers' Self-perceived Competences to Manage AR Resources

Addressing the section of the second research question that refers to the management competences, "What are teachers' self-perceived skills on managing AR resources",

Table 4 Teachers' response frequencies of Likert type questions about their skills on creating (designing, developing, modifying) AR resources ($N=150$)

	Likert Scale	1 Strongly Disagree	2 Disagree	3 Do not know	4 Agree	5 Strongly Agree	Median	Mode	IQR
C1	I can design AR educational experiences using AR applications and tools to meet specific educational objectives	33	27	41	28	21	3	3	2
C2	I can develop AR educational resources using easy-to-use AR templates and asset libraries.	29	22	46	35	18	3	3	2
C3	I can modify and adapt AR educational resources to my teaching goals.	29	28	38	39	16	3	4	2

Table 5 Teachers' response frequencies of Likert type questions about their skills on using AR resources to teach ($N = 150$)

	Likert Scale	1 Strongly Disagree	2 Disagree	3 Do not know	4 Agree	5 Strongly Agree	Median	Mode	IQR
U1	I can use AR educational resources and tools employing various pedagogies and teaching methods.	21	33	40	32	24	3	3	2
U2	I can use AR educational resources and tools to teach (e.g., present, demonstrate, explain the educational content) my students.	21	24	40	34	31	3	3	2
U3	I can use AR educational resources and tools (e.g., AR and multimodal game-based and/or simulation-based assessments) to assess the students' progress.	26	32	46	29	17	3	3	2
U4	I can use AR educational resources (e.g., avatars, multimodal interfaces) to guide, feedback, advise, support, and inspire students.	25	34	41	27	23	3	3	2

participants were asked questions about their self-perceived skills on managing namely, searching (M1), organising (M2), evaluating AR (M3) resources as well as considering ethical (M4) and safety issues (M5). Teachers' self-reported skills to manage AR resources (including searching, organising, evaluating, and considering ethical and safety issues) are presented in Table 6. The Cronbach's alpha reliability coefficient is 0.955, which indicates a high level of internal consistency for the subscale.

In terms of central tendency, teachers do not seem to be quite sure if they can manage AR resources (median = 3). Moreover, considering the mode, the most frequent answer was "I do not know". From the teachers who gave a non-neutral answer, more teachers believe that they can search ($n = 73$, 49%), evaluate ($n = 58$, 39%), and organise ($n = 56$, 37%) AR resources respectively comparing to those who cannot search ($n = 37$, 25%), evaluate ($n = 48$, 32%) and organise ($n = 49$, 33%). More teachers ($n = 57$, 38%) reported confident with ethical related issues compared to those who reported that they do not ($n = 49$, 33%). Teachers' confidence about safety related AR issues seems to be divided. Teachers' self-reported confidence to manage AR resources (i.e., search, evaluate and organise) is promising for the employment of AR in teaching while the lack of safety AR competences is an important issue to consider.

Relationships between Teachers' Attitudes towards AR, Their Competences to Create, Use and Manage AR Resources

In order to address the third research question and determine the relationship between the questionnaire subscales we have

Table 6 Teachers' response frequencies of Likert type questions about their skills to manage AR resources ($N = 150$)

	Likert Scale	1 Strongly Disagree	2 Disagree	3 Do not know	4 Agree	5 Strongly Agree	Median	Mode	IQR
M1	I can use search engines, digital repositories, and databases to find existing AR educational resources and tools using appropriate criteria, metadata filters, and recommender systems.	22	15	40	39	34	3	3	1.25
M2	I can evaluate AR educational resources and tools using appropriate criteria.	29	19	44	30	28	3	3	2
M3	I can organize and schedule the most appropriate AR educational resources and tools for achieving specific educational objectives.	30	19	45	37	19	3	3	2
M4	I can ensure and control the ethical and responsible use of AR resources and tools by all participating in the educational activities (e.g., respecting participants' personality, privacy, rights).	31	18	44	36	21	3	3	2
M5	I can secure the safe use of AR resources and tools by all participating in the educational activities (e.g., securing participants' resources, safety, health).	30	23	42	36	19	3	3	2

conducted Spearman's rank-order correlation tests. We have considered that calculating the mean for data measured at the ordinal level as appropriate (Carifio & Perla, 2008;2007) and acceptable (Harpe, 2015; Sullivan & Artino, 2013). A Spearman rank order correlation was calculated on the mean scores of the questionnaire subscales to determine if they are significantly correlated. Results are depicted in Table 7. Correlations between 0.30 and 0.50 are considered moderate, whereas those above 0.50 are considered strong (Cohen, 1988).

