Education and Information Technologies
https://doi.org/10.1007/s10639-024-12481-w

Factors influencing student teachers' intention to use mobile augmented reality in primary science teaching

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Received: 28 July 2023 / Accepted: 15 January 2024

Abstract

Thanks to the advancement of mobile technologies, Augmented Reality (AR) has become broadly accessible through mobile devices such as smartphones and tablets. Mobile Augmented Reality can benefit science education in a variety of ways. However, except from some sporadic experimental cases, it is rather rarely employed by teachers and has not yet been fully introduced in education. Moreover, little research exists about the adoption behavior of mobile AR by pre-service teachers. Against this background, the current study proposes and validates an integrated adoption model to explain and predict the factors that significantly influence student teachers' intentions to use mobile AR in teaching primary science. The study also introduces two new constructs, Perceived Immersion and Perceived Educational Value in the context of mobile AR. Eighty-nine undergraduate pre-service primary school teachers participated in a mobile augmented reality workshop creating mobile augmented reality experiences for teaching physics to primary school pupils. Following that, student teachers answered an online survey. The quantitative survey data was analysed using structural equation modelling. The study confirmed the proposed model explaining and predicting approximately 72% of the variance of student teachers' Behavioral Intention to Use mobile AR to teach primary science. Perceived Immersion and Perceived Educational Value significantly influence Behavioral Intention to Use after being mediated by Perceived Usefulness. The study offers insight into the factors influencing pre-service primary teachers' intentions to utilise mobile augmented reality (AR) in their future lessons, which is relevant given the growing interest in utilising these technologies in education. Implications are discussed.

Keywords Augmented reality · Mobile learning · Science education · Technology acceptance · Teachers' education

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1 Introduction

Augmented Reality (AR) can benefit education in a variety of ways. Research reports that it can increase students' motivation, engagement and academic performance (Bacca et al., 2014; Chiang et al., 2014; Garzón & Acevedo, 2019; Arici et al., 2021; Chang et al., 2022). Today, AR technology can be deployed and presented in a variety of platforms. It has been initially developed in use with computers with a display and camera (fixed Augmented Reality), but it is now available to sophisticated equipment such as Head Mounted Displays (HMD) and also to mobile devices such as smartphones and tablets (mobile AR). The portability and accessibility of smartphones and tablets and the development of two mainstream mobile augmented reality development environments (ARKit from Apple and ARCore from Google) have made mobile AR widely accessible and available (De Lima et al., 2022; Wu et al., 2013). Smartphones and tablets are the most popular delivery medium of augmented reality and therefore mobile AR is now the most preferred AR technology (Akçayır & Akçayır, 2017). Beyond their portability and accessibility features, mobile devices are cost effective and easy to use for AR (Furió et al., 2013), they facilitate social interactions and collaboration (Ke & Hsu, 2015; Hwang et al., 2012; Bressler & Bodzin, 2013) and support motivation and engagement in location-based outdoor learning activities (Nikou & Economides, 2018; Chiang et al., 2014).

Moreover, studies demonstrated that mobile AR is a promising educational practice in science education (Li et al., 2021). It can help students understand abstract and complex subjects e.g., physics subjects such as forces and movement (Fidan & Tuncel, 2019), enhance students' self-efficacy and conceptions of learning physics (Cai et al., 2021) and enhance students' motivation, learning outcomes and cognitive load, during natural science inquiry activities (Pedaste et al., 2020; Chiang et al., 2014). Also, mobile AR can help to overcome challenges associated with lack of equipment or expensive laboratory materials (Fidan & Tuncel, 2019).

Despite all the aforementioned benefits of mobile AR, *its educational use is still rather limited* (De Lima et al., 2022). Apart from a few isolated cases, mobile AR technology has not yet been effectively implemented in education. Mobile AR is a technology that has not yet been fully introduced in education except from some sporadic experimental cases. Teachers are still hesitant to use mobile AR in their classroom practice (Nikou et al., 2022). Teachers and student teachers can act as catalysts to accelerate the adoption and integration of any new technology in the educational process; therefore, teachers' and student teachers' attitudes and perceptions about mobile AR adoption and integration are very important. Nevertheless, their views have not been extensively investigated (Perifanou et al., 2023; Heintz et al., 2021). Moreover, very little research exists on student teachers' intentions to adopt and integrate mobile AR in science education (Alalwan et al., 2020; Arici et al., 2021; Faqih & Jaradat, 2021). Against this background, the current study considers mobile augmented reality, and it is aiming to investigate the factors that influence student teachers' intention to use it in teaching primary science.

2 Background - literature review

Technology acceptance research has provided extensive evidence that the successful application of information technologies depends on user acceptance, i.e., the willingness of a user group to use information technology for the purposes that it is intended to assist (Dillon, 2001). One of the broadly applied theories regarding users' intention to use technology is the Technology Acceptance Model (TAM) (Davis, 1989). The model identifies the following two critical factors that affect users' intention to use technology: perceived usefulness, "the degree to which a person believes that using a particular system will enhance his/her job performance" and perceived ease of use, "the degree to which a person believes that using the system would be free of effort" (Davis, 1989, p. 320). The model has been effective in predicting how teachers and preservice teachers plan to incorporate technology into the classroom (Farjon et al., 2019; Joo et al., 2018; Scherer & Teo, 2019; Watson & Rockinson-Szapkiw, 2021). Literature reports just a few successful applications of mobile AR acceptance models for teachers. For example, a study in explaining and predicting pre-service teachers' mobile AR acceptance suggested that perceived usefulness has the most significant direct effect on the intention to use (Rahmat & Mohamad, 2021). Since the model's first introduction, several external variables have been added to better predict and explain teachers' acceptance of technology systems. For example, social influence, effort expectancy, performance expectancy and facilitating conditions are four of these variables that have been introduced through the Unified Theory of Acceptance and Use of Technology (UTAUT) model (Venkatesh et al., 2003), a major successor of TAM. The aforementioned four variables have been found to influence pre-service teachers use behaviour of mobile augmented reality in a number of studies (Ateş & Garzón, 2023; Mikropoulos et al., 2022; Ning et al., 2019).

