JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

ACCEPTANCE OF AUGMENTED REALITY VIA MOBILE DEVICES BY HIGHER EDUCATION STUDENTS IN PHYSICS PRACTICAL WORK

Laila Ayaichi,
Aziz Amaaz,
Abderrahman Mouradi

Abstract. *Augmented Reality (AR) is an emerging technology with strong potential to enhance the educational value of physics lab work. However, its integration in higher education remains inconsistent, often hindered by students' limited prior experience and varying levels of acceptance. This study investigates the factors influencing students' intention to adopt AR, using the Technology Acceptance Model (TAM) as a theoretical framework. A comparative quantitative approach was applied to a sample of 756 undergraduate and graduate physics students, including 334 with prior AR experience and 442 without. Data were collected through a structured questionnaire based on validated instruments and distributed via Microsoft Forms. Results indicate significant differences between the two groups: students with prior AR exposure reported more favorable perceptions regarding its usefulness, ease of use, general attitude, and intention to adopt it. Structural equation modeling (SEM-PLS) confirms that perceived ease of use positively affects perceived usefulness, which in turn moderately influences attitude, the primary predictor of behavioral intention. These findings validate the relevance of TAM in explaining and predicting AR adoption in physics education and suggest that prior experience, while influential, is only one of several factors affecting the successful acceptance of AR in a university setting.*

Keywords: *augmented reality, technology acceptance model, practical work, physics, higher education, intention*

Laila Ayaichi, Aziz Amaaz, Abderrahman Mouradi
Abdelmalek Essaadi University, Morocco

Introduction

The rapid evolution of immersive technologies is profoundly transforming educational practices, particularly in science education. Faced with the increasing complexity of scientific concepts, it is becoming essential to adopt innovative teaching approaches that promote engagement and facilitate understanding. In this context, augmented reality (AR) is emerging as a relevant solution, offering an enriched learning environment where digital elements are integrated into the real world to illustrate abstract phenomena (Alqarni, 2021; Low et al., 2022). By enabling direct, real-time interaction with three-dimensional virtual objects, AR opens up new possibilities for making learning more concrete and immersive (Azuma, 1997; Sugara & Mustika, 2016; Sumadio & Rambli, 2010). This technology offers the capacity to improve the quality of teaching and training in academic institutions (AlGerafi et al., 2023). Applied to teaching, AR can facilitate the transmission of complex ideas and the reproduction of dynamic operations that are difficult for students to access directly, as well as promoting learning in subjects requiring fine spatial understanding (Dünser et al., 2012; Stojšić et al., 2020). AR technology can also serve as a valuable primary or complementary resource for increasing student engagement in courses and encouraging their interest in learning (Khan et al., 2019; Kirikkaya et al., 2019)

The fast adoption of smartphones, combined with recent innovations in immersive technologies, has made AR accessible to a wide audience (Martín-Gutiérrez et al., 2017). AR via mobile devices has benefited from significant advances, enabling enriched user experiences without the need for additional hardware (Patil et al., 2023). This approach not only helps reduce costs but also lowers the performance requirements of mobile devices, making AR more accessible (Sánchez-Juárez et al., 2023). The integration of AR improves interaction with users and expands its application in various fields (Awan et al., 2024). Studies have shown that mobile AR is a promising pedagogical approach to teaching science (F. Li et al., 2023; Nunes et al., 2024). It can be an aid to students' understanding of abstract and complex concepts such as forces and motion in physics (Fidan & Tuncel, 2019), while enhancing their confidence and perceptions of learning physics (Cai et al., 2021; Nikou, 2024).

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

In science education in general, and in physics in particular, the learning process involves supplementing theoretical concepts with practical work that enables students to apply their acquired knowledge and reinforce their understanding of the concepts studied (Jungmann, 2019). In traditional laboratories, real-world materials or physical devices are used as manipulative tools to support teaching or learning (Zacharia & Michael, 2016). Nevertheless, some problems remain, such as expensive instrumentation, non-reusable experimental assets, unforeseeable reliability issues, and difficulties in modeling some effects (Shufan et al., 2018), (Liu et al., 2021). The use of mobile AR in practical physics work has been shown to facilitate better understanding and interaction with complex concepts, thus addressing the difficulties students face in traditional learning environments(Rahman et al., 2022). In addition, mobile AR can offset difficulties related to a lack of equipment or the high cost of laboratory materials (Fidan & Tuncel, 2019). In this context, AR offers significant advantages, particularly through applications such as equipment recognition, virtual navigation in laboratory spaces, and learning how to use experimental equipment. These functionalities reduce the time needed to perform manipulations while improving students' technical skills (Ayaichi et al., 2024). Additionally, AR significantly enhances the quality of laboratory reports due to the ease of use of equipment and simplification of experimental protocol implementation (Ayaichi et al., 2024).