The construct of attitudes towards AR was correlated at a statistically moderate significant level with AR creation ($r = 0.373$, $p < 0.01$), AR use ($r = 0.394$, $p < 0.01$), and AR management ($r = 0.370$, $p < 0.01$). Moreover, AR creation was correlated at a statistically high significant level with AR use ($r = 0.777$, $p < 0.01$) and AR management ($r = 0.706$, $p < 0.01$), and AR use was correlated at a statistically high significant level with AR management *(*$r = 0.783$, $p < 0.01$). Teachers with positive attitudes towards AR, and better AR creation and management skills are more likely to be more competent to use AR in their teaching.

Differences in Teachers' AR Attitudes and self-perceived Skill Levels across Multiple Groups

Addressing the fourth research question on the *differences in teachers' AR attitudes and self-perceived skill levels across gender*, *age*, *teaching level and teaching experience*, *teaching subject*, *general digital skills level and previous class use of AR*, we performed rank-based nonparametric tests. The Kruskal–Wallis tests revealed no significant differences among the individual subgroups for the grouping variables *gender*, *age* and *teaching level* (Table 8). The alpha level was set < 0.05 and the obtained sample size of the survey 150 was used for the assessments.

However, for the grouping variables of *teaching subject (*Science, Informatics/Engineering, Economics/Social Sciences, Languages/Literature, Arts and Other), *general digital skills level (*Beginner, Intermediate and Proficient) and *previous class use of AR* (yes/no), the tests revealed statistically significant differences among the subgroups.

Table 7 Spearman rank order correlations for the subscales of the questionnaire

	Attitude	AR creation	AR use	AR management
Attitude	-	0.373**	0.394**	0.370**
AR creation		-	0.777**	0.706**
AR use			-	0.783**
AR management				-

**$p < 0.01$;

For the *teaching experience* grouping variable significant differences were found only for the subscales of modifying, evaluating and security and safety competences (Table 8).

The conducted post-hoc analysis for each individual questionnaire item for the grouping variables teaching subject, general digital skills level, and previous class use of AR, revealed similar effect sizes, indicating similar magnitude of difference among the subgroups within the grouping variables across the questionnaire subscales. Therefore, the effect sizes for each individual questionnaire item have been deemed unnecessary for detailed presentation, while the effect sizes (omega-squared estimates) for the aggregate (mean) values for each questionnaire subscales are as follows. Omega-squared estimates are considered a less biased estimate of the population effect size than partial eta-squares (Albers & Lakens, 2018). As the following Table 9 presents, the effect sizes of the ***teaching subject*** were *moderate* for the AR attitudes, AR creation, use and management. The effect sizes of the ***general digital skills*** were *large* for the AR attitudes, AR creation, use and management. The effect sizes of the ***previous AR class use*** were *small for* the AR attitudes and *large* for AR creation, use and management.

Discussions

The current study investigated teachers' attitudes and self-perceived competences on integrating Augmented Reality in education. While few similar studies exist, these studies are based on various other frameworks, e.g., TAM (Koutromanos et al., 2023), TPACK (Belda-Medina & Calvo-Ferrer, 2022). Our study is novel because it is the first one that explores teachers' perceptions on the competences needed to integrate Augmented Reality in education and uses the validated TARC model (Nikou et al., 2022, 2023) which focuses exclusively on AR-specific competences. Furthermore, our study examines all specific AR subscales instead of the overall AR competence level. Moreover, the study contribution results from the fact that it analyses data collected from educators worldwide. Our findings have shown that teachers feel positive regarding the educational uses of AR. They believe that AR can make teaching interesting and in general, they would be willing to integrate AR in their own teaching. This is in agreement with previous finding (Alkhattabi, 2017; Belda-Medina & Calvo-Ferrer, 2022; Perifanou et al., 2023; Salmee & Abd Majid, 2022). However, despite their positive attitudes towards educational AR, teachers are hesitant to use it due to a number of obstacles (Akçayır & Akçayır, 2017; Arici et al., 2021; Heintz et al., 2021; Nikou et al., 2022; Perifanou et al., 2023). One of these obstacles is the lack of teachers' skills to integrate AR in education (Barroso-Osuna et al., 2019; Garzón et al., 2019; Perifanou et al., 2023). While previous research has

