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Original Article

Dentistry Section

Evaluation of Mobile Augmented Reality in Orthodontic Training using the Technology Acceptance Model: A Multicentre Quasi-experimental Study

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ABSTRACT

Introduction: Mobile Augmented Reality (MAR) has shown potential in orthodontic education, yet evidence within orthodontic training specifically remains scarce. Understanding student acceptance is critical to guiding its curriculum integration.

Aim: To evaluate undergraduate dental students' acceptance of a Machine Learning-Enabled Mobile Augmented Reality System (MAR-ORTHO-EDU 2.0) based on the Technology Acceptance Model (TAM).

Materials and Methods: This multicentre quasi-experimental study was conducted across four Malaysian public universities (Universiti Sains Malaysia, Universiti Islam Antarabangsa Malaysia, Universiti Kebangsaan Malaysia, and Universiti Teknologi MARA) from November 2022 to June 2023. A total of 227 undergraduate dental students (years 3 and 4) were enrolled: 105 in the control group and 122 in the intervention group. The present paper reports the TAM component of this larger study, administered exclusively to the intervention group (n=122) following a didactic lecture, system demonstration, and one-week access to the MAR-ORTHO-EDU 2.0 application. The TAM questionnaire assessed Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude toward Use (AT), and Behavioural Intention (BI) via convenience sampling. Demographic variables, including gender, year of study, and Emotional Intelligence (EQ), were recorded. Pearson's correlation and multivariable linear regression were used for analysis ($p<0.05$).

Results: The TAM questionnaire demonstrated robust internal consistency (Cronbach's α=0.88-0.91). Participants reported favourable acceptance across all domains. The strongest correlation was observed between AT and PU (r=0.791), followed by AT and BI (r=0.780). Multivariable regression indicated that PEOU (p=0.029) and AT ($p<0.001$) were significant predictors of BI, collectively explaining 69.1% of the variance. PU was not significant in the multivariable model, suggesting mediation through AT.

Conclusion: These findings indicate that dental students showed favourable acceptance of MAR-ORTHO-EDU 2.0, with ease of use and attitude, rather than PU, emerging as the primary drivers of adoption intention in orthodontic training.

Keywords: Clinical competence, Dentistry, Educational technology, Students, User-computer interface

INTRODUCTION

Orthodontic education is both specialised and complex. Students must not only grasp theoretical foundations such as craniofacial development, physiology, and biomechanics, but also develop precision in clinical procedures including wire bending and bracket positioning [1,2]. Unlike purely theoretical disciplines, clinical competence in orthodontics depends on manual skill and clinical reasoning [3]. Current training models face real challenges: a multi-country survey found that graduates commonly lack confidence in malocclusion diagnosis, and some students who perform well in basic assessments struggle when confronted with actual clinical problems [4,5]. In response, digital simulation technologies, particularly Virtual Reality (VR) and Augmented Reality (AR), have attracted growing interest, with systematic reviews confirming that their effectiveness in developing psychomotor skills is comparable to conventional teaching methods [6].

MAR uses the hardware capabilities of smartphones and tablets to overlay digital information onto real-world environments in real time [7]. Unlike VR, which creates a fully enclosed virtual space, MAR is portable and has shown broad potential in healthcare education, though it remains in the early stages of implementation [8]. In orthodontic education, MAR has been applied to clinical skill training such as bracket positioning [9], offering dynamic interactivity that traditional teaching materials cannot provide. Empirical evidence suggests that MAR not only demonstrates good usability but also accelerates skill acquisition [10].

Given the potential of MAR in orthodontic education, understanding the factors that influence its adoption is essential. This study therefore applies the TAM as a theoretical framework [11], which identifies PU (the degree to which technology improves learning performance) and PEOU (the perceived effort required to operate it) as the core determinants of usage intention. TAM has been widely validated in educational research [12] and applied to assess AR and VR adoption in healthcare settings [13].

While MAR has been explored in dentistry, orthodontic-specific studies remain scarce and largely confined to clinical applications. To address this gap, the present study evaluates undergraduate dental students' acceptance of MAR-ORTHO-EDU 2.0, a machine learning-enabled MAR system, using the TAM. The specific objectives were: 1) to assess students' perceptions of the MAR system in terms of PU, PEOU, AT, and BI; 2) to examine the relationships among TAM constructs; and 3) to identify significant predictors of BI to use MAR in orthodontic education. Using a multicentre quasi-experimental design across four Malaysian dental schools, this study provides evidence for integrating MAR into the orthodontic curriculum.

