



EARLY CHILDHOOD TEACHERS' ADOPTION OF AUGMENTED REALITY: EVIDENCE FROM A UTAUT2-BASED MODEL IN PRESCHOOL SCIENCE EDUCATION

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Abstract

Augmented reality (AR) has been increasingly recognised as a promising digital tool for enhancing inquiry-oriented science learning in early childhood settings. Nevertheless, empirical evidence remains limited regarding the factors that shape preschool teachers' readiness to adopt AR within their educational practice. Drawing on the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2), this study examines the determinants influencing preschool teachers' intentions to adopt AR for science education in Turkey. The sample comprised 1,020 pre-service and in-service preschool teachers who engaged in a multi-phase research process that included interaction with AR-based science scenarios, structured informational content, and completion of an adapted UTAUT2 questionnaire designed for early childhood contexts. Data were analysed using confirmatory factor analysis and structural equation modelling. The findings indicated that all seven UTAUT2 constructs exerted statistically significant effects on behavioural intention. In particular, hedonic motivation, performance expectancy, and habit emerged as the most influential predictors, suggesting that enjoyment-related and routine-oriented considerations play a central role in early childhood teaching environments characterised by play-based learning and established daily practices. Overall, the model accounted for 62% of the variance in teachers' behavioural intention, demonstrating strong explanatory capacity and supporting the relevance of the UTAUT2 framework for early science education. By extending technology acceptance research to a previously underexplored developmental and pedagogical context, the study underscores the need for AR design, professional development, and institutional support strategies that are closely aligned with the realities of preschool teaching.

Keywords: *augmented reality, early childhood education, preschool science education, technology acceptance, UTAUT2*

Introduction

Early childhood education is fundamentally concerned with nurturing young children's natural curiosity, exploratory behaviour, and emerging scientific thinking through developmentally appropriate learning experiences. In preschool settings, learning is typically grounded in hands-on exploration, sensory engagement, and inquiry-based activities that allow children to construct understanding through direct interaction with their environment. Within this pedagogical context, teachers play a central role in selecting and implementing educational approaches that support both cognitive development and meaningful engagement.

In recent years, the increasing availability of digital technologies has begun to reshape early childhood learning environments, offering new possibilities for extending children's experiences beyond the constraints of traditional classroom materials. When thoughtfully

selected and purposefully integrated, digital tools can provide novel ways to visualise, explore, and interact with scientific phenomena that are otherwise difficult to observe directly. Research suggests that immersive and interactive technologies may enrich early learning by enhancing engagement, supporting conceptual understanding, and fostering foundational scientific skills (Chatzigeorgiadou et al., 2022; Moomaw, 2024; Osterhaus et al., 2021; Zheng et al., 2022). At the same time, growing expectations regarding digital competence place preschool teachers in a critical decision-making role, requiring them to evaluate which technologies genuinely align with young children's developmental needs and pedagogical goals (Slutsky et al., 2021).

Among emerging technologies, augmented reality (AR) has attracted increasing attention due to its capacity to integrate digital content with the physical environment, enabling learners to interact with three-dimensional representations of animals, plants, scientific processes, and natural phenomena (Huang et al., 2022). Within early science education, AR holds particular promise because it can make abstract or invisible concepts such as biological structures, life cycles, or natural processes accessible to young children through vivid and manipulable simulations (Şakir, 2025a). By fostering enjoyment, encouraging inquiry, and supporting multimodal engagement, AR has the potential to complement hands-on science experiences and deepen children's understanding of the natural world (Cheng et al., 2024). However, the integration of AR into preschool classrooms also presents notable challenges, including teachers' confidence in using unfamiliar technologies, the availability of developmentally appropriate content, and the need for adult mediation during AR-based activities.

Despite the growing interest in AR across various educational levels, its application in early childhood science education remains limited. While studies conducted in primary, secondary, and higher education contexts have highlighted the motivational and conceptual benefits of AR (Marín et al., 2022; Mystakidis et al., 2022; Seralidou et al., 2024), comparatively little is known about preschool teachers' perceptions of its usefulness, ease of use, and pedagogical appropriateness. Early childhood educators operate within distinctive developmental, curricular, and institutional constraints, and their technology-related decisions cannot be assumed to mirror those of teachers working with older learners.

Consequently, there remains a lack of empirically grounded understanding of the factors that shape preschool teachers' intentions to adopt AR for science education. Without a clear explanation of the cognitive, motivational, social, and contextual determinants influencing teachers' intentions, efforts to promote AR integration risk being misaligned with classroom realities, professional needs, and institutional conditions. Addressing this gap requires a theoretically grounded examination of preschool teachers' intentions to adopt AR within the specific context of early childhood science education, thereby providing a foundation for more informed implementation, professional development, and educational design.

Theoretical Framework

Digital Technologies and Augmented Reality in Preschool Science Education

Early childhood represents a developmental period during which children construct understanding of the world through active exploration, sensory engagement, and concrete experiences. Science education is closely aligned with these developmental characteristics, as it emphasises inquiry, guided observation, and hands-on experimentation. Traditional preschool science activities such as object manipulation, nature-based exploration, and simple experiments play a central role in fostering early scientific reasoning, classification skills, and problem-solving abilities (Akçay Malcok & Ceylan, 2022; Burns et al., 2025; Lin et al., 2021).

The increasing presence of digital technologies in early learning environments has expanded the pedagogical possibilities available to preschool teachers. Developmentally

appropriate digital tools can extend children's experiences beyond what can be directly observed or manipulated in the classroom by providing multimodal representations of scientific phenomena that are otherwise inaccessible. By engaging visual, auditory, and tactile modalities, such tools can support conceptual understanding, stimulate curiosity, and sustain young learners' attention. However, the educational value of digital technologies in preschool contexts is not inherent; rather, it is contingent upon teachers' technological confidence, pedagogical beliefs, and willingness to experiment with innovative educational approaches (Raviv & Galili, 2024).