Research into the acceptance of technologies has largely demonstrated that their usefulness relies on user adherence, i.e., their readiness to embrace these technologies in line with the purposes for which they were designed (Dillon, 2001).The Technology Acceptance Model (TAM), one of the most popular frameworks for analyzing intention to use AR technology, was proposed by (Davis & Granić, 2024). This model identifies two fundamental elements influencing this adoption: perceived usefulness (PU), corresponding to the belief that a specific technology can improve performance, and perceived ease of use (PEOU), which refers to the idea that using this technology requires no particular effort (Nikou, 2024). Therefore, in the context of AR via mobile devices, perceived usefulness translates into the belief that this technology can optimize performance in experimental physics. At the same time, perceived ease of use is defined as students' confidence level in their capacity to employ AR with minimal effort. In addition to these two determinants, the TAM model also considers attitude and intention to use, which play a key role in technological adoption. "Attitude refers to users' preference for using specific technologies or systems, while intention to use reflects their cognitive readiness to engage with these technologies" (X. Li et al., 2022). In the context of AR integration via mobile devices, the students' attitude manifests itself in a favorable inclination to adopt this technology for practical physics work. In addition, their intention of use shows an active willingness to integrate AR to enhance their learning experience.

Contemporary studies have thoroughly investigated the integration of AR within science pedagogy, especially through mobile devices in hands-on physics activities. These investigations have emphasized how AR influences students' attitudes and their inclination to embrace this technology within their educational journey (Fidan & Tuncel, 2019; Kumar & Mantri, 2021). Several factors shaping these attitudes and intentions have been recognized, including student involvement, drive, and the perceived user-friendliness of AR (Sirakaya & Çakmak, 2018).

Existing scholarly work on employing AR via mobile devices in practical physics exercises highlights its impact on students' viewpoints regarding this technology and their comprehension of physics. Research by (Cai et al., 2017) indicated that utilizing AR for physics instruction cultivates a favorable student attitude, heightening their interest in the subject and their satisfaction with the interactivity provided. Moreover, this approach amplifies their motivation and dedication to learning the material. The results by (Tuli et al., 2022) corroborated these observations, demonstrating that the application of AR via mobile devices in practical electronic tasks yielded a notably positive effect on students' attitudes. Participants using the AR-enhanced lab guide displayed greater enthusiasm for grasping electronics principles, demonstrated increased motivation and engagement compared to students in a control group using traditional teaching methods. Additionally, students who had experience with AR reported reduced anxiety concerning technology use and expressed a strong desire to re-employ it in future learning scenarios. Furthermore, the research of (Boboc et al., 2021), using the TAM model, identified key factors such as PU, PEoU, and perceived enjoyment (PE) as significantly influencing students' attitudes about using AR in practical physics work. Finally, the study by (Akçayır et al., 2016) revealed that the use of AR via mobile devices in physics PWs significantly enhanced students' attitudes, who now perceived these sessions more positively and attractively. Students found that AR via mobile devices made lab experiments more interactive, while facilitating understanding of complex concepts through digital visualizations. What's more, the technology transformed their perception of physics PWs, making them more interesting and less intimidating. Participants appreciated the immersive nature of AR, believing it increased their motivation to actively participate in experiments. The favorable attitudes found in these studies highlight the favorable potential of AR in the teaching of physics practical work,

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

provided that the integration of this technology is accompanied by appropriate training and consideration of students' needs and skills.

Although the existing literature has extensively documented the effects of AR on learning, few studies have specifically examined its integration via mobile devices in the context of physics lab work (Lyrath et al., 2023; Sun et al., 2023; Thees et al., 2020). The acceptance of AR by students in this particular context, based on the Technology Acceptance Model (TAM), remains largely unexplored. Some preliminary research (Álvarez-Marín et al., 2021; Boboc et al., 2021; Johan et al., 2023) has begun to address this issue, but without providing a systematic analysis of the factors that determine the adoption of AR in science practical work. This gap is all the more significant given that AR, particularly via mobile devices, has significant educational potential: it facilitates the visualization of abstract phenomena, enhances student engagement, and supports the acquisition of experimental skills (Ayaichi et al., 2024; Lyrath et al., 2023). The present study aims to address this gap by analyzing, through the lens of the TAM model, the factors impacting the acceptance of AR by undergraduate students in physics practical work. It is distinguished by its context of application (higher education in physics in a Southern country) and by its desire to provide both a theoretical contribution, by refining the TAM model in a new disciplinary framework, and practical implications for designers of immersive educational environments.