Other theoretical models that have been deployed as well to study intention to use mobile AR technology are the Theory of Planned Behavior (Ajzen, 1985), Task-Technology Fit (Goodhue & Thompson, 1995) and Flow Theory (Csikszentmihalyi, 1975). For example, Ateş and Garzón (2023) examined teachers' intentions to use augmented reality in science courses using constructs from Theory of Planned Behavior and UTAUT. They have found that attitudes, subjective norm, perceived behavioral, effort expectancy, performance expectancy, facilitating conditions, hedonic motivation, price value and habit can explain science teachers' behavioral intentions to use AR, with an explanatory power of 42%. Faqih and Jaradat (2021) combined constructs from the Task Technology Fit and UTAUT and found that task technology fit, performance expectancy, effort expectancy, social influence, facilitating condition, and hedonic motivation explain 49% of the variance in intentional behavior of teachers to adopt AR technology in their classes. Another study by Zhou (2018) integrated perspectives of the UTAUT model and Flow Theory and found that the intention to use mobile AR is significantly influenced by users' performance expectancy as well as their flow experience, which includes perceived enjoyment, attention focus, and perceived control.

The predictive power of the acceptance models has been enriched by adopting non-utilitarian constructs as well such as hedonic motivation, satisfaction and enjoyment. Hedonic and emotional benefits have found to affect users' intention use mobile AR games (Rauschnabel et al., 2017). Satisfaction and enjoyment are key factors of mobile learning experiences (Nikou & Economides, 2016) and they have also found to drive users 'attitudes in mobile AR game-based learning environments (Ibili et al., 2019). Another important predictor of teachers' intention to use mobile AR is self-efficacy (Karacan & Polat, 2022; Koutromanos & Mikropoulos, 2021). Mikropoulos et al. (2022), in a study on pre-service teachers' intention to use mobile AR in their future teaching, provided evidence for the predictive power of mobile self-efficacy on perceived ease of use. Finally, there exists a small number of studies that have enhanced their suggested models by including education-related variables, such as instructors' technological and pedagogical knowledge (Jang et al., 2021). Based on the above discussion, Table 1 summarizes all the factors impacting the intention of student teachers to adopt mobile AR.

Studies published to date have employed a wide range of utilitarian and hedonic motivation constructs. The current study introduces an educational related construct: the perceived educational value of the mobile AR instructional episode. Hereafter, we define the "educational value" of mobile AR with respect to the idea of the "pedagogical triangle". The configuration of the "pedagogical triangle" describes the relations of the educator, the educand (the one being educated) and the world (Briançon, 2019) and it can be said to represent a "theory" of pedagogy (Friesen & Kenklies, 2023). The educational value is

Table 1 Factors found in previous studies to influence teachers' intention to use mobile AR

Studies on teachers' intention to use mobile AR	Constructs
Ateş and Garzón (2023)	ATT, SN, PE, EE, FC, HM, PC, H, BIU
Faqih and Jaradat (2021)	PE, EE, SI, FC, HM, TTF, BIU
Ibili et al. (2019)	SN, PEOU, ANX, PU, SF, ATT, BIU
Jang et al. (2021)	PEOU, PU, SN, ATT, TPACK
Karacan and Polat (2022)	PU, C, ATT, SI, SE, FC, BIU
Mikropoulos et al. (2022)	ATT, PU, ENJ, PRA, MSE, FC, PEOU, BIU
Ning et al. (2019)	SI, FC, PE, EE, BIU
Nizar et al. (2019)	EE, SI, FC, BIU
Rahmat and Mohamad (2021)	UI, PU, PEOU, BIU
Rauschnabel et al. (2017)	ATT, HF, EF, SN, BIU
Zhou (2018)	PE, ENJ, ATF, PC

PU Perceived Usefulness, *PEOU* Perceived Ease of Use, *ATT* Attitudes, *SN* Social Norms, *SI* Social Influence, *PE* Performance Expectancy, *EE* Effort Expectancy, *FC* Facilitating Conditions, *BIU* Behavioral Intention to Use, *ENJ* Enjoyment, *SE* Self-Efficacy, *MSE* Mobile Self-Efficacy, *PRA* Perceived Relative Advantage, *TPACK* Technological, Pedagogical, Content Knowledge, *HM* Hedonic Motivation, *PC* Price Value, *H* Habit, *SF* Satisfaction, *TTF* Task Technology Fit, *ANX* Anxiety, *C* Compatibility, *UI* User Interface, *HF* Hedonic Factors, *EF* Emotional Factors, *ATF* Attention Focus, *PC* Perceived Control defined in relation to the nature and the role of the three main components of the "pedagogical triangle", i.e., the quality of the teaching, the quality of the student learning experience and the reinforcement and improvement of the educand-world relationship. Previous studies have examined teachers' perceptions on the value of other instructional practices e.g., game-based learning (Huizenga et al., 2017) or they have developed evaluation tools for specific educational software (Papadakis, 2021; Pombo & Marques, 2020). However, the perceived educational value of mobile AR, is a holistic judgment of the teaching and learning and not a benchmark to rate a specific practice or app. Moreover, mobile AR is a technology that combines the benefits of mobile learning and augmented reality and introduces new opportunities for teaching and learning. While many affordances and possibilities of mobile AR have been already recognized by educational researchers (Sural, 2017), it would be important to also consider educators' judgements on the educational value of the mobile AR episodes and how this educational value-judgments affect educators' intention to use mobile AR. Incorporating educators' value-judgements in the aforementioned models would potentially increase their predictive power and amplify the importance of the underlying pedagogies.