Based on the TAM framework and the study aim stated above, the following hypotheses were formulated.

The null hypotheses proposed that: PU does not significantly predict BI to use MAR (H_{01}); PEOU does not significantly predict BI (H_{02}); PEOU does not significantly affect PU (H_{03}); and AT does not significantly predict BI (H_{04}).

Correspondingly, the alternate hypotheses proposed that: PU significantly and positively predicts BI (H_{11}); PEOU significantly and positively predicts BI (H_{12}); PEOU significantly and positively affects PU (H_{13}); and AT significantly and positively predicts BI (H_{14}).

MATERIALS AND METHODS

This multicentre quasi-experimental study was conducted across four Malaysian public universities (Universiti Sains Malaysia (USM), Universiti Islam Antarabangsa Malaysia (UIAM), Universiti Kebangsaan Malaysia (UKM), and Universiti Teknologi MARA (UiTM)) from November 2022 to June 2023. Ethical approval was obtained from Universiti Sains Malaysia (Reference: USM/JEPeM/22020143), and informed consent was obtained from all participants.

Sample size: Sample size was determined via a priori power analysis using G*Power for a two-group comparison. With α=0.05, power=0.80, and effect size d=0.45 [14-16], the minimum required sample was 78 participants per group (156 total); accounting for 16% attrition, the recruitment target was 200. The overall study recruited 227 participants: 105 in the control group (USM and UIAM) and 122 in the intervention group (UKM and UiTM). The control group evaluated knowledge gain (Kirkpatrick Level 2) via pre-test/post-test comparison. The TAM evaluation was administered exclusively to the intervention group (n=122), as TAM requires direct technology exposure. Sample adequacy was further confirmed using Green's (1991) criterion (N ≥ 50 + 8m): with six predictors, the minimum required sample was 98, which the intervention group exceeds [17].

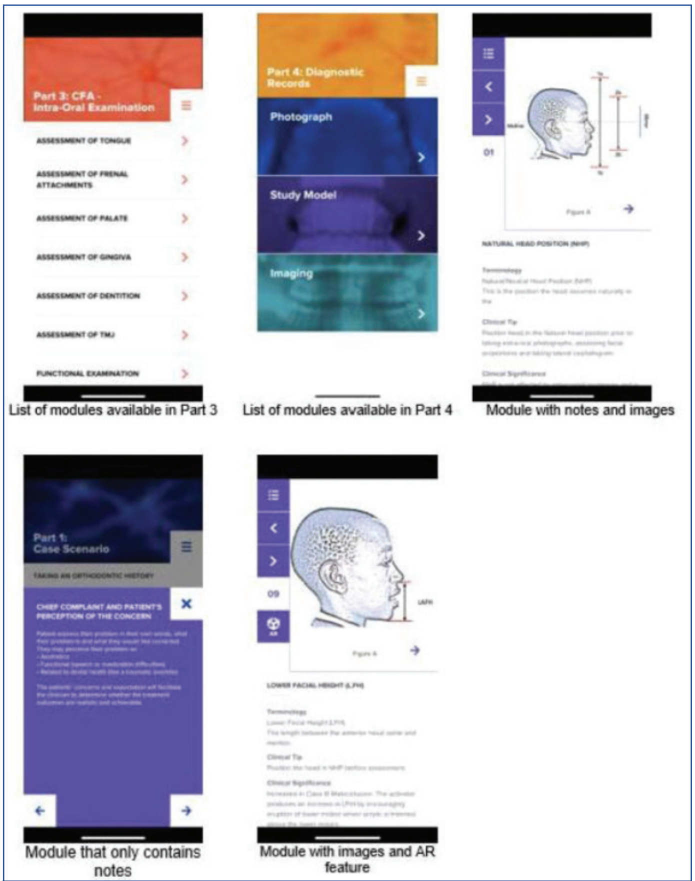
Study Procedure

Participants attended a lecture on orthodontic examination and diagnosis, followed by a 20-minute demonstration of MAR-ORTHO-EDU 2.0. They were then given one week of independent access to the system to explore its components and complete in-app exercises. Upon completion, participants completed the TAM questionnaire to assess their acceptance of the system.