Within this broader digital landscape, AR has emerged as a particularly promising technology for early science education. AR overlays digital elements such as three-dimensional objects, animations, and contextual audio onto the physical environment, allowing children to interact with virtual scientific phenomena in real space (Ateş, 2025). This integration of physical and virtual elements creates immersive learning experiences that extend the pedagogical possibilities of conventional preschool science materials, such as static images, books, and physical manipulatives. Empirical research suggests that AR can transform static representations into dynamic, manipulable models, enabling preschool children to explore scientific structures and processes from multiple perspectives (Ateş & Polat, 2025b; Şakir, 2025a). Such interactions may support emerging scientific thinking by allowing children to observe changes, make comparisons, and engage in simple predictive reasoning within a safe and playful learning context (Demircioglu et al., 2023).

The educational affordances of AR are particularly relevant for supporting conceptual understanding in early science education. Its interactive and game-like features align closely with preschool children's preference for playful and exploratory engagement, while its vivid simulations can concretise complex scientific ideas that cannot be replicated through hands-on materials alone (Li & Taber, 2022; Tariq, 2025). Nevertheless, the successful incorporation of AR into preschool classrooms requires careful pedagogical judgement. Teachers must ensure that AR-based activities support social interaction, align with play-based learning principles, and can be managed within practical constraints such as limited attention spans, established classroom routines, and device availability (Herman et al., 2025).

As digital technologies become increasingly embedded in early childhood curricula, understanding how preschool teachers evaluate, accept, and form intentions towards adopting technological innovations has become a critical concern. Unlike educators at later educational stages, early childhood teachers must consider young children's need for adult scaffolding, developing motor and cognitive capacities, and curricular emphases on experiential and play-centred learning (Wang et al., 2024). These distinctive pedagogical and developmental considerations shape how teachers assess the appropriateness and educational value of emerging technologies and underscore the need for theoretical frameworks that are sensitive to the specific characteristics of early childhood contexts.

A range of theoretical models has been used to examine technology adoption in educational settings. While these frameworks provide valuable insights, they do not fully capture the motivational, affective, habitual, and contextual dimensions that often underpin early childhood teachers' technology-related decision-making. The UTAUT2 extends earlier models by incorporating constructs such as HM, PV, and HBT, alongside more traditional predictors such as perceived usefulness and perceived ease of use (Tamilmani et al., 2021). These extensions render UTAUT2 particularly well suited to early childhood education contexts, where teachers' intentions to adopt technologies often reflect a combination of pedagogical reasoning, personal enjoyment, contextual support, and familiarity with digital tools (Fokides & Giagiakou, 2025).

By integrating perspectives from preschool science pedagogy, AR research, and technology acceptance theory, UTAUT2 provides a comprehensive and nuanced framework for examining the factors that shape preschool teachers' intentions to adopt AR for science

education. Its multidimensional structure enables systematic analysis of both individual perceptions and contextual enablers, offering a robust theoretical foundation for understanding how early childhood educators evaluate emerging technologies within developmentally appropriate learning environments.

UTAUT2 Framework in the Context of AR-Supported Preschool Science Education

The UTAUT2 offers a well-established conceptual lens for examining how individuals develop intentions towards engaging with new technologies and the conditions that influence these intentions (Venkatesh et al., 2012). The framework integrates eight interrelated constructs including performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating conditions (FC), hedonic motivation (HM), price value (PV), habit (HBT), and behavioural intention (BI) which together provide a comprehensive explanation of intended technology adoption (Tamilmani et al., 2017). While UTAUT2 has been extensively employed across a range of educational settings, its application within early childhood education remains comparatively underdeveloped (Wang, 2025). In particular, empirical investigations focusing on preschool teachers' intentions to adopt augmented reality for science education are scarce, despite the recognised potential of interactive and multimodal technologies to support inquiry-based learning. This lack of context-specific evidence highlights the need to adapt and empirically test the UTAUT2 framework within early childhood classrooms, where developmental considerations, pedagogical practices, and institutional conditions differ markedly from those of later educational stages.

PE, defined as the belief that a technology will enhance educational effectiveness and learning outcomes, represents a central determinant of teachers' technology-related intentions (Ateş & Garzón, 2023). In preschool science education, teachers may perceive AR as a resource capable of making abstract scientific concepts more accessible, increasing children's engagement and curiosity, strengthening inquiry-related behaviours such as observing and predicting, and enriching hands-on exploration through supplementary visual support. Although prior research has demonstrated the pedagogical benefits of AR among older learners (Caffaratti et al., 2025), limited evidence exists regarding whether preschool educators perceive comparable value, particularly within play-based and experiential learning environments. Examining PE in this context is therefore essential for understanding whether teachers view AR as a pedagogically meaningful option for early science education.

EE, defined as the perceived ease associated with intending to use AR tools, is particularly salient in preschool settings, where teachers must manage intensive supervision demands and provide clear, developmentally appropriate guidance to young learners (Sung & Lee, 2025). Intentions to adopt AR may depend on teachers' confidence in navigating applications, their perceptions of the technology's intuitiveness and manageability, and the extent to which anticipated preparation demands align with the practical constraints of early childhood classrooms (Wong et al., 2012). To date, research has paid limited attention to how preschool educators evaluate the usability of AR during the intention-formation stage, or how anticipated complexity may discourage intentions to adopt AR for science-related activities. Addressing this gap is critical for clarifying the conditions under which AR is perceived as a feasible educational option in early childhood education.