To achieve this aim, five hypotheses were formulated. The first (H1) posits that prior experience with AR via mobile devices positively influences students' attitudes toward its use in physics practicals. Four additional hypotheses (H2 to H5) are grounded in the TAM framework proposed by Davis & Granić, 2024: H2. PU positively influences attitudes towards the integration of AR through mobile devices by students in practical physics work. H3. PEOU positively affects PU of students' use of AR via mobile devices in practical physics assignments. H4. PEOU positively affects attitude about using AR via mobile devices by students in practical physics work. H5. Students' attitude positively influences their perceived intention to use AR through mobile devices in experimental physics sessions.

Research Methodology

In Moroccan higher education, practical work plays a central part in several areas of physics, such as mechanics, optics, and electronics. These practical activities are essential to enable students to apply the theoretical topics covered in class (Ayaichi et al., 2024). The present study sought to assess Moroccan students' attitudes towards the utilization of AR via mobile devices in physics PW.

Context and Participants

The study was conducted on a sample of 756 students studying in bachelor's and master's programs in physics at the Higher Normal School of Tetouan (Abdelmalek Essaadi University, Morocco). These students constitute the study sample. They were selected from a larger population of students enrolled in training courses that include practical physics work. Their direct involvement in these educational activities makes their participation particularly relevant for analyzing the factors influencing the adoption of AR in an experiential physics-teaching context. Participants were recruited using convenience sampling (non-probabilistic), based on their availability and access to AR devices. This choice is justified by the need to target students who have already been exposed to AR as part of their curriculum and those who have not, in order to compare perceptions between these two subgroups. The sample size (n=756) was determined based on methodological recommendations in quantitative research, which suggest a minimum ratio of 10 respondents per observed variable for structural equation modeling (SEM-PLS) analyses (Hair et al., 2019). This volume therefore ensures sufficient statistical power and valid, generalizable results in the context of the study.

Table 1 shows the demographic profile of a sample of 756 participants. These participants are teachers in initial training, enrolled in training programs for teaching physical sciences at the primary and secondary levels, who will be required to implement practical physics work in their future careers. Most of the respondents were identified as female (79.6%), while male respondents constituted 20.4% of the sample. Regarding academic status, the overwhelming majority of participants were enrolled in bachelor's programs (97.1%), with a mere 2.9% enrolled in master's programs. Notably, over half of the respondents (55.8%) had never used PLAR, while 44.2% reported previous experience.

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 1
The Sample Demographic Characteristics

Characteristics	Categories	*N*	%
Gender	Female	602	79.6
	Male	154	20.4
Education Level	Bachelor	734	97.1
	Master	22	2.9
Using AR	Having used AR	334	44.2
	Never used AR	422	55.8%
Total		756	100

Instruments

The questionnaire used the TAM to identify the elements that influence AR adoption. This well-established model in technology adoption studies is based on several latent concepts, including perceived usefulness, perceived ease of use, intention to use, and students' attitudes toward AR. These concepts cannot be measured directly, but rather are inferred from participants' responses. The questionnaire included 24 items in total, with socio-demographic questions (gender, level of education, ownership, and type of mobile device) and items specific to the use of AR in practical physics work. Each latent construct was measured using several items, based on a 5-point Likert scale (1: strongly agree, 5: strongly disagree). Perceived usefulness of AR was assessed using 5 items, while perceived ease of use was gauged using 4 items. In addition, students' attitudes to the use of AR were assessed with 6 items, and their intention to adopt this technology in practical physics work was measured through 5 items. The questionnaire items were partly adapted from questionnaires validated in previous studies of technology acceptance (Davis & Granić, 2024; Venkatesh & Davis, 2000), and some were developed specifically for the context of this study to ensure their relevance to practical physics work.

Procedures

The questionnaire was developed through Microsoft Forms and administered online to participants. It was administered in French, to ensure that all participants could understand the questions better. The choice of language was motivated by the fact that French is the main language of instruction in Moroccan universities, particularly in scientific fields such as physics. The introduction to the questionnaire provided a brief explanation of the possible applications of AR in practical physics work, to enlighten participants who had not yet had experience with this technology. A specific question in the questionnaire identified students who had already used AR in practical physics work. Furthermore, this study strictly adhered to the ethical principles of confidentiality and informed consent. Participants received comprehensive information regarding the research objectives, the guaranteed anonymity of their responses, and the voluntary nature of their participation. No personally identifiable data was collected, and all information was processed securely to ensure confidentiality.