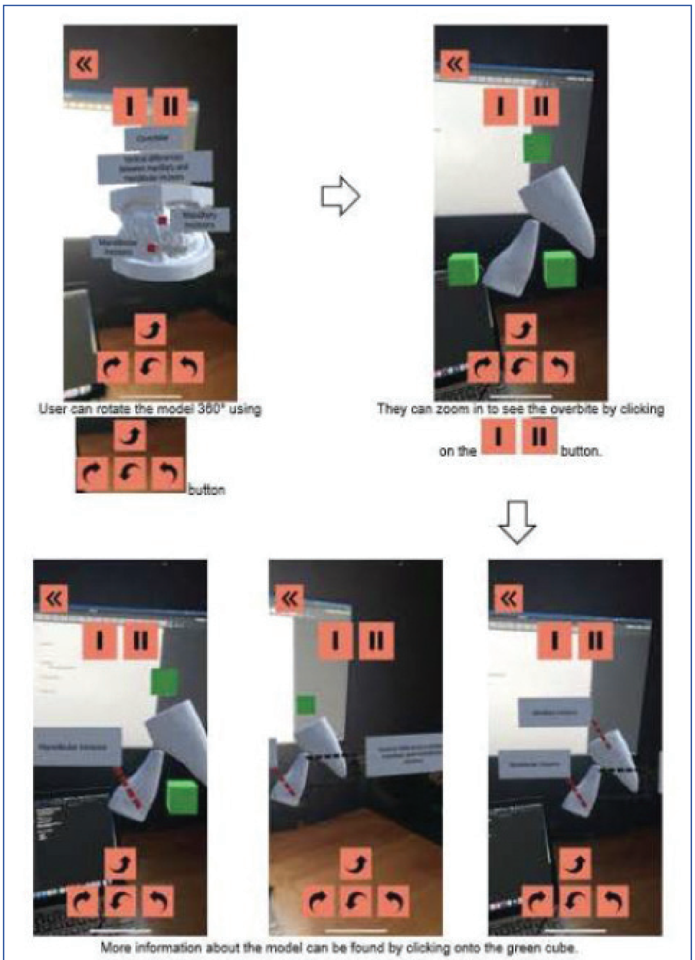
The MAR-ORTHO-EDU system

The MAR-ORTHO-EDU 2.0 is a MAR application for orthodontic education employing marker-less tracking via a You Only Look Once (YOLO) deep learning algorithm for facial recognition. The system features interactive 3D models that students can rotate, zoom, and examine to identify facial and dental landmarks and is compatible with both Android and iOS devices. As illustrated in [Table/Fig-1], the system comprises multiple learning modules covering intra-oral examination and diagnostic records, presenting content through text notes, clinical images, and AR-enhanced features. The system enables 360°degree interactive 3D model manipulation, allowing students to examine overbite relationships and dental anatomy from multiple angles. This supports spatial understanding beyond conventional 2D images, as demonstrated in [Table/Fig-2].

Data collection instruments: Data were collected using three validated instruments. Section A (Demographics and ICT): Recorded age, gender, year of study, university, self-perceived ICT literacy (rated on a single-item scale from 1 to 10, where higher scores indicate greater perceived ICT proficiency; the mean score was computed by averaging responses across all 122 participants), device types, and internet connectivity, summarised in [Table/Fig-3]. Section B (TAM Questionnaire): Adopted and adapted from Ghani MTA et al., (2019) [18], originally validated by five Subject Matter Experts (Cronbach's α >0.75 for all constructs). References to mobile digital games were replaced with MAR-ORTHO-EDU, retaining the original 20-item structure on a 7-point Likert scale (modified from 5-point to increase sensitivity). Four constructs were assessed: PU (PU, 5 items; range 5–35), PEOU (PEOU, 6 items; range 6-42), AT (AT, 5 items; range



[Table/Fig-1]: MAR-ORTHO-EDU 2.0- A machine learning-enabled Mobile Augmented Reality (MAR) system for orthodontic education.



[Table/Fig-2]: Interactive 3D model manipulation features of the MAR-ORTHO-EDU 2.0 system.