SI refers to the extent to which teachers perceive expectations or encouragement from colleagues, school leaders, parents, and the broader institutional culture regarding the use of a particular technology (Chang, 2012). While SI has been shown to affect technology-related intentions in school settings, relatively few studies have examined how such pressures operate in relation to preschool teachers' intentions to adopt AR. This omission is noteworthy, as early childhood educators often rely on collaborative professional norms, administrative guidance,

and parent partnerships when considering new educational approaches (Mason et al., 2025). Investigating SI in the context of preschool science education can therefore provide insight into how collective expectations may either facilitate or constrain teachers' willingness to adopt AR.

FC, including the availability of appropriate devices, technical support, reliable internet access, and developmentally suitable applications, play a critical role in shaping early childhood educators' intentions to adopt AR (Wu, 2024). Preschool classrooms frequently face infrastructural constraints, and concerns related to resource availability or technical reliability may affect teachers' readiness to consider AR more strongly than in later educational stages (Nikolopoulou, 2021). However, existing literature offers limited systematic analysis of how such structural conditions influence preschool teachers' intentions towards AR adoption, leaving an important gap in understanding the practical realities that shape technology-related decision-making in early science contexts.

HM, defined as the degree of enjoyment or pleasure anticipated from using a technology, is particularly relevant in early childhood education, where playfulness, positive affect, and intrinsic motivation are central to effective education. Despite its conceptual relevance, few empirical studies have examined whether preschool teachers perceive AR as enjoyable or motivating, or whether such perceptions strengthen their intentions to adopt the technology. Investigating HM therefore provides insight into an often-overlooked affective driver of technology acceptance in early science learning environments.

PV refers to teachers' perceptions of the balance between the anticipated benefits of AR and its associated costs. Despite the financial constraints faced by many preschool programmes, PV remains underexamined in early childhood education research. Given the variability in the cost of AR applications and devices, understanding how teachers evaluate affordability, institutional funding, and perceived value is essential for determining whether economic considerations influence intentions to adopt AR for science education.

HBT, defined as the extent to which technology-related behaviours become automatic through repeated experience, has also received limited attention in studies involving early childhood educators. Teachers who are accustomed to integrating digital tools into their educational routines may be more inclined to form positive intentions towards adopting AR, whereas those with limited prior experience may exhibit greater hesitation. However, little empirical research has examined how habitual technology use shapes intentions to adopt AR in preschool contexts, particularly for science activities that require both structured guidance and opportunities for open-ended exploration.

Collectively, these determinants shape preschool teachers' behavioural intention, which represents the most immediate and theoretically grounded indicator of technology adoption readiness within the UTAUT2 framework. Although UTAUT2 has demonstrated strong explanatory power across diverse educational settings, the limited application of the model to preschool science education constitutes a significant theoretical and empirical gap. By examining how UTAUT2 constructs operate in relation to preschool teachers' intentions to adopt AR for science activities, the present study directly addressed this gap.

Drawing on the theoretical arguments presented above, the study proposed the following hypotheses:

- H1. Higher PE increases preschool teachers' intention to adopt AR for science education.
- H2. Greater perceived EE increases preschool teachers' intention to adopt AR for science education.
- H3. Positive SI increases preschool teachers' intention to adopt AR for science education.
- H4. Perceived FC positively influence preschool teachers' intention to adopt AR for science education.
- H5. Higher HM increases preschool teachers' intention to adopt AR for science education.

H6. More favourable perceptions of PV increase preschool teachers' intention to adopt AR for science education.

H7. Stronger habitual tendencies increase preschool teachers' intention to adopt AR for science education.

Research Methodology

General Background

The data collection process was carefully designed to generate valid, reliable, and contextually grounded evidence regarding preschool teachers' perceptions of, and intentions to adopt, AR for science education. As AR remains a relatively novel educational technology in early childhood settings, the research team implemented a structured, multi-stage procedure to ensure that all participants had a comparable baseline understanding of AR before completing the questionnaire. This approach reduced the likelihood of misconceptions and enabled respondents to make informed judgements regarding the UTAUT2 constructs.

The first stage involved developing an introductory multimedia module in Turkish to familiarise participants with the conceptual foundations and pedagogical functions of AR. Rather than focusing on specific commercial applications, the module provided a general explanation of AR as a technology that overlays virtual elements onto real-world environments. Examples were explicitly contextualised for preschool science education, illustrating how AR can visualise scientific processes, enable children to manipulate virtual objects, and support inquiry-based learning through interactive representations. Sample scenarios were included to assist participants in envisioning realistic classroom applications.

To complement this conceptual introduction, participants were provided with a short technical guide written in accessible language. The guide outlined general device requirements for AR use (e.g., tablets or smartphones), common interface features of AR applications, and typical integration strategies in early childhood education. Importantly, it also addressed implementation concerns frequently encountered by preschool teachers, including classroom management, limits on children's screen time, and the need for adult supervision during AR activities. By providing this balanced overview, the guide supported participants in evaluating both the affordances and the practical constraints associated with adopting AR in daily teaching routines.

Following the establishment of a shared foundational understanding, the study adopted a survey research strategy, within which a structured questionnaire served as the primary data collection instrument. The questionnaire was developed based exclusively on the UTAUT2 framework and adapted to reflect the context of preschool science education. All items were translated into Turkish and subjected to linguistic and pedagogical review to ensure clarity and appropriateness for teachers with diverse levels of technological experience.

To support participants who were less familiar with questionnaire-based research, an optional online orientation session was offered. These sessions addressed questions regarding AR integration, elaborated on hypothetical examples of AR-supported science activities, and presented short video clips demonstrating how AR might support children's inquiry skills. The sessions also aimed to reduce anxiety among teachers who reported lower confidence in using digital technologies.

A pilot study was conducted with 220 preschool teachers who were invited to provide feedback on the clarity of the questionnaire items, the appropriateness of the questionnaire length, and the perceived level of difficulty. This feedback informed revisions to ambiguous wording, adjustments to item sequencing to improve coherence and flow, and refinements to the technical layout of the online questionnaire platform. This iterative process ensured that the final instrument was both user-friendly and psychometrically robust.