Another contextual factor that the current study introduces is perceived immersion in mobile AR environments. Immersion is the "psychological state that one is participating in a comprehensive, suboptimal experience" (Jennett et al., 2008 as cited in Shin, 2019, p. 302) and it is an important aspect of user experience in games and virtual and augmented reality. The number of studies investigating immersion in virtual reality has grown in recent years (Cheng & Tsai, 2020; Xie et al., 2022). However, with very few exceptions (Salar et al., 2020) little research exists to investigate immersion in mobile augmented reality. We can define immersion in mobile AR, the user's sensation of involvement in the AR world e.g., users can interact with triggered virtual objects as if they are real. Investigating the subjective experience of preservice teachers being immersed in a mobile AR environment can shed more light on their intention to use it in teaching science in the future. The current study proposes an integrated model of mobile AR adoption by pre-service teachers in particular, introducing two new variables, i.e., Perceived Immersion and Perceived Educational Value, adding more predictive power compared to previous studies shown in Table 1.

3 Conceptual framework and hypotheses

Considering the discussions mentioned above, the proposed framework, utilizes the constructs from the Technology Acceptance Model (Davis, 1989) combined with a number of additional external variables in order to explain and predict student teachers' intention to use mobile AR to teach science. The following hypotheses have been developed.

3.1 Perceived ease of use and perceived usefulness

Perceived Ease of Use (PEOU) has been defined as “the degree to which a person believes that using the system would be free of effort” and Perceived Usefulness (PU) is “the degree to which a person believes that using a particular system would enhance his or her job performance” (Davis, 1989, p. 320). Technology acceptance literature has shown that perceived ease of use has a positive effect on perceived usefulness and Behavioral Intention to use (BIU) and perceived usefulness has a positive effect on behavioral intention to use (Granić, 2022). If users believe an information system is helpful and simple to use, they are more likely to use it. Most studies in the area of mobile AR have found that perceived ease of use and perceived usefulness have a significant impact on the behavioral intention to use (Ghobadi et al., 2023; Guest et al., 2018). Studies on student teachers’ intention to use mobile AR also confirm this finding (Ateş & Garzón, 2022; Faqih & Jaradat, 2021; Ibili et al., 2019; Mikropoulos et al., 2022; Ning et al., 2019). Therefore, we hypothesize that:

H1. Perceived Ease of Use (PEOU) has a positive influence on Behavioral Intention to Use (BIU).
H2. Perceived Ease of Use (PEOU) has a positive influence on Perceived Usefulness (PU).
H3. Perceived Usefulness (PU) has a positive effect on Behavioral Intention to Use (BIU).

3.2 Enjoyment

Enjoyment (ENJ) is related to hedonic gratifications, and it plays an important role in technology acceptance research. In this study we define enjoyment as the extent to which student teachers perceive mobile AR as enjoyable. Studies indicated that the perception of enjoyment can positively and significantly affect the intention to use augmented reality (Cabero-Almenara et al., 2019; Pombo & Marques, 2020). Moreover, studies with student teachers also confirmed the positive influence of enjoyment on the behavioral intention to use mobile augmented reality (Mikropoulos et al., 2022; Rauschnabel et al., 2017). If educators feel that using mobile AR in their classes is enjoyable they are more likely to use it. Therefore, we add the construct of enjoyment in our model, and we make the following hypothesis.

H4. Enjoyment (ENJ) has a positive effect on Behavioral Intention to Use (BIU).

3.3 Perceived educational value

The variable of Perceived Educational Value (PEV) is introduced in the context of the “pedagogical triangle” that connects the educator, the educand (the one being educated, i.e., the student) and the world (narrowly: content or curriculum) (Friesen & Kenklies, 2023; Houssaye, 2014). Each angle of this triangular configuration (educator, student and learning content) has its own role. The educator teaches, i.e., "influences the educand (student), with an intention to improve them and their relation to the world" (Friesen & Kenklies, 2023, p.245). The educand receives education as a type of influence, in other words they experience learning. The learning goal is to change i.e., improve the educand's relation to the world (Friesen & Kenklies, 2023; Ponte & Rönnerman, 2009). von Humboldt (2000) associates this educand-world relation to the idea of "bildung", the lifelong process of human development. Facilitating the process of improving the educand-world relation facilitates the accomplishing of the learning outcome. Hence, the educational value of this pedagogical triadic configuration can be defined in relation to how well the roles of its three main components are performed, i.e., the quality of teaching, the quality of the student learning experience and the improvement of the educand-world relation. To the best of our knowledge, no studies exist to explore how perceived educational value affects learners' attitudes and intention towards AR. We hypothesize that preservice teachers who judge the educational value of mobile AR positively, also enjoy it and find it useful. Therefore, we hypothesize:

> H5. Perceived Educational Value (PEV) has a positive effect on Enjoyment (ENJ).
> H6. Perceived Educational Value (PEV) has a positive effect on Perceived Usefulness (PU).