5–35), and BI (BI, 4 items; range 4–28). Internal consistency was confirmed with Cronbach's α=0.88–0.91for all domains. Section C (EQ): The Schutte Self-Report Emotional Intelligence Test (SSEIT) assessed EQ across 33 items on a 5-point Likert scale (range 33-165), included as a covariate for individual differences in technology adoption [19].

STATISTICAL ANALYSIS

Data were analysed using IBM Statistical Package for Social Sciences (SPSS) version 26.0. Descriptive statistics were calculated for demographic variables and TAM construct scores. Internal consistency was assessed using Cronbach's alpha (acceptable threshold: $\alpha \geq 0.70$) [20]. Pearson's correlation examined associations among TAM constructs. Simple linear regression assessed bivariate relationships between each predictor (PU, PEOU, AT) and BI. Multivariable linear regression identified significant predictors of BI while controlling for gender, year of study, EQ, ICT literacy, device type, and internet connection. The coefficient of determination (R^2) evaluates the variance explained. Statistical significance was set at $p<0.05$.

RESULTS

A total of 122 undergraduate dental students from two Malaysian public universities participated in the TAM evaluation. The participants had a median age of 21.0 years (IQR=1.0), with a predominantly female composition of 95/122 (77.9%). Most participants were in their third year of study, 75/122 (61.5%), with UiTM contributing the larger proportion of participants, 75/122 (61.5%), compared to UKM, 47/122 (38.5%). The mean EQ score was 122.5±12.4, and self-perceived ICT literacy averaged 7.2±1.61. The majority of participants, 80/122 (65.6%) utilised a combination of tablet, iPad, smartphone, laptop, and notebook devices, with 72/122 (59.0%) accessing both Wi-Fi and mobile data for internet connectivity. Detailed demographic characteristics are presented in [Table/Fig-3].

The TAM questionnaire was used to assess participants in the MAR-ORTHO-EDU intervention group (n=122). The questionnaire covered four domains: PU, PEOU, AT, and BI. The TAM questionnaire demonstrated robust internal consistency reliability, with Cronbach's alpha values of 0.90 (PU), 0.91 (PEOU), 0.90 (AT), and 0.88 (BI). Respondents generally exhibited favourable acceptance of MAR-ORTHO-EDU as part of their learning method. Descriptive findings are summarised in [Table/Fig-4].

Pearson's correlation analysis revealed significant positive associations among all TAM constructs [Table/Fig-5]. The strongest correlation was observed between AT and PU (r=0.791, $p<0.001$), followed by AT and BI (r=0.780, $p<0.001$), PU and BI (r=0.690, $p<0.001$), PEOU and AT (r=0.688, $p<0.001$), PU and PEOU (r=0.631, $p<0.001$), and PEOU and BI (r=0.614, $p<0.001$). These findings indicate that favourable perceptions of usefulness, ease of use, and attitude toward the MAR-ORTHO-EDU system were all significantly associated with students' BI to adopt the system. Scatter plots illustrating the pairwise relationships among all TAM constructs are presented in [Table/Fig-6a-f].

Of the 122 participants, 96 had complete data across all variables and were included in the multivariable regression analysis. The relationships between PU, PEOU, and AT with BI scores were evaluated. All three domains showed significance at the simple regression level. However, in the multivariable analysis controlling for gender, year of study, EQ scores, ICT literacy, device type, and internet connection method, only PEOU (Adj.b=0.130, 95% CI: 0.014, 0.246; p=0.029) and AT (Adj.b=0.395, 95% CI: 0.169, 0.622; p=0.001) exhibited significant independent associations with BI. The full model explained 69.1% of the variance in BI (R^2=0.691, Adjusted R^2=0.638), [Table/Fig-7]. None of the covariates demonstrated

Variables	n (%)	Mean (SD)/ Median (IQR)
Age (years)	-	21.0 (1.0) *
Gender		
Female	95 (77.9)	-
Male	27 (22.1)	-
Year of study		
Third	75 (61.5)	-
Fourth	47 (38.5)	-
University		
UKM	47 (38.5)	-
UiTM	75 (61.5)	-
EQ score	-	122.5 (12.4)
ICT literacy	-	7.2 (1.61)
Device types		
Laptop/notebook only	9 (7.4)	-
Tablet/iPad/smartphone	12 (9.8)	-
Tablet/iPad/smartphone/laptop/notebook	80 (65.6)	-
Tablet/iPad/smartphone/laptop/notebook/desktop	18 (14.8)	-
Other	3 (2.5)	-
Internet connection methods		
Wi-Fi only	10 (8.2)	-
Wi-Fi/mobile data	72 (59.0)	-
Wi-Fi/mobile data/wired LAN	29 (23.8)	-
Other	11 (9.0)	-