Several steps were taken to guarantee the reliability and validity of the data. First, the questionnaire was developed using items from previous studies of the TAM model (Venkatesh & Davis, 2000). Next, a panel of three experts in educational technology and science pedagogy assessed the content validity by examining the relevance and clarity of the items. A pretest was conducted with 30 students to identify any ambiguities or comprehension difficulties. The questionnaire's internal reliability was confirmed by a Cronbach's alpha coefficient greater than 0.70 for all measured dimensions. Finally, convergent and discriminant validity were verified using AVE and Fornell-Larcker analyses in accordance with the literature's recommended criteria.

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Data Analysis

Descriptive and inferential statistical analyses were done with SPSS software (version 26). Descriptive statistics were used to summarize the characteristics of study participants. Means for the various latent variables, including PU, PEOU, attitude towards AR, and intention to adopt the technology, were calculated by combining the relevant items for each variable. Interpretation of the results was based on the following scale: scores between 1 to 1.79 indicated strong disagreement, 1.80 to 2.59 indicated disagreement, 2.60 to 3.39 indicated a neutral position, 3.40 to 4.19 indicated agreement, and 4.20 to 5 indicated strong agreement. To assess differences between students with and without prior experience of AR in physics laboratory activities, Mann-Whitney U tests were used.

Data collected on student perceptions was analyzed using structural equation modeling (SEM) with the partial least squares method (PLS-SEM). SmartPLS 4 software was used to perform these analyses to test the study's hypotheses. The PLS-SEM method was selected for its ability to handle complex models that include multiple latent variables and their indicators while being less restrictive in terms of assumptions about the data distribution. This method also maximizes the explained variance of the dependent constructs, offering a better understanding of the causal links between the variables in the model (Hair Jr. et al., 2021).

Research Results

Before proceeding to the main analysis, a check for multicollinearity between latent variables was carried out using SPSS software. Multicollinearity arises when independent variables exhibit a high degree of intercorrelation, potentially skewing regression coefficient estimations and undermining the reliability of statistical results. When significant multicollinearity is present, determining the unique contribution of each variable to the dependent variable becomes challenging, resulting in coefficient instability and inflated standard errors (Hair Jr. et al., 2021). To assess this phenomenon, collinearity statistics have been calculated, including tolerance indices and variance inflation factors (VIF), as detailed in Table 2

Table 2
Multicollinearity Analysis

Independent variable	Tolerance	VIF
PU	.429	2.333
PEOU	.286	3.500
ATT	.259	3.859
INT	.357	2.802

As illustrated in Table 2, an assessment of multicollinearity among the independent variables (PU, PEOU, ATT, and INT) was conducted utilizing tolerance indices and variance inflation factors (VIF). The findings indicate that the tolerances exceed the critical threshold of .1, while the VIF values remain well under the critical level of 5 (Hair Jr. et al., 2021). These observations confirm the absence of problematic multicollinearity between the variables, validating their inclusion in the statistical model and guaranteeing the reliability of the results of subsequent analyses.

Measurement Reliability and Validity

Table 3 shows the results of our assessment of the reliability and validity of the concepts studied in this research. It provides detailed information on the external saturations of the indicators, as well as their means (*M*) and standard deviations (*SD*), enabling us to analyze their respective contribution to each latent variable. Scale reliability is assessed using Cronbach's alpha coefficient and composite reliability (rho_c). Convergent validity is verified by calculating the average variance extracted (AVE).

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 3
Internal Reliability and Convergent Validity

	Items	External load	*M*	*SD*	Cronbach's alpha	Composite reliability (rho_c)	Average variance extracted (AVE)
PU	**PU 1:** Using AR via mobile devices would enhance the effectiveness of practical work in physics.	.877	4.15	0.768	.643	.848	.736
	PU 2: Using AR via mobile devices would save me time when setting up experimental assemblies for practical physics work.	.839	4.15	0.719			
PEOU	**PEOU 1:** Using AR via mobile devices would allow me to better understand the experimental setups used in physics lab work.	.831	4.13	0.776	.777	.870	.691
	PEOU 2: Using AR via mobile devices would improve my ability to carry out experimental protocols (experiments) during practical physics work.	.835	4.11	0.818			
	PEOU 3: The use of AR via mobile devices in practical physics work would improve the quality of my lab reports.	.827	4.11	0.769			
Attitude	**Att 1:** Learning how to use the AR system would be clear and understandable.	.753	4.01	0.802	.848	.892	.623
	Att 2: The use of AR via mobile devices would make physics lab sessions more interesting.	.837	4.15	0.790			
	Att 3: The use of AR via mobile devices would not be boring during physics practicals.	.767	3.96	0.860			
	Att 4 : Using AR via mobile devices in the classroom for practical physics work would be a good idea.	.803	4.24	0.728			
	Att 5: Using AR via mobile devices in physics lab work would be fascinating.	.783	3.99	0.765			
Intension	**Int 1:** I would appreciate the use of AR via mobile devices during physics lab work.	.831	4.08	0.778	.886	.917	.687
	Int 2: I would enjoy using AR via mobile devices in physics practicals.	.845	4.11	0.803			
	Int 3: I would like to use AR via mobile devices in practical work in other disciplines.	.826	4.06	0.832			
	Int 4: As a teacher, if my school has the necessary infrastructure, I will use AR via mobile devices in my students' practical work.	.820	4.19	0.878			
	Int 5: As a physics teacher, I would recommend other teachers to use AR via mobile devices in physics practical work.	.824	4.17	0.812			