Table 8 Kruskal Wallis tests on teachers' groups across the questionnaire items

	A1	A2	A3	A4	C1	C2	C3	U1	U2	U3	U4	M1	M2	M3	M4	M5
Grouping variable: *Gender*																
Chi-square	1.795	1.295	3.891	1.142	0.308	0.731	0.823	2.177	2.150	1.553	0.720	5.739	1.196	1.792	1.671	2.480
df	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Asymp. sig	0.408	0.523	0.143	0.565	0.827	0.694	0.663	0.337	0.341	0.460	0.698	0.057	0.550	0.408	0.434	0.289
Grouping variable: *Age*																
Chi-square	8.796	11.371	11.852	9.269	0.817	6.038	6.205	9.295	9.365	2.930	2.194	5.734	6.485	3.636	5.024	4.930
df	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Asymp. sig	0.117	0.045	0.037	0.099	0.121	0.303	0.287	0.098	0.095	0.711	0.822	0.333	0.262	0.603	0.413	0.424
Grouping variable: *teaching level*																
Chi-square	5.524	4.322	3.909	2.491	6.863	4.322	6.860	2.371	2.081	1.642	2.430	4.444	1.785	4.217	3.105	3.658
df	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Asymp. sig	0.137	0.229	0.272	0.477	0.076	0.229	0.076	0.499	0.556	0.650	0.488	0.217	0.618	0.239	0.376	0.301
Grouping variable: *teaching subject*																
Chi-square	15.941	11.157	16.034	21.987	17.979	17.734	15.156	12.354	16.338	22.167	9.470	17.467	15.917	12.910	12.972	15.684
df5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Asymp. sig	**0.007**	**0.048**	**0.007**	**< 0.001**	**0.003**	**0.003**	**0.010**	**0.030**	**0.006**	**< 0.001**	0.092	**0.004**	**0.007**	**0.024**	**0.024**	**0.008**
Grouping variable: *teaching experience*																
Chi-square	11.743	10.529	8.886	9.075	9.598	8.341	14.720	9.575	9.719	7.902	7.263	13.441	17.012	10.760	17.359	15.622
df	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Asymp. sig	0.109	0.161	0.261	0.247	0.213	0.303	**0.040**	0.214	0.205	0.341	0.402	0.062	**0.017**	0.149	**0.015**	**0.029**
Grouping variable: *general digital skills*																
Chi-square	12.670	12.607	7.937	9.993	25.549	32.308	33.123	24.831	21.369	18.063	18.207	20.493	23.687	14.475	21.318	20.086
Df	2	2	2	2	2	2	2	2	2	2	2					
Asymp. sig	**0.002**	**0.002**	**0.019**	**0.007**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Grouping variable: *previous in-class AR use*																
Chi-square	8.521	7.885	10.648	5.138	23.296	14.508	23.112	35.173	28.966	20.380	27.842	5.149	13.183	20.929	14.823	22.051
Df	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asymp. sig	**0.004**	**0.005**	**0.001**	**0.023**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**0.023**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

Note: The alpha level was set < 0.05

Table 9 Effect sizes for the aggregate (mean) values for the questionnaire subscales

		Effect	H (5)	*p*	ω[2]
Teaching subject	AR attitudes	Moderate	18.664	0.002	*0.130*
	AR creation	Moderate	18.816	0.002	0.099
	AR use	Moderate	16.870	0.005	0.079
	AR management	Moderate	16.813	0.005	0.081
			H (2)	p	ω^2
General digital skills	AR attitudes	Large	9.468	0.009	0.101
	AR creation	Large	35.930	< 0.001	0.231
	AR use	Large	20.308	< 0.001	0.149
	AR management	Large	22.912	< 0.001	0.142
			H (1)	p	ω^2
Previous class use of AR	AR attitudes	Small	9.714	< 0.001	0.034
	AR creation	Large	22.548	< 0.001	0.153
	AR use	Large	23.226	< 0.001	0.213
	AR management	Large	17.880	< 0.001	0.113

identified the lack of AR competences in general, our study is the first one that investigates teachers' perceived competences levels on all subscales of AR educational integration as described in the TARC framework (Nikou et al., 2022, 2023). In principle, teachers self-reported that they are not sure if they can create, use or manage AR educational experiences or resources.

The recorded neutrality on teachers' beliefs regarding their ability to create, use, manage AR for teaching implies that there is a lack of actual AR classroom experience. Indeed, while AR is gaining popularity in education, its application in the classroom is rather limited mainly due to the lack of the appropriate digital infrastructure (Akçayır & Akçayır, 2017; Alalwan et al., 2020; Arici et al., 2021) and the lack of teachers' competences (Alkhattabi, 2017; Hientz et al., 2021; Perifanou et al., 2023).