3.4 Perceived immersion

Immersion is the "psychological state that one is participating in a comprehensive, suboptimal experience" (Jennett et al., 2008 as cited in Shin, 2019, p.). It is an important aspect of user experience in virtual and augmented reality since it features the intersection between user subjectivity and external objectivity (Shin, 2019). Users may experience a stronger sense of immersion in virtual reality environments; however, researchers also highlighted the importance of immersion in augmented reality environments (Shin, 2019). In our study we define Perceived Immersion (PIM) as the extent of student teachers' involvement and engagement and the enhancement of their AR experience. Research demonstrates that perceived immersion positively affects behavioral intention to use and enhances learners' interactions within a VR environment (Xie et al., 2022) increasing flow (Salar et al., 2020). Furthermore, in the context of the pedagogical triangle, learning interactions among the educator, the educand and the world (content), increase the educational value of the learning experience (Friesen & Kenklies, 2023). Therefore, we can hypothesize that perceived immersion can positively affect perceived educational value. Moreover, perceived immersion in VR increases user satisfaction and enjoyment (Hudson et al., 2019) and improves affective learning outcomes (Huang et al., 2020). Similarly, we hypothesize that perceived immersion in AR can positively affect enjoyment.

Based on the above, in an immersive mobile AR environment we hypothesize:

> H7. Perceived Immersion (PIM) has a positive effect on Enjoyment (ENJ).

H8. Perceived Immersion (PIM) has a positive effect on Perceived Educational Value (PEV).

3.5 Mobile augmented reality self-efficacy

Self-efficacy, defined in the context of social cognitive theory (Bandura, 1997) is a combination of cognitive, social, emotional, and behavioural skills needed to perform a task. Computer self-efficacy, as a subcategory of self-efficacy, is "an individual's perceptions of his or her ability to use computers in the accomplishment of a task" (Compeau & Higgins, 1995, p. 191) and has been playing a significant role in the adoption of computer-based systems as a positive antecedent of competence (Joo et al., 2018). Self-efficacy has been found a significant predictor of perceived ease of use in virtual reality systems (Xie et al., 2022). Mobile self-efficacy is defined as "an individual's perceptions of his or her ability to use mobile devices in order to accomplish particular tasks" (Nikou & Economides, 2017a, p. 61). It has an important direct effect on perceived ease of use and an indirect effect on behavioral intention to use a mobile-based-based assessment (Nikou & Economides, 2017b). In the context of mobile AR, Mikropoulos et al. (2022) also found that student teachers' mobile self-efficacy significantly predicts perceived ease of use. Moreover, we argue that an individuals' judgement of mobile technology skills can be considered an important factor in perceived immersion. Further, since self-efficacy and enjoyment are strong predictors of motivated behaviours (Bandura, 1997), in our context of mobile AR we hypothesise that:

H9. Perceived Mobile Augmented Reality Self-Efficacy (MARSE) has a positive effect on Enjoyment (ENJ).
H10. Perceived Mobile Augmented Reality Self-Efficacy (MARSE) has a positive effect on Perceived Immersion (PIM).
H11. Perceived Mobile Augmented Reality Self-Efficacy (MARSE) has a positive effect on Perceived Ease of Use (PEOU).

3.6 Social influence

Social Influence (SI) is the "degree to which an individual perceives that important others believe he or she should use the new system" (Venkatesh et al., 2003, p. 451). Social Influence is equivalent to the notion of Subjective Norms in the Theory of Planned Behavior (Ajzen, 1985). Literature reviews on educational technology adoption (e.g., Kemp et al., 2019) has shown that social influence positively affects users' perceptions about the usefulness of an information system and has a significant impact on an individual's behavioral intention to use it. In our study, we define social influence as the extent to which student teachers perceive that important other (e.g., professors, peer students, senior colleagues) believe he or she should use mobile AR in teaching. Previous studies on mobile AR with student teachers provided evidence that social influence has a positive effect on behavioral intention to use (Ateş & Garzón, 2022; Faqih & Jaradat, 2021; Ibili et al., 2019). We also hypothesize here that social influence has a positive effect on perceived educational value. When student teachers believe that significant others who influence their teaching think that mobile AR has a high educational value, they will also believe it. We make the following hypotheses:

H12. Social Influence (SI) has a positive effect on Perceived Educational Value (PEV).
H13. Social Influence (SI) has a positive effect on Behavioral Intention to Use (BIU).

Based on the above hypotheses, Fig. 1 depicts the proposed theoretical model.

4 Methods

4.1 Participants and procedure

The study was conducted in the context of a student teachers' course on teaching science in the primary school. Since the programme's enrolled students were willing to participate in the study, a convenience sampling strategy was employed. Participants were eighty-two (92%) female and seven (7.8%) male undergraduate pre-service primary school teachers. 59% of the participants self-reported that they had never had any kind of AR experience before. 92% said that they had never had any kind of AR classroom AR experience before. The experiment comprised three stages during a period of month. During the first (two-hours) stage student teachers