Full data collection was conducted over a five-month period, from July to November 2025. During this time, participants were invited to complete the online questionnaire at their convenience; completion required approximately 15–20 minutes. Participants who had not completed the questionnaire received fortnightly reminder emails to maximise the response rate. A dedicated email communication channel was established throughout the data collection period to provide technical support, respond to participant enquiries, and ensure that all respondents were able to complete the questionnaire without undue barriers.

Sample

The study employed a large and diverse sample of 1,020 preschool teachers in Turkey, comprising both pre-service and in-service educators. This sample size was considered appropriate for the study's analytical approach and research objectives. Structural equation modelling (SEM), which was used to test the UTAUT2-based model, requires relatively large samples to ensure stable parameter estimation and adequate statistical power. Methodological guidelines recommend minimum sample sizes ranging from 200 to 400 for SEM, depending on model complexity (Hair et al., 2018; Kline, 2016). The present sample substantially exceeds these thresholds, thereby enhancing the reliability and robustness of the model estimates.

The inclusion of both pre-service and in-service teachers was an intentional sampling decision aimed at capturing a broad range of perspectives on AR adoption. This approach allowed the study to reflect both anticipated technology use among future educators and intention formation shaped by practical classroom experience. Such heterogeneity strengthens the external validity of the findings within the national context and supports more nuanced interpretation of teachers' technology-related intentions.

The pre-service teacher subgroup comprised 530 participants enrolled in early childhood education programmes at multiple universities across different geographical regions. As these individuals were still in training, their responses provide insight into prospective teachers' perceptions of AR prior to entering professional practice. Most participants were aged between 18 and 25 years, with approximately 87% identifying as female, reflecting national demographic trends in early childhood education. Approximately 72% reported prior familiarity with educational technologies through coursework or practicum experiences, although direct exposure to AR was limited.

The in-service teacher subgroup consisted of 490 practising preschool teachers employed in both public and private early childhood institutions. Teaching experience ranged from 2 to more than 25 years, with 64% reporting over five years of professional experience. Educational qualifications varied, with 78% holding bachelor's degrees, 18% master's degrees, and 4% doctoral degrees. Participants worked in both urban (71%) and rural (29%) settings, allowing consideration of contextual differences in access to digital infrastructure. Notably, 69% of in-service teachers reported regular use of educational technologies in their professional practice, making this subgroup particularly relevant for examining UTAUT2 constructs related to AR adoption intentions (See Table 1).

Table 1
Demographic and Professional Characteristics of the Sample (N = 1,020)

Characteristic	Category	n	%
Teacher Status	Pre-service	530	52.0
	In-service	490	48.0
Gender	Female	887	87.0
	Male	133	13.0
Age Group	18–25	462	45.3
	26–35	318	31.2
	36 and above	240	23.5
Teaching Experience (In-service only)	2–5 years	176	35.9
	> 5 years	314	64.1
Educational Qualification (In-service only)	Bachelor's degree	382	78.0
	Master's degree	88	18.0
	Doctoral degree	20	4.0
School Location (In-service only)	Urban	348	71.0
	Rural	142	29.0
Regular Use of Educational Technologies (In-service only)	Yes	338	69.0
	No	152	31.0

Note. Percentages may not total 100 due to rounding. Pre-service teachers reported familiarity with educational technologies primarily through coursework and practicum experiences; direct prior exposure to AR was limited.

Instrument

The study used a structured questionnaire based entirely on the UTAUT2 framework. A total of 31 items were adapted from validated UTAUT2 measures (Ateş & Gündüzalp, 2025; Ateş & Polat, 2025a; Venkatesh et al., 2012) and recontextualised for AR-supported preschool science education. Each construct was operationalised using multiple items to capture its conceptual dimensions comprehensively.

The questionnaire assessed the following constructs: PE, EE, SI, FC, HM, PV, HBT, and behavioural intention. All items used a five-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (5), enabling participants to express nuanced perceptions.

Prior to finalisation, the questionnaire underwent a structured expert review process involving three specialists in early childhood science education and two scholars in educational technology. The experts independently evaluated each item for content relevance, developmental appropriateness, conceptual clarity, and alignment with the UTAUT2 constructs in the context of preschool science education. Evaluations were conducted using a standardised rating form, and qualitative feedback was solicited to identify ambiguous wording, redundancy, or contextual mismatch. Based on expert ratings, a Content Validity Index (CVI) was calculated at

the item level. All retained items met the recommended minimum threshold for content validity ($I-CVI \geq .80$), indicating satisfactory expert agreement. Items that did not meet this criterion were revised or removed. Following expert review, the revised instrument was pilot-tested, and further refinements were made based on psychometric performance and participant feedback.

Data Analysis

Data analysis was carried out through a systematic, multi-stage process using SPSS (Version 27) and AMOS (Version 24). Given that the UTAUT2 constructs were adapted to a new target group—preschool teachers—and applied within the relatively unexplored context of augmented reality (AR), particular attention was paid to establishing the validity and reliability of the measurement model.

An initial subset of responses from 210 participants was utilised to review item wording, assess clarity, and examine preliminary factor structures. Insights from this stage informed minor revisions to item phrasing and scale organisation, ensuring conceptual alignment with early childhood science education. Following these refinements, confirmatory factor analysis (CFA) was performed on the full dataset using maximum likelihood estimation.

The CFA results supported an acceptable level of model fit. The chi-square statistic was $\chi^2 = 894.32$ with 312 degrees of freedom ($p < .05$), resulting in a χ^2/df ratio of 2.86. Additional fit indices further indicated satisfactory measurement model adequacy: goodness-of-fit index (GFI) = .91, Tucker–Lewis index (TLI) = .92, incremental fit index (IFI) = .93, comparative fit index (CFI) = .93, root mean square error of approximation (RMSEA) = .06, and standardised root mean square residual (SRMR) = .05.