The results in Table 3 suggest that the model's latent variables broadly meet established criteria for reliability and validity. Most constructs demonstrate strong internal and composite reliability, as well as acceptable levels of convergent validity. Although Cronbach's alpha for the PU construct is slightly below the commonly accepted threshold of .70, it is worth noting that values between .60 and .70 have been deemed satisfactory in previous exploratory studies (Hair Jr. et al., 2021; Taber, 2018). Furthermore, convergent validity is confirmed by the AVE values, all of which surpass the recommended threshold of .50. This indicates that each of the constructs effectively captures a significant proportion of the variance in its respective items, reinforcing the credibility of the measurement instruments used. Furthermore, analysis of the factor coefficients reveals that they systematically exceed the .70 thresholds, consolidating the robustness of the model and its relevance for further analysis.

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 4 illustrates the relationships between the different parts of the model, allowing analysis of the strength of the linear relationships between the latent variables employed to assess students' attitudes toward using AR in practical physics work. Analyzing the correlations between these constructs is an essential step in examining the model's discriminant, with the aim of ensuring that each construct measures a concept that is distinct and differentiated from the other constructs included in the study. This assessment is essential to check the reliability of the results and assure that the constructs do not overlap conceptually.

Table 4
Discriminant Validity Results According To the Fornell-Larcker Criterion

Items	ATT	INT	PEOU	PU
ATT	.789			
INT	.765	.829		
PEOU	.757	.698	.831	
PU	.674	.662	.716	.858

The results in Table 4 suggest that the model's discriminant validity is globally acceptable in terms of the Fornell-Larcker criterion. Indeed, the square root of the average variance extracted (AVE) for each construct (diagonal values) is higher than its correlations with the other constructs (off-diagonal values), indicating a clear distinction between the concepts measured. For example, for the ATT construct (.789), this value exceeds its correlations with INT (.765), PEOU (.757) and PU (.674), thus meeting the criterion. Although some correlations are relatively high, notably between ATT and INT (.765) and PEOU and PU (.716), they remain below critical thresholds, confirming discriminant validity. These results suggest that the model's constructs measure distinct concepts, reinforcing the robustness of the model's structure.

Normality tests carried out on the responses collected for each of the latent variables revealed a lack of normality in the distribution of scores. Consequently, in order to compare the perceptions of students who had already used AR in practical work with those of students who had never used this technology, Mann-Whitney tests were carried out. The results of these comparative analyses are presented in Table 5.

Table 5
Mann Whitney Test Results for Both Groups

Items	Having Used AR (N=334)			Never Used AR (N=422)			Mann-Whitney Test U			
	M	*SD*	Interpretation	*M*	*SD*	Interpretation	*U*	*Z*	*P*	*r*
PU	4.389	.5268	totally agree	3.957	.6543	agree	43320	-9.386	<.001	.34b
PEOU	4.2784	.57502	totally agree	3.8436	.60956	agree	41320	-9.874	<.001	.36b
Attitude	4.317	.5419	totally agree	3.850	.5841	agree	39844	-10.333	<.001	.38b
Intension	4.366	.6140	totally agree	3.929	.6689	agree	42064	-9.617	<.001	.35b

Note: [a] large effect size, [b] medium effect size, [c] small effect size,

The results shown in Table 5 reveal notable variations between students who have used AR and those who have never experimented with this technology. Students familiar with AR express a greater favorable perception of its PU and PEOU, adopting a more positive attitude and demonstrating a more marked intention to use it. Indeed, those who have already used AR tend to agree wholeheartedly with these aspects, while novice students tend to agree more, without achieving the same level of endorsement. These differences underline the impact of prior experience on acceptance of AR and suggest that previous use of this technology fosters a more positive perception of its benefits and accessibility.