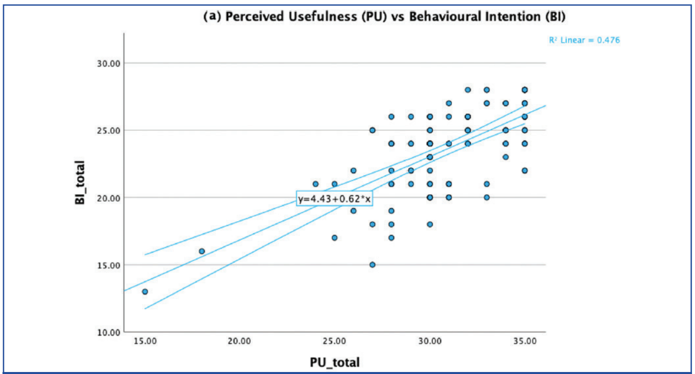
[Table/Fig-3]: Demographic characteristics and ICT-related factors of participants (n=122).
SD: Standard deviation; IQR: Interquartile range; UKM: Universiti Kebangsaan Malaysia; UiTM: Universiti Teknologi MARA; EQ: Emotional intelligence; ICT: Information and communication technology; LAN: Local area network; * Median (IQR)

Domain	Score range	Mean±SD
Perceived Usefulness (PU)	15-35	30.89±3.45
Perceived Ease Of Use (PEOU)	18-42	34.48±4.86
Attitude Toward Use (AT)	20-35	30.63±3.35
Behavioural intention to use (BI)	13-28	23.57±3.10

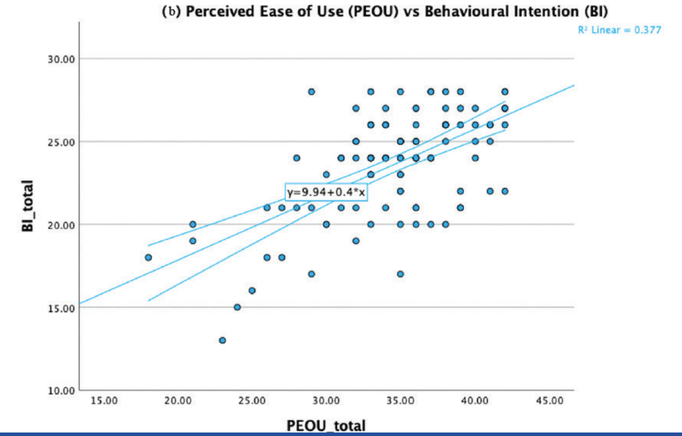
[Table/Fig-4]: Respondents' TAM Scores (n=122).
SD: Standard deviation; * Score range possible: PU: 5–35, PEOU: 6–42, AT: 5–35, BI: 4–28

Variable	Mean±SD	PU	PEOU	AT	BI
PU	30.89±3.45	(0.90)			
PEOU	34.48±4.86	0.631**	(0.91)		
AT	30.63±3.35	0.791**	0.688**	(0.90)	
BI	23.57±3.10	0.690**	0.614**	0.780**	(0.88)

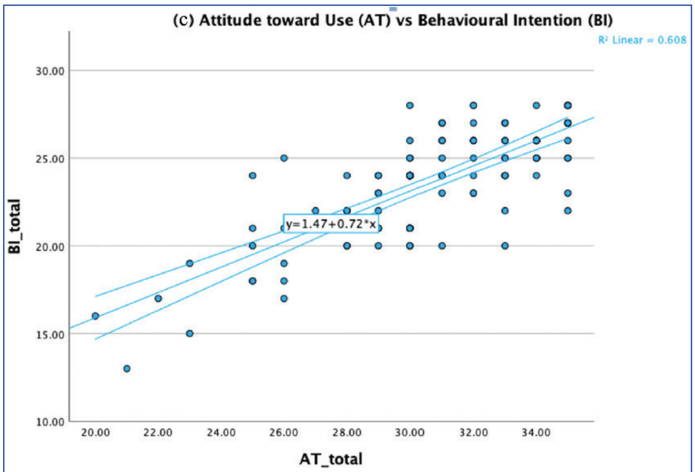
[Table/Fig-5]: Means, standard deviations, cronbach's alpha reliability coefficients, and pearson's correlation coefficients (r) among TAM constructs (n=122).
PU: Perceived usefulness; PEOU: Perceived ease of use; AT: Attitude toward use; BI: Behavioural intention to use; Values in parentheses on the diagonal represent Cronbach's alpha reliability coefficients; **p<0.001 (two-tailed)