Reliability and validity were subsequently assessed. Composite reliability (CR) values ranged between .84 and .90, exceeding the recommended minimum threshold of .70 and indicating strong internal consistency. Convergent validity was established through average variance extracted (AVE) values, which ranged from .60 to .73. In addition, Cronbach's alpha coefficients varied from .80 to .91, further confirming acceptable reliability across all constructs.

Discriminant validity was examined using the Fornell–Larcker criterion. For each construct, the square root of the AVE was greater than the corresponding inter-construct correlations, demonstrating that the UTAUT2 dimensions measured conceptually distinct aspects of preschool teachers' technology-related perceptions.

Once the measurement model had been satisfactorily validated, structural equation modelling (SEM) was employed to test the hypothesised relationships among the UTAUT2 constructs. This analysis enabled examination of the predictive effects of performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, and habit on preschool teachers' behavioural intentions to adopt AR for science education (see Tables 2 and 3).

Table 2
UTAUT2 Constructs, Items, Factor Loadings, and Measurement Metrics

Con- struct	Item Statement	FL	M	SD	AVE	CR	α
PE	Using AR helps children understand science concepts better.	.84	4.32	0.71	.70	.88	.86
	AR would allow me to enrich science activities in my classroom.	.86	4.29	0.74			
	AR improves children's curiosity and engagement during science learning.	.82	4.35	0.69			
EE	Learning to use AR tools would be easy for me.	.78	3.92	0.88	.67	.89	.83
	Interacting with AR applications would be simple and clear.	.83	3.95	0.84			
	I would feel confident managing AR during science activities.	.85	4.01	0.82			
	It would be easy for me to become skillful at using AR.	.81	3.98	0.86			
SI	My colleagues support the idea of using AR in preschool science teaching.	.80	4.08	0.89	.66	.86	.88
	School administrators encourage the integration of AR in early learning.	.82	4.10	0.93			
	Parents expect teachers to use modern technologies like AR.	.81	4.06	0.91			
FC	I have access to devices needed to use AR in my classroom.	.83	3.75	0.96	.69	.90	.87
	Age-appropriate AR apps are available for preschool use.	.85	3.78	0.92			
	I can receive technical support if I encounter problems using AR.	.82	3.84	0.90			
	I have adequate knowledge to integrate AR into science activities.	.80	3.81	0.88			
HM	Using AR in science activities would be enjoyable for me.	.86	4.21	0.80	.72	.89	.90
	AR makes teaching science more fun and engaging.	.84	4.25	0.77			
	Incorporating AR would increase my enjoyment of teaching.	.85	4.18	0.83			
PV	The benefits of AR justify its financial cost.	.82	3.66	1.02	.65	.86	.84
	Using AR would offer good value for the required investment.	.85	3.71	0.97			
	The cost of AR applications is reasonable for preschool contexts.	.78	3.59	1.04			
HBT	Using AR would become a natural part of my teaching routine.	.82	3.94	0.90	.68	.87	.86
	I would feel the need to use AR regularly in science activities.	.84	3.91	0.93			
	I expect AR to become a habitual tool in my classroom.	.81	3.89	0.88			
BI	I intend to use AR in my future science teaching.	.88	4.26	0.81	.75	.90	.88
	I plan to integrate AR into my science activities regularly.	.87	4.22	0.79			
	I am committed to adopting AR for preschool science education.	.86	4.18	0.84			

Note. FL = factor loading; M = mean; SD = standard deviation; AVE = average variance extracted; CR = composite reliability; α = Cronbach's alpha.

Table 3
Correlation Matrix and Discriminant Validity Using AVE Square Roots

Construct	PE	EE	SI	FC	HM	PV	HT	BI
PE	.84							
EE	.48	.82						
SI	.44	.46	.81					
FC	.42	.50	.49	.83				
HM	.55	.43	.40	.47	.85			
PV	.40	.41	.37	.43	.44	.81		
HBT	.53	.51	.39	.46	.45	.38	.82	
BI	.62	.58	.54	.59	.61	.52	.57	.87

Notes: All correlations are significant at $p < .01$. Discriminant validity is supported because $\sqrt{\text{AVE}}$ values (diagonal) are higher than all inter-construct correlations.

Research Results

Structural Model Analysis

After the adequacy of the measurement model had been established through confirmatory factor analysis (CFA), the hypothesised relationships among the UTAUT2 constructs were examined using structural equation modelling. The structural model was estimated via maximum likelihood procedures using AMOS version 24 in order to assess the direct effects of the proposed predictors on preschool teachers' behavioural intention to adopt AR for science education.

Overall, the findings indicated that the structural model exhibited a satisfactory level of fit to the data. The chi-square statistic was 948.21 with 348 degrees of freedom, resulting in a χ^2/df ratio of 2.72, which is generally regarded as acceptable for models of comparable complexity in educational research. Consistent with this result, multiple incremental and absolute fit indices suggested good model adequacy. As reported in Table 4, the goodness-of-fit index (GFI) reached .91, while the incremental fit index (IFI) and comparative fit index (CFI) were .94. In addition, the Tucker-Lewis index (TLI) was .92. Error-based indicators further supported model fit, with a root mean square error of approximation (RMSEA) of .05 and a standardised root mean square residual (SRMR) of .04. Taken together, these statistics demonstrate that the proposed UTAUT2-based structural model provides an appropriate representation of the observed data and is suitable for evaluating the hypothesised paths.

Beyond overall model fit, the structural analysis revealed strong explanatory capacity. The set of UTAUT2 predictors jointly explained 62% of the variance in preschool teachers' behavioural intention to adopt AR for science education ($R^2 = .62$). This level of explained variance is substantial within the educational technology literature and indicates that the model offers a comprehensive account of the key factors shaping teachers' intention formation.