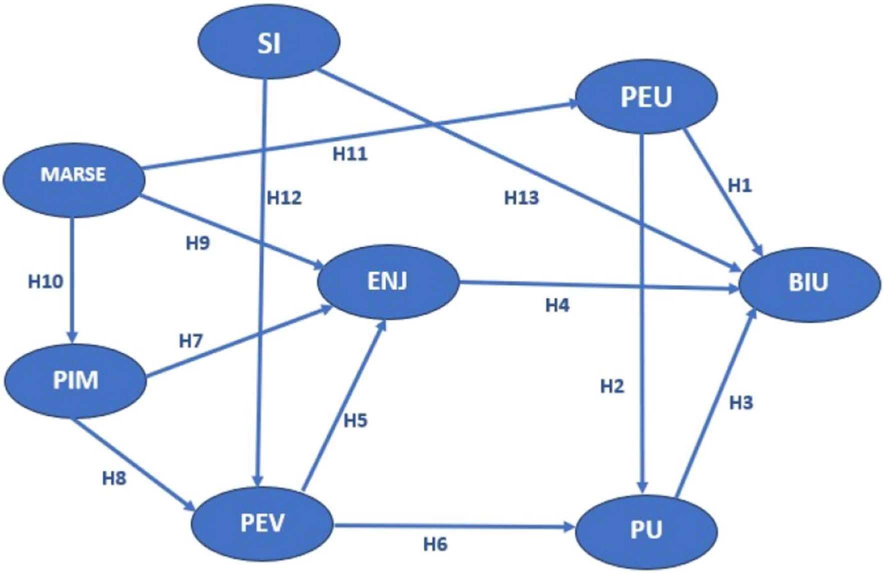

Fig. 1 PLS proposed model

were introduced to the Physics topic under consideration i.e., forces and how to teach them to primary pupils. Students explored practical applications on electrostatic forces acting on distance and how charged objects interact with each other (e.g., involving hair and a balloon). During the second (two-hours) stage, student teachers were given a tutorial on the AR creation platform. The tutorial covered the main steps of a trigger-based AR building process: explain the development environment, how to upload assets, how to resize and move objects around the stage, how to create simple animations and view the AR project on a mobile device. During the third (three-hours) stage, student teachers created simple trigger-based AR experiences that could be potentially used to teach electric forces to primary school pupils. Participants used pre-defined images (e.g., an electric dipole) recognised by the AR application as triggers. These images were triggering virtual overlay content which could be text, other images or animations (e.g., two opposite charges showing to repeal with some additional information on the phenomenon, even a short quiz). The overlay content was seen using mobile devices (smartphones or tables). Participants created and shared with each other various AR artefacts demonstrating the impact that electrical forces have when apply to charges e.g., i.e., forces acting on distance (same charges repel, different charges attract), set a still charge in motion or change its velocity (magnitude and/or direction). Class discussions followed on how the AR digital artefacts developed by the students could be used in the context of teaching primary science. After the intervention, participants completed the online questionnaire about the factors that influence their intention to use mobile AR in their science teaching.

4.2 Instruments

For the development of the questionnaire, we incorporated items from previously validated instruments. For Perceived Ease of Use (PEOU) and Behavioral Intention to Use (BIU) we adopted items from Venkatesh et al. (2003). For Perceived Usefulness (PU) and Social Influence (SI), we adopted items from Venkatesh et al. (2003) and Ateş and Garzón (2022). For Mobile AR Self-Efficacy (MARSE) we adopted items from Nikou and Economides (2018) and Mikropoulos et al. (2022).

For Perceived Immersion (PIM) we developed three items based on Cheng and Tsai (2020) and Jennett et al. (2008). Users' immersion in virtual environments has been originally (Jennett et al., 2008) defined in relation to six factors: basic attention, temporal dissociation, transportation, challenge, emotional involvement and enjoyment. Because the mobile AR environment utilised in our study did not involve certain tasks for student teachers, only three of the above scales, as defined in and adopted from Jennett et al. (2008), were included in our study: basic attention (the extent to which users feel that they are focused on the virtual environments), transportation (the extent to which users have a stronger awareness of being in the virtual environment than in the real world) and emotional involvement (the extent to which users feel emotionally attached to the task). For Enjoyment (ENJ) we adopted items from Venkatesh et al. (2003) and Giannakos and Jaccheri (2018). For Perceived Educational Value (PEV) we have developed a scale consisting of three items corresponding to the three components of the pedagogical triangle (Friesen & Kenklies, 2023), namely the educator, the educand and the world. The educators' personal judgements on the educational value of the mobile AR refers to the quality of teaching, the student experience and the learning outcomes. In conclusion, our measurement instrument consists of 8 constructs with 22 items in total. Pre-test of the instrument was made with twenty-five student teachers and after a few minor corrections, the final version of the questionnaire revised by two experts in technology-enhanced learning. For the internal consistency of the instrument, Cronbach's a for all constructs was greater than 0.7. All items were measured on a five-point Likert-type scale with 1 corresponding to "strongly disagree" and 5 to "strongly agree". The questionnaire used is shown in the Appendix.

5 Data analysis and results

We have employed Partial Least-Squares (PLS), as a main predictive modeling method (Chin, 1998; Fornell & Larcker, 1981), to analyze the quantitative survey data in order to explain and predict the factors influencing behavioural intention to use mobile AR, using SmartPLS4 (Ringle et al., 2022). Our sample size is more than the suggested threshold of 30, which is equivalent to 10 times the maximum number of independent variables influencing a dependent variable (Chin, 1998).

5.1 Instrument validation

To ensure the quality of the model, we have verified the internal consistency, convergent and discriminant validity of the proposed research model. All requirements for the convergent validity are satisfied. Every factor loading on each relative construct exceeds 0.70, each construct's composite reliability exceeds 0.70, and every average variance extracted (AVE) value ranges from 0.854 to 0.933 ($AVE > 0.50$), exceeding the variance resulting from measurement error for that construct (Table 2). The square root of the average variance extracted (AVE) of a construct is higher than any correlation with another construct, which supports discriminant validity (Table 3). Thus, both convergent and discriminant validity for the proposed research model is verified (Hair et al., 2014).