Regarding the competences related to the creation of AR, the central tendency indicated a neutrality; teachers were not quite sure if they can create educational AR. From the teacher population who gave a non-neutral response, teachers did not feel confident utilising augmented reality tools and software and create educational experiences that address certain learning objectives. However, there is a number of teachers who said they can develop or modify AR educational resources. It seems that, while designing AR experiences is a difficult task for teachers because it requires specialised knowledge (Cuendet et al., 2013), easy-to-use AR creation platforms (e.g., Blippar, thinglink, etc.) and asset libraries (e.g., Sketchfab) are helpful for teachers and instructional designers to develop or modify AR resources (MacCallum & Parsons, 2019; Pellas & Kazanides, 2019). Further developing AR creation platforms that do not require programming knowledge or special graphics skills from users could motivate teachers to design and develop AR learning experiences for their students.

Regarding the competences related to the use of AR, again the central tendency indicates a neutrality; teachers were not quite sure if they could use educational AR. From the teacher population who gave a non-neutral response, there is a number of teachers who said that they feel confident to use AR tools to teach their students (e.g., present, demonstrate, explain the educational content). This is probably due to their high level of technology integration self-efficacy in general (Gomez et al., 2022). However, teachers who said that they could deploy various pedagogies with AR were not many. This is in agreement with previous studies (Belda-Medina & Calvo-Ferrer, 2022; Cabero & Barrroso, 2016; da Silva et al., 2019). Moreover, teachers did not feel confident to use AR educational resources and tools to assess the students' progress (through e.g., AR and game or simulation-based assessments) or to guide, feedback, advise, support, and inspire students (through e.g., avatars, multimodal interfaces). Previous research has shown that pedagogical approaches can positively affect the impact of AR in education. For that reason, various pedagogies have been proposed e.g., discovery-based learning, situated learning, problem-based learning, or collaborative learning (Wang et al., 2018). However, AR teaching interventions seem to have emphasised more the technical characteristics of the AR technology and not the instructional strategies to apply them (Garzon et al., 2020). Evidently, there is a lack of appropriate teacher training in deploying AR in educational practice. Teachers should receive the appropriate training in order to put AR into practice utilising the appropriate pedagogical methods.

Regarding the competence related to the management of AR, teachers' perceived skills were also reported as neutral; teachers were not quite sure if they can use educational AR. From the teacher population that gave a non-neutral response, more teachers seem to feel confident to use search engines, digital repositories, and databases to locate AR teaching tools and resources, they can assess AR tools and resources according to suitable standards and can organize suitable AR teaching materials and instruments for accomplishing particular learning goals. Moreover, they can guarantee and oversee the ethical and responsible use of AR resources and tools by all those taking part in the educational activities (e.g., honouring participants' rights, privacy, and personalities). The self- reported relatively high competence level of teachers (from those who did not gave a neutral response) in searching, organising and ensuring ethical behaviour may be attributed to their general digital literacy and professional skills and experience. However, when it comes to safety related issues (e.g., securing participants' resources, participants' safety and health) teachers' responses were almost equally split among those who can and those who cannot support. Therefor safety issues in the context of AR are another important issue to be considered in teacher training.

Finally, our findings indicated that no significant differences exist among the individual subgroups for the grouping variables *gender*, *age and teaching level* across all the subscales. Regarding the influence of *gender* in the use of AR in education, previous research reports controversial results. Some studies found gender differences (e.g., Hsu, 2019) while other studies did not find gender differences (e.g., Adedokun-Shittu et al., 2020; Cabero-Almenara et al., 2019) in AR attitudes. According to Valencia et al. (2021), there are gender differences in students' motivation or interest in the use of AR; females were more enthusiastic and excited about the usage of AR than males (Dirin et al., 2019) and exhibited a more positive attitude towards and behavioural intention to use augmented reality (AR) than did males. (Álvarez-Marín et al., 2020). However, other studies have found no significant difference between genders with regard to their AR acceptance (Cabero-Almenara et al., 2019). Gender differences related to ICT skills have been questioned during the last years (Hohlfeld et al., 2013); gender-based digital divide within educators keeps reducing and educators' digital competences are not shown to be related to gender (Cabero-Almenara et al., 2019). In agreement with a recent meta-analysis on gender differences in information and communication technology use & skills (Qazi et al., 2022), our study found no significant difference between genders with regard to their perceived digital skills. Regarding the influence of *age* in the use of AR, our study found no significant differences among the participants for the grouping variable of age. Age-based digital competences have been studied extensively, with controversial results. Studies exist that have found associations between age and digital competence (Cabezas-González et al., 2017) while more recent studies (Jiménez-Hernández et al., 2020) showed no positive correlation between age and digital competence among teachers, which is in agreement with our results.