Table 4
Structural Model Fit Indices

Fit Indices	Suggested Value*	Model Values
χ^2	—	948.21
df	—	348
χ^2/df	≤ 2 to ≥ 5	2.72
GFI	≥ 0.90	0.91
IFI	≥ 0.90	0.94
TLI	≥ 0.90	0.92
CFI	≥ 0.90	0.94
RMSEA	≤ 0.08	0.05
SRMR	≤ 0.08	0.04
R ² (Behavioral Intention)	—	0.62

Note: *Suggested values based on Hair et al. (2018), Hu & Bentler (1999), and Kline (2005).

Hypothesis Testing

The structural relationships among the UTAUT2 constructs were examined using maximum likelihood estimation. Standardised path coefficients, t values, and significance levels were used to evaluate support for the proposed hypotheses. The results revealed that all hypothesised paths exerted statistically significant direct effects on preschool teachers' behavioural intention to adopt AR for science education.

PE had a strong and positive effect on behavioural intention ($\beta = .31$, $t = 7.12$, $p < .001$), indicating that teachers who believed AR could meaningfully enhance children's science learning were more likely to intend to adopt it. This finding supported H1. EE also exerted a significant influence on behavioural intention ($\beta = .27$, $t = 6.03$, $p < .001$), confirming that perceptions of ease of learning and using AR increased teachers' intentions to adopt it, thereby supporting H2.

SI demonstrated a significant effect on behavioural intention ($\beta = .22$, $t = 5.14$, $p < .001$), suggesting that encouragement from colleagues, administrators, and parents played an important role in shaping teachers' adoption intentions. This result supported H3. FC were likewise significant ($\beta = .19$, $t = 4.28$, $p < .001$), indicating that access to appropriate devices, applications, and institutional support contributed positively to teachers' willingness to adopt AR, thus confirming H4.

HM emerged as one of the strongest predictors of behavioural intention ($\beta = .33$, $t = 7.89$, $p < .001$). Preschool teachers who perceived AR as enjoyable and stimulating were more likely to express intentions to adopt it for science education, providing support for H5. PV showed a weaker but statistically significant effect on behavioural intention ($\beta = .14$, $t = 3.47$, $p < .001$), indicating that teachers' evaluations of the balance between anticipated benefits and associated costs influenced their adoption intentions. This finding supported H6.

HBT also exerted a significant positive effect on behavioural intention ($\beta = .29$, $t = 6.55$, $p < .001$). Teachers who routinely used digital technologies in their educational practice were more inclined to adopt AR, thereby supporting H7.

Taken together, the UTAUT2 constructs explained a substantial proportion of variance in behavioural intention. As shown in Table 5 and Figure 1, the model accounted for 62% of the total variance in preschool teachers' behavioural intention to adopt AR ($R^2 = .62$), demonstrating

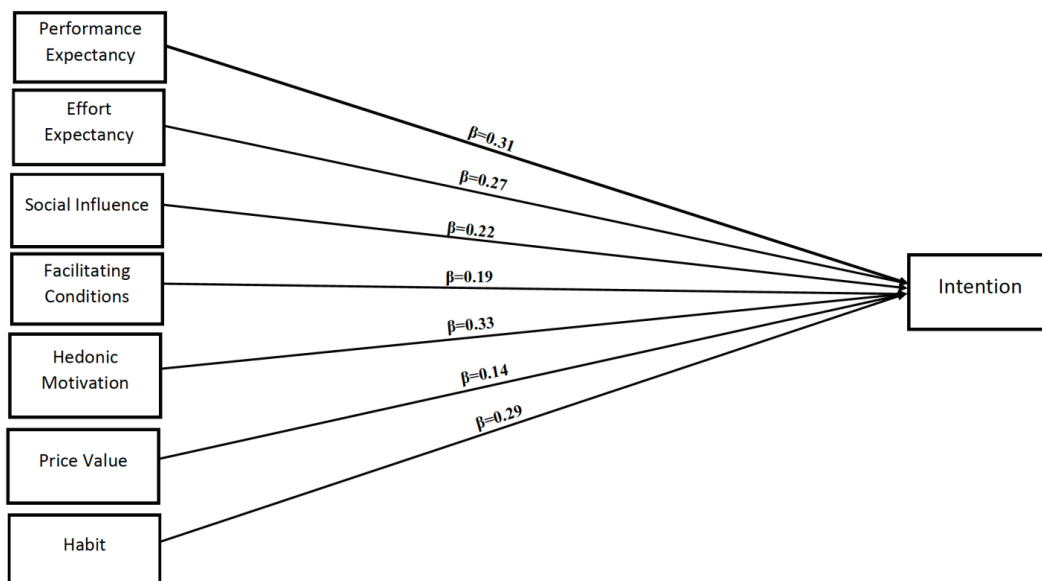
strong explanatory power. These findings highlight the combined influence of cognitive, social, and motivational factors in shaping preschool teachers' intentions regarding the adoption of AR for science education.

Table 5
Structural Path Coefficients for the UTAUT2 Model

Hypothesis	Path	β	t-value	p-value	Supported
H1	PE $\rightarrow$ BI	0.31	7.12	< .001	Yes
H2	EE $\rightarrow$ BI	0.27	6.03	< .001	Yes
H3	SI $\rightarrow$ BI	0.22	5.14	< .001	Yes
H4	FC $\rightarrow$ BI	0.19	4.28	< .001	Yes
H5	HM $\rightarrow$ BI	0.33	7.89	< .001	Yes
H6	PV $\rightarrow$ BI	0.14	3.47	< .001	Yes
H7	HT $\rightarrow$ BI	0.29	6.55	< .001	Yes

Note. β = standardised path coefficient. R^2 for behavioural intention = .62. All reported paths are statistically significant at $p < .001$.