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Structural Model

As part of the evaluation of hypotheses, statistical tests were carried out to analyze path coefficients, *t*-values, and p-values, enabling us to determine the importance of the relations among latent variables. These tests are used to validate or reject the hypotheses formulated in the model. Additionally, the effect size (f^2) was measured to evaluate the significance of each relationship, with the following ranges: a weak effect for f^2 <.20, a medium effect for .20≤ f^2 < .50, and a strong effect for f^2 ≥ .60 (Cohen, 2013). Table 6 presents the results of the hypothesis test and the effect size.

Table 6
Relation between Variables (Path Coefficients)

Hypothetical relation	Path coefficient (β)	*t-value*	*p-value*	Results	f^2
ATT → INT	.765	31.982	< .001	Accepted	1.414
PEOU → ATT	.562	14.887	< .001	Accepted	.394
PEOU → PU	.716	32.957	< .001	Accepted	1.052
PU → ATT	.272	6.587	< .001	Accepted	.092

The data in Table 6 show that all the hypotheses formulated are confirmed, with statistically significant correlations between the constructs studied (p < .001). Analysis of path coefficients (β) reveals effects of varying intensity, ranging from weak to very strong, in line with Cohen's criteria for evaluating effect sizes (f^2) (Cohen, 2013). PEOU exerts a substantial influence on PU, indicating that the less difficult a technology is perceived to be to use, the more beneficial it is judged to be. Similarly, PEOU significantly influences students' attitude towards AR, representing a moderate to strong effect and emphasizing the role of ergonomics and usability in technology adoption. Attitude towards AR (ATT) was the main predictor of intention to use (INT), with a very strong impact. This result shows the key role of students' perceptions and preferences in their willingness to adopt this technology in their practical work.

Although perceived usefulness contributes to the formation of a favorable attitude towards AR, its impact remains relatively limited compared with that of usability. PU's relatively weak effect on ATT can be explained by the fact that, in a pedagogical context, students' attitudes are influenced more by usability than by immediate perceived usefulness (Yanto et al., 2024). Indeed, until students have fully experienced the concrete benefits of AR, their perception of its usefulness may remain moderate and have a limited impact on their attitude. The findings confirm that the acceptance of AR in a practical physics context is mainly based on the perception of its PEOU and on the attitude adopted by students. Intention to use AR is notably influenced by attitude, suggesting that to encourage its adoption, it is essential to improve students' positive perceptions of this technology.

Table 7 presents the coefficients of determination (R^2), adjusted coefficients (adjusted R^2), and Q^2 values for the latent variables Attitude (ATT), Intention (INT), and Perceived Usefulness (PU). As shown in Figure 1, these relationships are represented graphically to enhance the understanding of the connections between latent variables and their path coefficients. The R^2 reflects the extent of variance accounted for by the model, while the adjusted R^2 offers a more precise estimate, taking into account the number of predictor variables. In addition, the Q^2, calculated using the blindfolding technique, measures the model's predictive capacity. A positive Q^2 value indicates good predictive relevance, while a value close to zero or negative reflects poor predictive ability (Hair Jr. et al., 2021). Together, these indicators allow us to assess both the explanatory quality and the predictive robustness of the model.

Table 7
R-Square and Adjusted R-Square Values for AR Acceptance Model Constructs

	R-square	*R-square adjusted*	*Q^2*
ATT	.609b	.608	.570
INT	.586b	.585	.470
PU	.513b	.512	.509

Note. [a] Substantial (R^2 around .75), [b] Moderate (R^2around .50), [c] Weak (R^2 around .25)