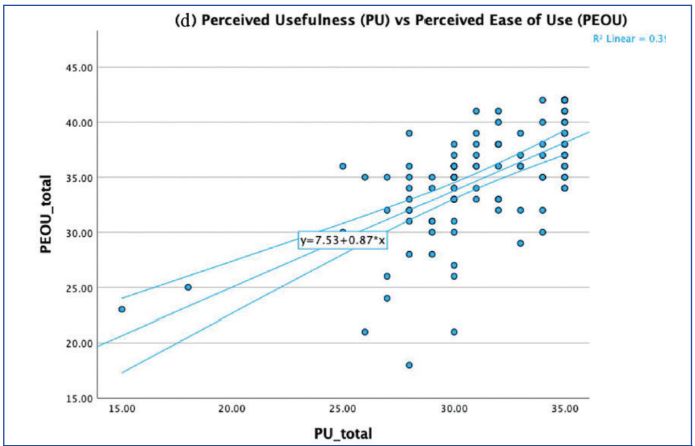
[Table/Fig-6a]: Perceived Usefulness (PU) vs Behavioural Intention (BI), r=0.690



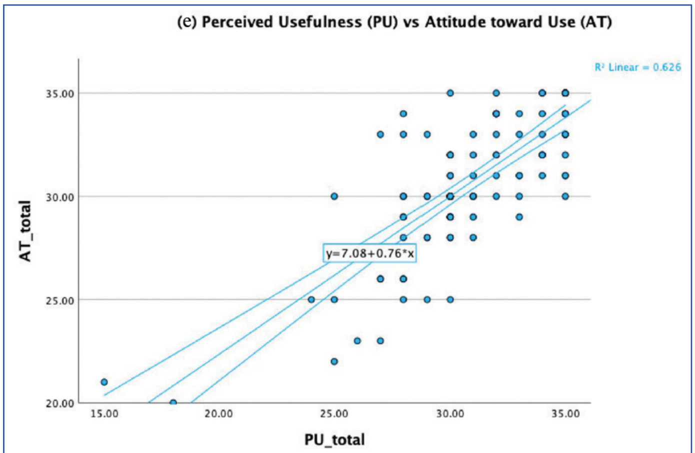
[Table/Fig-6b]: Perceived Ease of Use (PEOU) vs Behavioural Intention (BI), r=0.614.



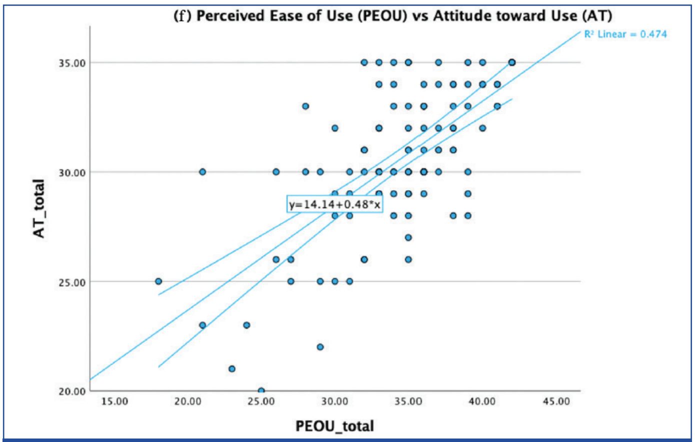
[Table/Fig-6c]: Attitude toward Use (AT) vs Behavioural Intention (BI), r=0.780.



[Table/Fig-6d]: Perceived Usefulness (PU) vs Perceived Ease of Use (PEOU), r=0.631.