Figure 1
Structural Model of UTAUT2



Discussion

Before considering the specific theoretical contributions of the findings, it is important to clarify the study's focus on behavioural intention rather than observed use behaviour. Within established technology acceptance research, including the original UTAUT and UTAUT2 frameworks, behavioural intention is conceptualised as the most immediate and theoretically grounded predictor of technology use (Venkatesh et al., 2012). In educational contexts and particularly in early childhood education, actual technology use is often shaped by institutional access, policy constraints, curricular requirements, and infrastructural conditions that may lie

beyond individual teachers' control. From this perspective, behavioural intention represents a meaningful indicator of teachers' readiness, openness, and motivational orientation towards adopting emerging technologies such as AR, even when opportunities for immediate implementation may be limited.

Building on this foundation, the findings of the present study offer several important theoretical contributions by extending and refining existing understandings of technology acceptance within early childhood education. By applying the UTAUT2 framework to preschool teachers' intentions to adopt AR for science education, the study demonstrates that the theoretical structure of UTAUT2 remains robust in settings characterised by distinctive developmental, pedagogical, and institutional features. The significance of all seven UTAUT2 constructs indicates that the model captures a comprehensive set of cognitive, motivational, and contextual determinants, thereby supporting its theoretical validity beyond the organisational and higher education contexts in which it has most frequently been tested (Venkatesh et al., 2012).

The results both converge with and diverge from previous technology adoption research, offering meaningful theoretical refinements. The strong influence of PE aligns with findings from earlier UTAUT-based studies involving teachers and students in primary, secondary, and higher education settings (e.g., Chen et al., 2025; Du & Lv, 2024; Kahnbach et al., 2024; Ke et al., 2025), which consistently identify perceived usefulness as a central antecedent of technology acceptance. However, in the present study, the effect of PE was closely matched by HM, a pattern less frequently observed in adult learning contexts, where enjoyment typically plays a secondary role. This divergence suggests that pedagogical environments emphasising play, exploration, and sensory engagement amplify the relevance of HM, indicating that motivational constructs may function differently when technology adoption decisions concern young children rather than adult learners (Prasad & Pandey, 2025).

Similarly, the substantial effect of HBT observed in this study contrasts with the mixed findings reported in previous UTAUT2 research, in which HBT often exerts a more modest influence on behavioural intention, particularly in higher education contexts where digital tool use is already well established (e.g., Rashid, 2025). In preschool settings, where classroom routines are foundational and teachers depend heavily on predictable structures to support children's learning, habitual tendencies appear to play a more prominent role (Yang et al., 2025). This finding suggests that the conceptualisation of HBT within UTAUT2 may require contextual recalibration when applied to early childhood education, where teachers' routines shape not only their own educational practices but also the consistency and stability necessary for young learners (Fokides & Giagiakou, 2025).

The findings related to FC and PV also have notable theoretical implications. While FC frequently emerge as a strong predictor of adoption in contexts where teachers independently manage digital tools (e.g., Ateş & Gündüzalp, 2025), the moderate, albeit significant, effect observed in this study indicates that early childhood educators rely more heavily on institutional infrastructure, shared resources, and administrative support. This suggests that the FC construct may benefit from operational refinements that account for classroom management demands and the need for adult scaffolding during technology use with young children (Nguyen et al., 2025). Similarly, the comparatively weaker influence of PV indicates that financial considerations may function differently in institutional settings where teachers are not primary decision-makers. This observation is consistent with theoretical perspectives from both UTAUT2 and Diffusion of Innovations, which emphasise that adoption drivers may vary according to organisational structures and authority relationships.

Comparisons with existing research on AR adoption further elucidate the theoretical contributions of the present study. Previous studies have consistently highlighted PE as a key driver of AR adoption, particularly due to its capacity to enhance visualisation and conceptual

understanding (Gronowski et al., 2024). The current findings confirm the importance of utility-based reasoning while also underscoring the heightened role of enjoyment and engagement in early childhood contexts (Tang, 2025). Whereas AR studies involving older learners often report that enjoyment contributes modestly to adoption decisions (Tu & Jia, 2024), the strong effect of HM identified here suggests that immersive technologies may activate affective pathways more strongly in educational settings where playful learning is a central pedagogical principle (Ateş & Garzón, 2023). This indicates that technology acceptance theories should more explicitly account for the combined cognitive and affective appeal of AR, particularly in domains where engagement and motivation are integral to learning outcomes.

Taken together, these findings demonstrate that while UTAUT2 is theoretically robust and applicable to early childhood science education, certain constructs carry different relative weights compared with other educational contexts. This nuance suggests that technology acceptance theories may benefit from contextual adaptation when applied to early childhood educators. More broadly, the results imply that models originally developed for general adult users should incorporate developmental and pedagogical considerations in order to more accurately reflect how teachers assess the usefulness, usability, and appropriateness of emerging technologies for young children.

Practical Implications

The findings of this study offer several practical implications for early childhood educators, policymakers, curriculum developers, and educational institutions seeking to integrate AR into preschool science education. First, the strong effects of PE and HM indicate that teachers are more inclined to adopt AR when they perceive that it meaningfully enhances children's inquiry processes, engagement, and conceptual understanding. Accordingly, professional development initiatives should prioritise practical demonstrations of how AR can enrich hands-on science experiences, rather than focusing exclusively on technological features. Professional learning workshops that combine pedagogical modelling with opportunities for teachers to experiment with AR applications may enhance both perceived usefulness and enjoyment.

Second, the significant influence of EE underscores the importance of providing user-friendly AR applications alongside clear and concise implementation guidance. Early childhood educators, who work within highly dynamic classroom environments and must provide substantial supervision and support to young children, benefit most from technologies that minimise preparation time and reduce cognitive load. Developers and school leaders should therefore prioritise AR platforms that are intuitive, require minimal navigation, and include built-in scaffolding suitable for early learners.