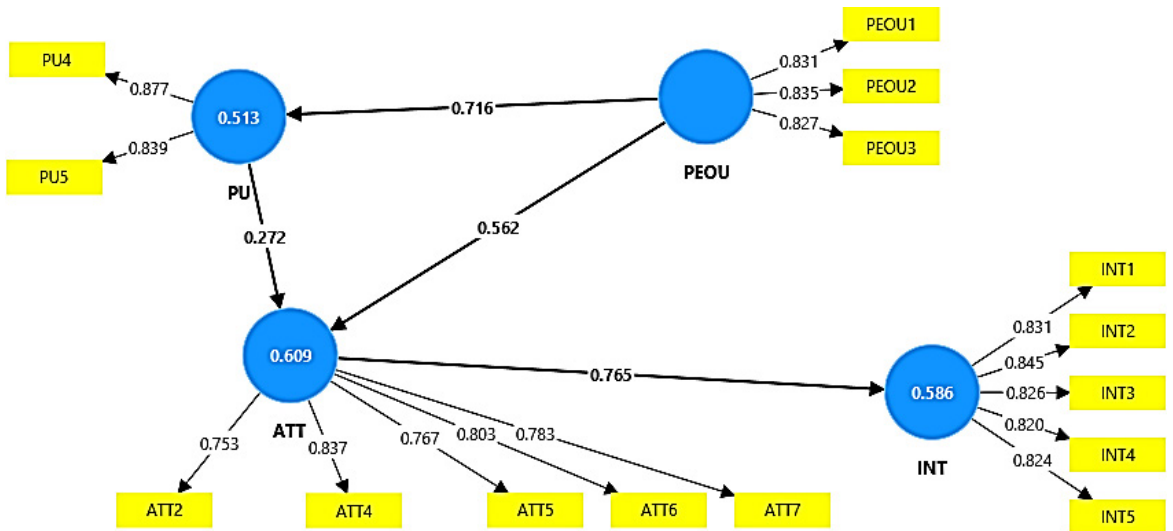
https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The proximity of the R^2 and adjusted R^2 values suggests a strong model fit, accounting for the number of predictors involved. This convergence between the two indices implies the absence of overfitting and strengthens the model's validity. On average, the model accounts for between 51% and 61% of the variance in latent constructs, aligning with generally accepted criteria for exploratory models in the social sciences (Chicco et al., 2021; Ozili, 2023). Specifically, attitude towards the use of AR (ATT) emerges as the best-explained variable, accounting for 60.9% of the variance, indicating a substantial influence of predictor factors on this dimension. Intention to use AR (INT) is also well-predicted by the model, with 58.6% of variance explained, suggesting a strong relationship between the determinants studied and technology adoption. PU, despite presenting a slightly lower explained variance ($R^2 = 0.513$), remains moderately influenced by the explanatory variables. These results underscore the robustness of the proposed model and highlight its ability to explain each of the latent variables. Furthermore, the Q^2 values confirm the predictive validity of the model, as they are all greater than zero, as recommended by Stone-Geisser (GEISSER, 1974; Hair Jr. et al., 2021; Stone, 1974).

The model's capacity for prediction is further supported by the variance explained and the Q^2 indicators. Specifically, the model demonstrates effectiveness in predicting student attitudes (ATT), their intention to utilize the technology (INT), and their perception of its utility (PU). This predictive power stems from the connections between the different variables, particularly PEOU and PU. The presence of high Q^2 values reinforces this capability, indicating that the model retains substantial predictive power beyond the observed sample. This evidence suggests that students' perceptions of AR in practical physics work can be effectively modeled and predicted from the determinants identified.

Figure 1
The Study's Final Structural Model



Discussion

This study examined the determinants of AR acceptance via mobile devices in physics practical work, using the TAM model. The results confirmed all the hypotheses formulated, showing that PU, PEOU, and student attitudes are key factors in the intention to adopt AR. These findings align with previous theoretical and empirical work (Álvarez-Marín et al., 2021; Huang & Liu, 2024; Or, 2024; Papakostas et al., 2023; Shyr et al., 2024; Wei et al., 2021).

Firstly, the results indicated that PU significantly influenced students' attitudes regarding the use of AR in physics lab work. Students who perceive AR as a useful educational tool develop a more favorable attitude toward its adoption. This finding is consistent with the conclusions of other studies (Álvarez-Marín et al., 2021; Fadl & Youssef, 2020; Fidan & Tuncel, 2019; Wojciechowski & Cellary, 2013), which identify PU as a determining factor in attitudes toward technology. These results highlight the importance of raising students' awareness of the practical and educational benefits of AR to encourage its adoption.

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Secondly, this research indicated that PEOU has a significant effect on the PU of AR. More specifically, when students find AR as easy to use, they are more inclined to recognize its usefulness. These results confirm those of previous studies (Ibáñez et al., 2016; Jang et al., 2021; Wei et al., 2021; Mahmud et al., 2024; Papakostas et al., 2023) and highlight the importance of designing intuitive and user-friendly AR tools to lower barriers to entry and improve perceptions of their effectiveness. Thirdly, the study also found that PEOU directly and significantly influences students' attitudes toward the use of AR. These results support the central premise of the TAM model, which states that technology, perceived as easy to use, generates a more positive attitude toward it. This finding is consistent with the results of studies such as those by (Boboc et al., 2021; Fadl & Youssef, 2020; Holdack et al., 2022; Hung et al., 2021; Zhai & Shi, 2020) These results show that designing AR applications tailored to students' needs is essential to maximizing their engagement and adoption. Finally, the study showed that students' attitudes positively influence their perceived intention to use AR in physics lab work. This finding is in line with previous studies (Álvarez-Marín et al., 2021; Fadl & Youssef, 2020; Fidan & Tuncel, 2019; Ismael et al., 2024; Jiang et al., 2022; Onbasi et al., 2021; Sırakaya & Alsancak Sırakaya, 2022), which highlight that a favorable attitude toward a technology significantly increases the intention to adopt it. These results show that it is essential to implement educational strategies aimed at reinforcing a positive attitude towards AR, for example, by promoting its advantages and simplifying its integration into teaching.