For the grouping variables of *teaching subject*, *general digital skills level and previous class use of AR*, our findings revealed statistically significant differences among the subgroups. General digital skills and previous class use of AR positively affect AR skills. Consistent with other studies conducted using other technologies, our study found that previous digital activity and existing digital skills have a positive influence on teachers' further AR competences (Saikkonen and Kaarakain 2021). The study also found a significant difference among the individual subgroups for the grouping variable of teaching subject. This agrees with other studies highlighting that teachers from technological degrees have higher digital competence (Falco, 2017). The agreement of our study with previous findings in other educational technologies is a step forward in exploring teachers' AR competence subscales in particular.Kaarakainen.

Conclusions

The findings of our study evidenced that teachers have positive attitudes towards educational AR. Moreover, these attitudes are positively related to the main competence areas of creating, using and managing AR resources. Therefore, positive attitudes towards AR can be an enabling and accelerating factor for the employment of AR teaching practices in the classroom. However, teachers do not feel confident in creating, using, or managing AR resources and experiences. This gap should be considered by pre-service and in-service teacher training programmes to further support educators' professional development in the area. Evidently, there is a lack of appropriate teacher training in deploying AR in educational practice. Teachers should receive the appropriate training in order to put AR into practice utilising the appropriate pedagogical methods. Since teaching subject, overall proficiency in digital skills, and prior classroom utilization of AR were found to exhibit significant differences in AR competence areas, educators' professional development programmes in AR should be customised to the teachers' subjects, emphasise teachers' upskilling in digital skills in general and encourage AR classroom use where appropriate.

Limitations and Further Studies

As with all studies, the current study has a number of limitations. First, due to the chosen convenience sampling procedure the sample is not representative of the teachers' population in every country of the world. Future research may attempt to repeat this study in specific countries or consider a more representative sample. Future studies with TARC are recommended to use stratified sampling techniques to ensure proportional representation from different regions and demographics or can use weighting adjustments in the data analysis phase to correct for any overrepresented or underrepresented groups. In addition, in the current study the participants were teachers with access to internet and an interest in AR. However, there may be other teachers who have not internet access or are not interested to participate in a survey about AR; so, the perceptions of these teachers were not recorded. Also, the findings of this study are based on the teachers' perceptions about their AR competence levels. However, they may overestimate or underestimate their real AR competence. In addition, it is known that women underestimate their competence (Kalaian & Freeman, 1994). Moreover, even though the survey was anonymous, it might have been susceptible to social desirability bias, a common type of bias in social science research (Krumbal, 2013). Nevertheless, most studies employ a self-assessment method since it is a quick and convenient method that also enables participants to reflect on the questions and become aware of their status (Ross, 2006). Another limitation of the questionnaire is that it was not supplemented with open-ended questions. Qualitative data explaining the survey results would have made the study more meaningful and this is something that needs to be considered in future research. Also, future research may objectively measure the teachers' AR competence asking them to solve real problems in AR. Finally, this study examined differences of the teachers' AR competence with regard to gender, age, teaching experience, teaching subject, educational level, etc. Future research may also examine the effect of other variables on the teachers' AR competence.

In order to effectively integrate AR in education, teachers should become self-aware and reflect about their AR competences, obtain training on AR, experiment with AR, collaborate with colleagues and integrate AR in their practice. TARC offers a valuable scale for teachers to self-evaluate their AR competences. As discussed above, future larger-scale studies can gain more insights on teachers' AR competence levels in order to inform teacher development programs, policymakers, and software businesses to create AR experiences to enhance teaching practices and empower educators.

Acknowledgements N/A.

Funding The study received no funding.

Data Availability The data that support the findings of this study are available upon reasonable request.

Declaration

Compliance with Ethical Standards The study was granted approval from the Ethics Committee of the Strathclyde Institute of Education, University of Strathclyde.

Disclosure statement The authors report there are no competing interests to declare.

Competing Interests The authors have no competing interests to declare that are relevant to the content of this article.

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