Third, the role of FC suggests that successful AR integration depends on reliable infrastructure, including stable internet access, functional devices, and readily available, developmentally appropriate applications, as well as supportive school leadership. Administrators can encourage adoption by ensuring that teachers have access to technical assistance, timely troubleshooting support, and structured opportunities for professional collaboration. The development of shared digital resource repositories or AR activity templates aligned with preschool science curricula may further support efficient and consistent classroom implementation.

Fourth, the significance of SI highlights the importance of professional culture in shaping technology adoption. AR integration is more likely when teachers feel supported by colleagues, school leaders, and the wider educational community. Peer mentoring initiatives, model classrooms, and collaborative lesson-planning sessions can help establish AR as a valued pedagogical resource rather than an optional enhancement. Additionally, parents' attitudes towards digital learning play a contributory role; therefore, family engagement activities or informational sessions demonstrating the educational value of AR may further strengthen teachers' motivation to adopt the technology.

Finally, the effects of HBT and PV point to the importance of sustained exposure to digital tools and institutional responsibility for cost-related decisions. Schools that progressively establish digital routines, such as the regular use of tablets or digital storytelling activities, may strengthen teachers' technological confidence and receptiveness to AR. At the policy and administrative levels, budgetary constraints can be mitigated through strategies such as subsidising applications or devices, negotiating institutional licences, or embedding AR within broader digital transformation initiatives.

Limitations and Future Research Directions

Although the present study offers important theoretical and practical contributions, several limitations should be acknowledged. First, the study relied on self-reported questionnaire data, which may be influenced by social desirability bias or individual response tendencies. While the large sample size enhances the robustness of the findings, the exclusively quantitative design limits the depth with which teachers' perceptions can be understood. Specifically, the study identifies which factors significantly influence preschool teachers' behavioural intentions, but it does not capture the qualitative reasoning, meanings, and contextual explanations that shape teachers' responses to AR. Future research could therefore complement survey-based findings with interviews, focus groups, classroom observations, or mixed-methods approaches to provide richer insight into how teachers interpret AR, negotiate pedagogical concerns, and make sense of technology adoption within their daily practice.

Second, and most importantly, the study examined preschool teachers' behavioural intention rather than their actual use behaviour. Although behavioural intention is a well-established and theoretically grounded predictor of technology adoption within the UTAUT2 framework, prior research indicates that intention does not always translate directly into sustained classroom practice. Consequently, the findings should be interpreted as reflecting teachers' readiness, openness, and motivational orientation towards adopting AR, rather than confirmed patterns of classroom implementation. This distinction represents a key limitation of the study and highlights the need for caution when extrapolating the results to actual teaching practice.

Future research should therefore move beyond intention-based models and examine how preschool teachers' stated intentions develop into actual classroom use over time. Longitudinal designs, implementation studies, classroom observations, and the analysis of usage data could provide valuable insight into the conditions under which AR is successfully incorporated into early childhood science education, as well as the barriers that may inhibit the translation of intention into practice.

Third, the exclusive focus on preschool teachers in Turkey limits the international generalisability of the findings. Cultural expectations regarding technology use, national education policies, professional development structures, and technological infrastructure vary across countries and may influence the relative salience of UTAUT2 constructs. Accordingly, the results should be interpreted as context-specific evidence rather than as universally applicable patterns of preschool teachers' technology acceptance. Future studies employing multi-country samples, cross-cultural comparative designs, and measurement invariance testing would be valuable for determining the extent to which the proposed relationships hold across different early childhood education systems.

Fourth, although the UTAUT2 framework explained a substantial proportion of variance in behavioural intention, early childhood education is shaped by additional pedagogical and developmental factors that were not explicitly incorporated into the model. Teachers' beliefs about child development, play-based pedagogy, classroom management, and professional identity may further influence technology-related decision-making. Integrating constructs from

pedagogical, developmental, or psychological theories may therefore enhance the explanatory power and contextual sensitivity of future research models.

Finally, AR represents only one category of immersive technology available in early childhood education. Future research could examine preschool teachers' acceptance of other emerging technologies, such as virtual reality, mixed reality, or artificial intelligence-supported tools, and compare how differing technological affordances influence PE, EE, and motivational factors. Qualitative studies exploring teachers' lived experiences, perceived barriers, and contextual challenges would also provide deeper insight into the complex processes underlying technology-related decision-making in preschool classrooms.

Conclusions and Implications

This study examined preschool teachers' intentions to adopt AR for science education through the lens of the UTAUT2. The findings demonstrate that all seven UTAUT2 constructs significantly influence behavioural intention, collectively explaining a substantial proportion of variance. These results confirm the applicability of the UTAUT2 framework within early childhood education and reveal important nuances in the operation of motivational and habitual constructs that reflect the developmental and pedagogical characteristics of preschool classrooms. By extending UTAUT2 to a context in which empirical evidence has been limited, this study contributes to a deeper theoretical understanding of technology acceptance in early childhood education while highlighting the potential of AR as a developmentally appropriate tool for supporting young children's scientific inquiry. At a practical level, the findings underscore the importance of pedagogically grounded professional development, accessible technological infrastructure, and supportive institutional environments that encourage teachers to explore innovative educational approaches. Importantly, the findings should be interpreted as indicating preschool teachers' readiness and motivational orientation towards adopting AR, rather than as evidence of confirmed or sustained classroom implementation. Although behavioural intention represents a meaningful and theoretically grounded indicator of adoption readiness, future research is needed to examine how these intentions translate into actual teaching practices over time. Taken together, the study suggests that when pedagogical value, perceived ease of use, institutional support, and teacher enjoyment converge, AR holds considerable promise for enriching science learning in early childhood settings and for shaping the ways in which young children explore and make sense of the natural world.

Ethical Approval

The study was conducted in accordance with institutional and ethical research standards. Participation was voluntary and informed consent was obtained from all participants.

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