Education and Information Technologies (2025) 30:17361–17403
https://doi.org/10.1007/s10639-025-13480-1

MANUSCRIPT

The convergence of GETAMEL and protection motivation theory: A study on augmented reality-based gamification adoption among science teachers

Hüseyin Ateş[1] · **Cengiz Gündüzalp**[2]

Received: 15 October 2024 / Accepted: 25 February 2025 / Published online: 11 March 2025
© The Author(s) 2025

Abstract

This study examines the determinants of science teachers' intentions to adopt augmented reality-based gamification through an integrated framework that merges the General Extended Technology Acceptance Model for E-Learning (GETAMEL) with Protection Motivation Theory. The research investigates how cognitive factors, including perceived usefulness and ease of use, interact with motivational constructs such as self-efficacy, anxiety, and perceived threats to influence adoption intentions. Furthermore, the study explores the moderating effect of professional status (pre-service vs. in-service teachers) to identify variations in adoption patterns. A structural equation modeling approach was employed to validate the proposed hypotheses using a diverse sample of 1,634 science teachers. The findings demonstrate that cognitive evaluations, motivational drivers, and social influences jointly shape teachers' intentions to adopt augmented reality-based gamification. Notably, in-service teachers show a stronger response to motivational factors, while pre-service teachers are more affected by perceived barriers. These results offer theoretical contributions to educational technology literature by integrating cognitive, motivational, and social perspectives. Additionally, the study provides practical recommendations for developing targeted professional development programs and strategies to foster augmented reality-based gamification adoption across diverse teaching contexts.

Keywords Augmented reality-based gamification · GETAMEL · Protection motivation theory · Technology adoption · Science teachers · Integrated theoretical framework

✉ Hüseyin Ateş
huseyin.ates@ahievran.edu.tr

[1] Department of Science Education, Kırşehir Ahi Evran University, Kırşehir, Turkey

[2] Department of Computer Technologies, Kazım Karabekir Vocational School of Technical Sciences, Kafkas University, Kars, Turkey

1 Introduction

The integration of digital technologies into science education has gained increasing attention for its potential to enhance student engagement and learning outcomes (Arici & Yilmaz, 2023). Among these technologies, Augmented Reality (AR) has emerged as a powerful tool, offering immersive learning experiences by superimposing digital information onto the real-world environment, thereby creating interactive and contextually rich educational settings (Barhorst et al., 2021). This potential is well-documented in studies by Hidayat and Wardat (2024) and Koumpouros (2024), who emphasize AR's ability to bridge the gap between theoretical knowledge and hands-on exploration. While AR enhances visualization and interactivity, its full pedagogical potential is realized when combined with gamification elements. Traditional AR applications may engage students through immersive simulations, but without structured incentives, challenges, and interactive goals, sustained motivation and deep cognitive engagement may be limited (Lampropoulos et al., 2022; Noreikis et al., 2019). Gamification addresses this gap by integrating game-based mechanics such as rewards, challenges, and progress tracking, which actively encourage participation and reinforce learning through goal-oriented experiences (Lampropoulos et al., 2023). When augmented with gamification strategies, AR transcends its conventional applications, evolving into what is termed AR-Based Gamification (AR-G). This innovative approach leverages game-like elements to create an interactive, engaging, and structured learning environment (Lampropoulos et al., 2023). As noted by Alptekin and Temmen (2020), AR-G not only enhances experiential learning but also fosters intrinsic motivation, making learning more dynamic and sustained. This integration proves particularly valuable in science education, where AR-G provides unparalleled opportunities for visualizing and manipulating complex, abstract scientific concepts (Alptekin & Temmen, 2020; Wang, 2022). By transforming abstract theories into interactive, problem-solving experiences, AR-G bridges conceptual gaps, enhances comprehension, and cultivates a deeper appreciation for scientific inquiry.

Despite the significant potential of AR-G in enhancing educational outcomes, its adoption within educational environments, particularly among science teachers, is shaped by a complex interplay of psychological and motivational factors. These factors are critical as science teachers are central to the effective integration of new technologies into classroom settings, thereby influencing students' learning experiences directly. Teachers' intentions to adopt new technologies are shaped by their beliefs, perceived benefits, and ease of integration, as explained by the General Extended Technology Acceptance Model for E-Learning (GETAMEL) framework (Ateş et al., 2024). Beyond these well-established factors, there is an increasing awareness of the role of other motivational elements such as perceived threats and coping mechanisms (Möller et al., 2022). These elements are derived from Protection Motivation Theory (PMT), which suggests that individuals' adoption behaviors are significantly influenced by their assessment of potential risks and their confidence in their ability to manage these risks (Maddux &

Rogers, 1983; Witte & Allen, 2000). Therefore, a comprehensive understanding of these motivational and psychological factors is not only pivotal for predicting and enhancing the adoption of AR-G by science teachers but also essential for developing targeted interventions that can effectively address these barriers. Such interventions could involve providing adequate training and resources, enhancing institutional support, and aligning technological implementations with teachers' professional needs and contexts. This approach ensures that the integration of AR-G into science education is not only technically feasible but also psychologically and motivationally supported, fostering a more conducive environment for innovative educational practices.