5.2 Test of the structured model and hypotheses

The path coefficients' values and their significance, as well as the variance (measured by R^2) measured by the antecedent constructs, all support the suggested structural model and its hypotheses. The results from the PLS analysis support eleven out of our thirteen hypotheses (hypotheses H2, H3, H4, H6, H7, H8, H9 H10, H11, H12 and H13 are accepted while H1 and H5 are rejected). A bootstrapping procedure have been applied to measure the t-values and the variance measured (R^2) by the antecedent constructs. Table 4 presents a summary of the structural model along with the results of the hypothesis testing, highlighting the

Table 2 Descriptive statistics and results for convergent validity for the measurement model (acceptable threshold values in brackets)

Construct Items	Mean (SD)	Factor Loading (>0.70)	Cronbach's a (>0.70)	Composite Reliability (>0.70)	Average Variance Extracted (>0.50)
Perceived Ease of Use	2.90 (0.90)		0.788	0.79	0.876
PEOU1		0.818			
PEOU2		0.843			
PEOU3		0.852			
Perceived Usefulness	3.63 (0.72)		0.826	0.881	0.894
PU1		0.832			
PU1		0.875			
PU3		0.869			
Social Influence	2.80 (0.84)		0.783	0.871	0.885
SI1		0.861			
SI2		0.921			
Perceived Immersion	3.79 (0.69)		0.789	0.885	0.877
PIM1		0.825			
PIM2		0.846			
PIM3		0.844			
Mobile AR Self-Efficacy	3.44 (0.78)		0.780	0.783	0.901
MARSE1		0.897			
MARSE2		0.913			
Enjoyment	3.64 (0.83)		0.873	0.878	0.922
ENJ1		0.875			
ENJ2		0.910			
ENJ3		0.895			
Perceived Educational Value	3.90 (0.54)		0.747	0.896	0.854
PEV1		0.778			
PEV2		0.857			
PEV3		0.802			
Behavioral Intention to Use	3.55 (0.76)		0.892	0.895	0.933
BIU1		0.906			
BIU2		0.912			
BIU3		0.901			

statistical importance of the model's relations. Figure 2 shows the path coefficient for each path. The dotted lines depict the hypotheses that are rejected (H1 and H5). The standardized path coefficients for the eleven supported hypotheses have values between 0.211 and 0.732. These values are considered to be medium to large (Cohen, 1988). The R^2 for the endogenous variables are 0.438 for PIM, 0.650 for PEV, 0.647 for ENJ, 0.536 for PEOU, 0.627 for PU and 0.717 for BIU.

Table 3 Discriminant validity for the measurement model (values in bold: the square root of the average variance extracted for each construct)

	BIU	ENJ	MARSE	PEOU	PEV	PIM	PU	SI
BIU	**0.906**							
ENJ	0.729	**0.893**						
MARSE	0.699	0.679	**0.905**					
PEOU	0.648	0.680	0.732	**0.838**				
PEV	0.704	0.667	0.570	0.552	**0.813**			
PIM	0.711	0.762	0.662	0.707	0.749	**0.839**		
PU	0.752	0.612	0.682	0.649	0.737	0.771	**0.859**	
SI	0.562	0.403	0.524	0.322	0.594	0.434	0.480	**0.891**

BIU Behavioural Intention to Use, *ENJ* Enjoyment, *MARSE* Mobile Augmented Reality Self-Efficacy, *PEOU* Perceived Ease of Use, *PEV* Perceived Educational Value, *PIM* Perceived Immersion, *PU* Perceived Usefulness, *SI* Social Influence

Table 4 Hypothesis testing results

Hypothesis	Path	Path Coefficient	Results
H1	Perceived Ease of Use → Behavioral Intention to Use	0.105	Not supported
H2	Perceived Ease of Use → Perceived Usefulness	0.348^{***}	Supported
H3	Perceived Usefulness → Behavioral Intention to Use	0.372^{***}	Supported
H4	Enjoyment → Behavioral Intention to Use	0.345^{***}	Supported
H5	Perceived Educational Value → Enjoyment	0.169	Not supported
H6	Perceived Educational Value → Perceived Usefulness	0.545^{***}	Supported
H7	Perceived Immersion → Enjoyment	0.445^{***}	Supported
H8	Perceived Immersion → Perceived Educational Value	0.606^{***}	Supported
H9	Mobile AR Self-Efficacy → Enjoyment	0.288^{***}	Supported
H10	Mobile AR Self-Efficacy → Perceived Immersion	0.662^{***}	Supported
H11	Mobile AR Self-Efficacy → Perceived Ease of Use	0.732^{***}	Supported
H12	Social Influence → Perceived Educational Value	0.331^{***}	Supported
H13	Social Influence → Behavioral Intention to Use	0.211^{**}	Supported

$^{**}p < 0.01$, $^{***}p < 0.001$

According to the analysis, the model explains 71.7% of the variation in preservice teachers' behavioral intention to use AR in science teaching.

Mobile AR Self-Efficacy significantly predicts Perceived Ease of Use (0.732), Enjoyment (0.288) and Perceived Immersion (0.662). Pre-service teachers who feel more confident and competent in using mobile AR find it easier and more enjoyable to use it. Moreover, they are able to better appreciate the feeling of immersion created by the AR through the triggered images, sound or other virtual elements that can mimic authentic learning experiences. Perceived Immersion is a significant predictor of Enjoyment (0.445) and Perceived Educational Value (0.606). Perceived immersion not only creates higher levels of enjoyment but also strengthens the