The analysis of the results also revealed significant differences between the perceptions of students who had already used AR and those who had never experienced it. The former gave higher scores to PU, PEOU, attitude, and intention to use, indicating a more favorable perception of the technology. These differences suggest that prior experience with AR promotes a better understanding of its features and educational benefits, while reducing apprehensions about its use. These observations confirm the principles of experiential learning theories (Kolb & Kolb, 2017; Weerasinghe et al., 2022), according to which direct interaction with a technology allows for a better perception of its relevance and ease of use. In addition, this prior experience has a moderating effect on the acceptance process, mitigating the cognitive barriers associated with the adoption of emerging technology. These results show the value of integrating introductory sessions on AR into teaching programs in order to promote its adoption and optimize its impact on learning in the laboratory.

In sum, this study highlights the existence of a significant interrelationship between PEOU, PU, attitude, and students' intention to adopt AR via mobile devices. These variables play a central role in learners' decision-making processes regarding the use of innovative technologies in an educational context. The results obtained offer concrete avenues for optimizing the pedagogical design and integration of AR into practical physics work. They also contribute to a better comprehension of the process of adopting digital learning tools in higher education.

Conclusion and Implications

The results of this study validate the effectiveness of the TAM in the use of AR in PW. The measuring instruments show high validity and reliability, guaranteeing the robustness of the conclusions. Analyses reveal that PEOU positively influences students' attitude, which consequently influences their intention to adopt. Moreover, PU also plays an important role in attitude formation. A key finding of this study is related to the effect of prior experience with AR on students' perceptions. Analyses indicate that students who have previously used AR perceive its usefulness and PEOU more favorably, thereby reinforcing their positive attitude and intention to use it. This effect highlights the importance of exposure and gradual familiarization with the technology to promote acceptance. Furthermore, R^2 values indicate that these variables account for a significant proportion of the variance in students' attitudes and intentions, emphasizing the crucial role of usability and perceived usefulness in AR acceptance. Additionally, the model exhibits notable predictive capability, as it reliably predicts students' attitudes and intentions toward AR adoption. These results suggest that enhancing AR adoption in practical work necessitates prioritizing PEOU and PU among students.

Limitations and future prospects

Although this study has provided relevant results, it is important to recognize certain limitations. First, the study was limited to a sample from a single Moroccan university, which may restrict the applicability of the results to other institutional or cultural contexts. In addition, the composition of the sample, which was predominantly female and mainly made up of undergraduate students, could introduce bias and limit the representativeness of the different student populations in the physical sciences. Furthermore, the analysis focused exclusively on

https://doi.org/10.33225/jbse/25.24.611

ISSN 1648–3898 /Print/
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practical physics work, which limits the applicability of the results to practical work in other scientific disciplines. Future research could therefore explore students' attitudes toward AR in other scientific fields, while incorporating additional variables, such as personal and psychological characteristics, which may affect the acceptance of this technology. Furthermore, the adoption of other technology acceptance models, including additional variables influencing usage intentions, could provide a deeper understanding of the phenomenon. Finally, longitudinal studies would allow for the examination of changes in attitudes and intentions to use AR over an extended amount of time, thus providing a dynamic perspective on the understanding of its adoption.

Declaration of Interest

The authors declare no competing interest.

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Received: *March 08, 2025* Revised: *June 24, 2025* Accepted: *July 30, 2025*

Cite as: Ayaichi, L., Amaaz, A., & Mouradi, A. (2025). Understanding collaborative problem-solving with smartphone-based asymmetric simulations in an authentic inquiry science lesson. *Journal of Baltic Science Education*, *24*(4), 611–623. https://doi.org/10.33225/jbse/25.24.611

Laila Ayaichi
(Corresponding author)
Energy, Materials and Computing Physics Research Team, Abdelmalek Essaadi University, Tetouan, Morocco.
E-mail: laila.ayaichi@etu.uae.ac.ma
ORCID: https://orcid.org/0009-0001-2919-6727

Aziz Amaaz
Computer Science and University Pedagogical Engineering Research Team, Abdelmalek Essaadi University, Tetouan, Morocco.
E-mail: aamaaz@uae.ac.ma
ORCID: https://orcid.org/0009-0006-7254-4527

Abderrahman Mouradi
Energy, Materials and Computing Physics Research Team, Abdelmalek Essaadi University, Tetouan, Morocco.
E-mail: abderrahman.mouradi@uae.ac.ma
ORCID: https://orcid.org/0000-0003-1560-2285