[Table/Fig-6e]: Perceived Usefulness (PU) vs Attitude toward Use (AT), r=0.791.



[Table/Fig-6f]: Scatter plots illustrating pairwise relationships among TAM constructs with linear regression lines and 95% confidence intervals (n=122) (f) Perceived Ease of Use (PEOU) vs Attitude toward Use (AT), r=0.688.
* p<0.001 (two-tailed) for all correlations. Linear regression lines shown with 95% confidence intervals.

Variables	SLR*		MLR†		
	‡(95% CI)	p-value	Adj. b§ (95% CI)	t stat.	p-value
TAM Constructs					
PU	0.62 (0.50, 0.74)	<0.001	0.18 (-0.02, 0.37)	1.81	0.065
PEOU	0.40 (0.30, 0.49)	<0.001	0.130 (0.014, 0.246)	2.21	0.029
AT	0.72 (0.61, 0.83)	<0.001	0.395 (0.169, 0.622)	3.49	0.001
Covariates					
Gender	—	—	0.03 (-0.98, 1.03)	0.05	0.960
Year of study	—	—	-0.04 (-0.89, 0.80)	-0.10	0.919
EQ score	—	—	0.01 (-0.03, 0.04)	0.52	0.605
ICT literacy	—	—	-0.03 (-0.29, 0.24)	-0.20	0.841
Device type	—	—	0.02 (-1.23, 1.28)	0.04	0.971
Internet connection	—	—	-0.76 (-2.79, 1.27)	-0.75	0.458
R^2=0.691; Adjusted R^2=0.638					

[Table/Fig-7]: Simple and multivariable linear regression of TAM constructs and covariates on Behavioural Intention (BI) to Use MAR-ORTHO-EDU 2.0 (n=96).
*Simple linear regression; †Multivariable linear regression controlling for gender, year of study, EQ scores, ICT literacy, device type, and internet connection method; ‡Crude regression coefficient (b) with 95% confidence interval; §Adjusted regression coefficient (Adj. b) with 95% confidence interval; --- Variable not included in simple linear regression model; PU: Perceived usefulness; PEOU: Perceived ease of use; AT: Attitude toward use; BI: Behavioural intention; EQ: Emotional intelligence; ICT: Information and communication technology; All covariates: p>0.05 (non significant)

significant associations with BI (all p>0.05), confirming that PEOU and AT were the primary determinants of BI to use MAR-ORTHO-EDU 2.0. Among the covariates, EQ scores did not demonstrate a significant independent association with BI (Adj. b=0.004, 95% CI: –0.030, 0.037; p=0.834).

DISCUSSION

The present study employed TAM to evaluate dental students' acceptance of MAR-ORTHO-EDU 2.0. The instrument demonstrated robust internal consistency across all domains, with Cronbach's α ranging from 0.88 to 0.91, confirming the reliability of the TAM questionnaire in this context [21].

Among the TAM constructs, PEOU received the highest scores, mirroring findings from recent meta-analyses. A meta-analysis on AR/MR in medical education reported that the Weighted Mean Difference for PEOU (WMD=0.35) exceeded that for PU

(WMD=0.27), suggesting ease of navigation is a key concern for AR users [22]. Similarly, Wang EY et al., (2025) found that 83% of participants acknowledged ease of use in an AR simulation system for paediatric anaesthesia training [23]. Some dental education studies, however, identified PU as the primary predictor of adoption intention [24], a discrepancy that may reflect differences in user population or technology evaluated.

MAR provides interactive 3D visualisation supporting understanding of complex orthodontic structures, a benefit noted in dental education [25,26]. Correlation analysis revealed significant positive associations among all TAM constructs, with the strongest correlation between AT and PU (r=0.791, p<0.001), followed by AT and BI (r=0.780, p<0.001) [11]. Multivariable regression identified PEOU (Adj. b=0.130, p=0.029) and AT (Adj. b=0.395, p=0.001) as significant predictors of BI, explaining 69.1% of the variance (R^2=0.691). PU did not reach significance (p=0.065), suggesting its influence operates indirectly through attitude. This contrasts with Nkenke E et al., (2012), where PU was the predominant predictor for dental implant planning software [27], highlighting that for mobile-based learning tools, ease of use requires a positive attitude.