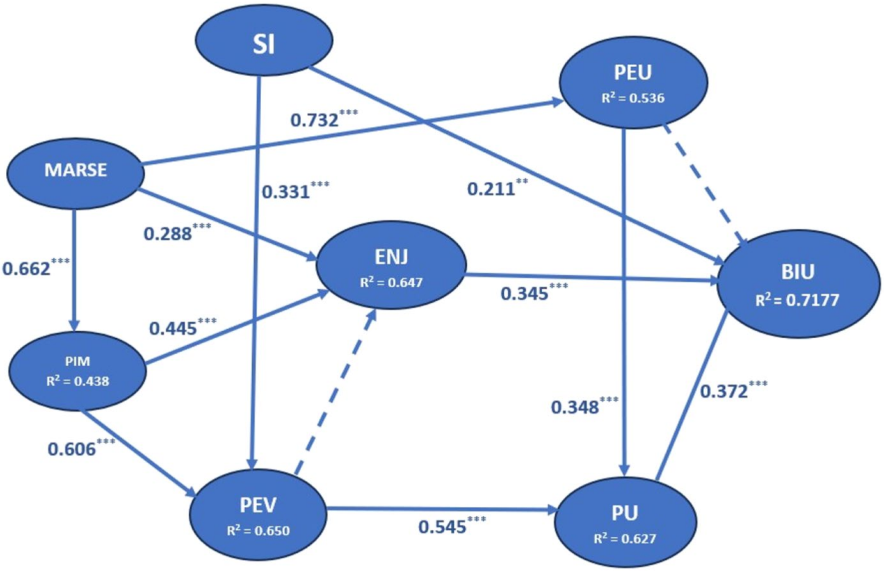

Fig. 2 PLS research model results

belief that AR has an important educational value. Higher immersion levels elevate enjoyment and educational importance. Moreover, Perceived Educational Value can predict Perceived Usefulness (0.545). If teachers believe that AR has an important educational value, then they perceive it as being more useful. Social Influence significantly predict Perceived Educational Value (0.331) and Behavioral Intention to Use (0.211). The influence of the social environment has an impact on how preservice teachers perceive the educational value of AR and of course their intention to use it in class. Enjoyment can significantly predict Behavioral Intention to Use (0.345). When preservice teachers enjoy teaching with AR, they are more likely to use it in their future classes. Moreover, they are more likely to use it if they find it easy to use and useful since Perceived Ease of Use predicts Perceived Usefulness (0.348) and Perceived Usefulness predicts Behavioral Intention to Use (0.372).

6 Discussions and conclusions

The study develops, proposes, and validates an integrated model to explain and predict student teachers' behavioral intention to use mobile augmented reality in primary science teaching. The findings show that teaching science with mobile augmented reality is driven by Mobile AR Self-Efficacy (MARSE), Social Influence (SI), Enjoyment (ENJ), Perceived Immersion (PIM), Perceived Educational Value (PEV), Perceived Ease of Use (PEOU) and Perceived Usefulness (PU).

Among all the previous constructs, Enjoyment (ENJ) and Perceived Usefulness (PU) have the strongest direct effect on the intention to use mobile AR, while Perceived Ease of Use (PEOU) has no effect whatsoever. This finding implies that student teachers would be keen to use mobile AR when it is enjoyable and useful. This is in agreement with previous findings on the importance of fun and usefulness of a lesson supported by augmented reality (Ateş & Garzón, 2022; Rauschnabel et al., 2017). Hedonic benefits like enjoyment always drive user engagement and it is important to consider them when designing learning activities. Mobile AR Self-Efficacy (MARSE) influences Perceive Ease of Use (PEOU), which agrees with previous findings (Mikropoulos et al., 2022). It also has an influence on Behavioral Intention to Use (BIU) after being mediated by Enjoyment (ENJ). This means that student teachers who have the skills to use mobile AR, they find it more enjoyable and easier to use it. Little empirical evidence exists on how mobile self-efficacy and perceived immersion are connected to the intention to use virtual reality training systems (Xie et al., 2022), our study sheds some light on the role of these variables in the context of mobile AR. MARSE directly affects Perceived Immersion (PIM) and has an influence on Perceived Educational Value (PEV) after being mediated by PIM. Student teachers who are more adept at using mobile augmented reality may more quickly and effectively develop immersive learning experiences that maximise their educational value. This highlights the importance of upskilling student teachers to be able to use mobile AR in their classes so they can provide immersive learning experiences to their pupils. Perceived Immersion (PIM) influences Behavioral Intention to Use (BIU) after mediated by Perceived Educational Value (PEV) and Perceived Usefulness (PU). Cheng and Tsai (2020) who studied immersion in virtual reality also found that basic attention (one aspect of immersion) influences Behavioral Intention to Use (BIU). Perceived Educational Value (PEV) does not have an impact on Enjoyment (ENJ) and this means that teachers who believe that mobile AR is important do not necessarily find it enjoyable. Also, it is important to note the role of Social Influence (SI) on Perceived Educational Value (PEV) and Behavioral Intention to Use (BIU). Social influence plays a pivotal role in AR acceptance and its integration in the classroom practice (Faqih & Jaradat, 2021; Ibili et al., 2019; Karacan & Polat, 2022; Ning et al., 2019) and it is always an important factor to be considered.

The current study contributes to the mobile augmented reality acceptance literature in four ways as follows. First, it provides a reliable and validated instrument to measure the factors that influence the intention to use mobile augment reality, a research area that is still not fully explored (Perifanou et al., 2023; Alalwan et al., 2020; Arici et al., 2021; Faqih & Jaradat, 2021). The proposed model explains 71.7% of the variation in preservice teachers' behavioral intention to use mobile AR in science teaching. Contributing factors are Social Influence, Mobile AR Self-Efficacy, Perceived Immersion, Perceived Educational Value, Enjoyment, Perceived Ease of Use and Perceive Usefulness. Second, our study explores student teachers' intention to use mobile augmented reality, a user group that has not been adequately investigated (Alalwan et al., 2020; Arici et al., 2021; Heintz et al., 2021). Student teachers can serve as catalysts to accelerate the adoption and integration of augmented reality in the educational process. Third, the study considers the use of mobile augmented reality in science education. Research has shown that mobile augmented reality can address many challenges associated with science education e.g., student difficulties to understand abstract and complex subjects, lack of laboratory equipment etc. (Cai et al., 2021; Pedaste et al., 2020; Fidan & Tuncel, 2019). Accelerating the adoption of mobile augmented reality in the context of science education is beneficial (Li et al., 2021). Fourth, the study extends our current understanding of mobile augmented reality adoption by introducing the constructs of perceived immersion and perceived educational value. Perceived Immersion has been studied in the context of desktop based non-AR digital games (Brown & Cairns, 2004; Cheng et al., 2015), AR location-aware settings (Georgiou & Kyza, 2018) and virtual reality (e.g., Xie et al., 2022; Hudson et al., 2019). Despite the significance of AR, very little research exists about perceived immersion in the context of educational mobile augmented reality. Ghobadi et al. (2023) have found that construction engineering students' perceived immersion affects their perceived ease of use. Salar et al. (2020) identified that one dimension of immersion, namely the focus of attention (Georgiou & Kyza, 2017), influences science education students' flow experiences. Likewise, our findings show that perceived immersion influences student teachers' perceived enjoyment. We have defined Perceived Educational Value as a measurement as the perceived quality of the educational experience based on the three components of the pedagogical triangle: the educator, the educand, the world and their relations (Friesen & Kenklies, 2023). The pedagogical triangle can be said that embodies a pedagogical theory (Houssaye, 2014) and therefore the introduced scale is rather attentive to the AR-based instructional episode as a whole. It is not specific to educational resources like previously developed instruments, such as the Educational Value Scale (Pombo & Marques, 2020) that measure users' subjective ratings of the educational value and usability of certain apps. The inclusion of the educational value in the technology acceptance model is important because it adds a pedagogical perspective. Previous studies have introduced pedagogical aspects in exploring adoption behavior from the perspective of the skills required for technology integration. For example, Jang et al. (2021) found that instructors' Technological, Pedagogical and Content Knowledge (TPACK) (Koehler & Mishra, 2009) has a significant influence on Perceived Usefulness. This agrees with our findings that the Perceived Educational Value significantly influences Perceived Usefulness. Furthermore, our study considers Perceived Educational Value as a holistic view of the quality of the instructional practice. To the best of our knowledge, our study is the first one to explore augmented reality adoption behavior of student teachers in the context of Physics education.

The main limitations of the study are the small convenience sample size (with the majority of the student teachers to be females) and its relatively short duration. The non-probabilistic nature may limit the generalisation of the results but we have assumed that our sample is representative of the preservice teachers' population. Future studies should take these into consideration. Longitudinal studies are needed with regard to teachers' perceptions and adoption behavior. Future research may investigate larger samples across other science subjects and contexts (different technology infrastructures). Moreover, a future improvement of the model could be to incorporate and test other variables that have shown to have a significant impact on educational technology adoption but have not been investigated in the AR context, such as task and technology aspects along with moderating factors such as gender and user attributes.

Considering the increasing interest towards utilizing mobile augmented reality technologies in education in general, the proposed model can be helpful for researchers, teacher educators and education administrators to better understand, plan and support pre-service and in-service teachers and to integrate mobile AR in their teaching. Helping teachers to adopt and integrate mobile AR in their professional practice is a dynamic and evolving research area with potential educational benefits.

Appendix

The questionnaire used in the study.

Constructs	Items	Descriptions
Perceived Ease of Use	PEOU1	My interaction with mobile AR is clear and understandable.
	PEOU2	It is easy for me to become skilful at using mobile AR.
	PEOU3	I find mobile AR easy to use.
Perceived Usefulness	PU1	Using mobile AR in my science classes would make my teaching more effective.
	PU2	Using mobile AR in my science classes would increase my teaching productivity.
	PU3	mobile AR is useful for my teaching.
Social Influence	SI1	People who influence my teaching think that I should use mobile AR in my science classes.
	SI2	People who are important to me think that I should use mobile AR in my science classes.
Mobile AR Self-Efficacy	MARSE1	I can complete a task using mobile AR.
	MARSE2	I am confident that I can effectively use AR applications. using mobile technology.
Perceived Educational Value	PEV1	Mobile AR increases the quality of my teaching.
	PEV2	Mobile AR offers better learning experiences to my students.
	PEV3	Mobile AR improves learning outcomes.
Enjoyment	ENJ1	Participating in mobile AR makes me feel good.
	ENJ2	Participating in mobile AR is exciting.
	ENJ3	Participating in mobile AR is enjoyable.
Perceived Immersion	PIM1	My attention is focused when I participate in mobile AR.
	PIM2	I am very involved in mobile AR.
	PIM3	Experiencing mobile AR make me feel that it is real.
Behavioral Intention to Use	BIU1	I intend to use mobile AR in science teaching.
	BIU2	I plan to use mobile AR in science teaching.
	BIU3	I predict I would use mobile AR in science teaching in the future.

Acknowledgements Not applicable.

Funding The study did not receive any funding.

Data availability The datasets used and/or analysed during the current study may be available from the corresponding author on reasonable request.

Declarations

Ethical approval The study received ethical approval by the University of Strathclyde School of Education Ethics Committee.

Competing interests The author declares that they have no competing interests.

Conflict of interest The corresponding author states that there is no conflict of interest.

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