With reference to the study hypotheses, three of the four null hypotheses were rejected. PEOU significantly predicted BI (H_{02} rejected, p=0.029), PEOU was significantly associated with PU (H_{03} rejected, r=0.631, p<0.001), and AT significantly predicted BI (H_{04} rejected, p<0.001). H_{01} was not rejected, as PU did not directly predict BI (p=0.065), suggesting its influence operates indirectly through AT (r=0.791, p<0.001).

Although EQ was included as a covariate, it did not demonstrate a significant independent association with BI (p=0.834), nor did any other covariate, including gender, year of study, ICT literacy, device type, or internet connection (all p>0.05), confirming TAM constructs as the primary drivers of BI. The mean EQ score obtained in the present study (122.5±12.4) was slightly lower than the normative means reported by Schutte NS et al., for males (124.78,±16.52) and females (130.94±15.09), suggesting that participants demonstrated an average level of EQ, which did not appear to influence their technology acceptance behaviour [19].

This pattern may be partly explained by students' existing familiarity with smartphone-based interaction, which likely reduced the perceived effort of using MAR-ORTHO-EDU 2.0 [28]. As noted by Amores-Valencia A et al., (2025), PEOU is critical for AR adoption when users engage with new interactive modalities [29], a finding consistent with the present results. AT emerged as the strongest predictor of BI, consistent with Kucuk S et al., (2020), who identified attitude as the primary indicator of mobile learning intention among medical students [30]. The positive attitudes observed here may stem from the inherently engaging nature of AR technology, combined with the familiarity of smartphone interaction, together fostering a favourable user experience [31,32].

The present study findings support the feasibility of MAR in orthodontic education, with the technology showing potential to benefit multiple aspects of student learning. The widespread availability of smartphones further strengthens this feasibility, enabling students to access learning content at any time and place [33,34]. Future development of the system should consider incorporating haptic feedback, which could better simulate the tactile sensations involved in clinical skill practice [35].

Since PEOU and AT were the primary predictors of BI, curriculum developers should ensure that MAR applications are easy to download and navigate, with clear onboarding guidance to help students feel confident before independent use. Prior orientation and structured demonstrations may foster positive attitudes, which in turn could drive adoption. Given that PU was not a significant independent predictor, its influence may already be shaped by attitude; efforts to build positive user experiences may therefore be sufficient to drive perceived utility as well. Toker S and Ozyürek AB (2024) similarly highlighted that infrastructure readiness, prior knowledge preparation, and learner attitudes collectively shape AR acceptance in dental education [36], reinforcing the importance of comprehensive student preparation before system deployment.

As the present study captured student acceptance at a single point in time, longitudinal research is needed to examine how perceptions of MAR evolve with extended use and across different stages of clinical training, which would also inform future system development. Expanding beyond TAM to frameworks such as the Unified Theory of Acceptance and Use of Technology (UTAUT) [37], which incorporates additional constructs including social influence and facilitating conditions, may offer a more complete picture of adoption behaviour. Furthermore, multi-institutional studies across diverse geographic and cultural contexts would provide broader data to guide the development of MAR tools that better serve orthodontic education globally. Future system iterations may also benefit from incorporating haptic feedback, as Felszeghy S et al., (2025) demonstrated its value in transferring manual skills from virtual to clinical settings [38].

Limitation(s)

The present study has several limitations. The TAM evaluation was conducted at two of the four study sites (UKM and UiTM), and participants were recruited via convenience sampling, which may limit generalisability to other geographic, cultural, and institutional contexts. First-time exposure to the system may have inflated acceptance scores, as novelty effects are known to diminish with continued use. Reliance on self-reported data may also have introduced social desirability bias. Additionally, TAM does not capture all determinants of technology acceptance, and constructs such as social influence and facilitating conditions were not examined. Finally, the one-week access period may not have been sufficient for participants to fully explore the system, potentially affecting their responses.

CONCLUSION(S)

In conclusion, dental students demonstrated favourable acceptance of MAR-ORTHO-EDU 2.0, with PEOU and AT emerging as the key predictors of BI, while PU did not exert a direct significant effect, suggesting its influence operates through attitude. These findings highlight that user-friendly design and adequate student preparation are central to successful MAR integration in orthodontic education. Future research should employ longitudinal designs and broader institutional samples to build on these findings.

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