This study navigates the complex process of technology adoption in science education by utilizing the GETAMEL (Abdullah & Ward, 2016) alongside PMT (Rogers, 1975). Together, these frameworks offer a comprehensive perspective for understanding the psychological, cognitive, and practical factors that influence teachers' intentions to adopt AR-G. GETAMEL examines how variables such as perceived ease of use, usefulness, attitude, subjective norms, experience, enjoyment, anxiety, and self-efficacy impact teachers' technology adoption behaviors (Ateş et al., 2024). This framework highlights the usability and functional aspects of AR-G and provides insights into how these factors affect science teachers' readiness to incorporate such tools into their pedagogical practices. PMT complements this cognitive model by delving into the psychological and motivational dimensions involved in technology adoption (Ateş & Kölemen, 2025). It explains how perceived threats and coping mechanisms shape behavior, focusing on whether individuals are motivated to adopt protective behaviors when confronted with potential risks (Milne et al., 2000; Rogers, 1975). In the context of AR-G, PMT helps explore science teachers' perceptions of technological risks—such as the fear of falling behind in digital competencies—and their confidence in coping with the challenges posed by new technologies. Together, these theories provide a dual framework for understanding the multifaceted nature of technology adoption, merging cognitive considerations with psychological resilience and readiness to transition toward advanced gamified educational environments. This integrated approach allows the study to address both practical concerns and deeper motivational factors influencing science teachers' behavioral intentions.

By applying these frameworks, the research seeks to provide a richer understanding of the adoption dynamics of AR-G, which is critical for designing targeted professional development programs that align with the needs and perceptions of teachers. Factors such as technological obsolescence, enhanced student engagement, and improved learning outcomes are balanced against emotional dimensions like perceived severity, vulnerability, and the efficacy of coping strategies. Interventions that reduce perceived threats and enhance teachers' confidence in using AR-G are essential to promoting a smoother integration process and fostering long-term adoption of innovative technologies (Ateş & Kölemen, 2025; Mahmud et al., 2023). Through this lens, the research aims to provide actionable insights that can inform the development of professional support programs and educational policies, creating a conducive environment for the adoption of AR-G in science education.

This study also contributes to the literature by addressing the gap left by traditional cognitive models such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT 2) (Venkatesh et al., 2012). While these models emphasize beliefs about ease of use and usefulness, they often overlook emotional and motivational factors that influence teachers' decisions. The inclusion of PMT offers a novel perspective by integrating both cognitive and motivational elements, thereby bridging a critical gap in technology adoption literature. This dual focus enriches our understanding of how teachers balance the perceived benefits of AR-G with their psychological readiness to embrace it. This broader analytical scope provides essential insights into developing interventions that are sensitive not only to logistical challenges but also to the emotional and psychological needs of educators. The study outlines several key objectives, as detailed below.

1. To develop a unified framework by integrating elements from the GETAMEL and PMT frameworks, providing a comprehensive understanding of the factors influencing science teachers' intentions to adopt AR-G in educational settings.
2. To compare the predictive power of the combined GETAMEL and PMT model against each individual framework, verifying whether the integrated model offers superior explanatory capabilities.
3. To investigate the moderating roles of demographic factors, such as professional status (pre-service versus in-service teachers) on the relationships within the integrated theoretical model.
4. To determine the relative significance of each construct within the unified framework in shaping teachers' intentions to adopt AR-G, thus identifying the most influential enablers and barriers.

2 Literature review

2.1 Augmented reality in science education

Augmented reality (AR) has emerged as a transformative tool in science education, enhancing learning by integrating digital content into real-world environments (Ateş & Garzón, 2023). AR facilitates experiential learning, allowing students to interact with complex scientific concepts in ways that improve engagement and comprehension (Crandall et al., 2015; Ibáñez & Delgado-Kloos, 2018). By enabling three-dimensional visualization and virtual experimentation, AR helps learners explore topics such as molecular structures, planetary systems, and physics simulations without the limitations of traditional resources (Altmeyer et al., 2020; Aw et al., 2020).

A key advantage of AR is its ability to promote active learning through interactivity and curiosity-driven exploration, which increases motivation, engagement, and knowledge retention (Chen & Liu, 2020; Sáez-López et al., 2020). AR applications bridge the gap between theoretical knowledge and practical application, making abstract scientific concepts more tangible and accessible (Akçayır & Akçayır, 2017).

Additionally, its flexibility allows for personalized learning experiences, accommodating diverse student needs and supporting inclusive education (Iqbal et al., 2019, 2022).

Despite these benefits, several challenges hinder the widespread adoption of AR in science education. Technical limitations, device availability, and software compatibility pose significant barriers (Scaravetti & François, 2021). Furthermore, integrating AR into existing curricula requires teacher training and professional development, as educators may face difficulties adapting to the technology (Perifanou et al., 2022). The perceived complexity of AR tools can also discourage adoption, emphasizing the need for user-friendly interfaces and institutional support (Ateş, 2024). Addressing these challenges is crucial for maximizing the potential of AR in enhancing science education.

2.2 Gamification in science education

Gamification enhances science education by integrating game design elements—such as points, rewards, challenges, and feedback mechanisms—to increase motivation, engagement, and knowledge retention (Ateş & Kölemen, 2025; García-López et al., 2023). By leveraging intrinsic motivators (autonomy, mastery, social interaction) alongside extrinsic motivators (badges, leaderboards, competition), gamification fosters interactive learning experiences that encourage students to actively participate in educational activities (Lampropoulos & Kinshuk, 2024).

A significant advantage of gamification is its alignment with inquiry-based learning, where students explore, experiment, and solve problems in a low-risk, engaging environment (Pirker & Gütl, 2015; Srisawasdi & Panjaburee, 2019). Additionally, collaborative game-based activities promote teamwork and peer learning, reinforcing both academic and social development (Uz Bilgin & Gul, 2020). Real-time feedback mechanisms—such as progress tracking and performance indicators—allow students to monitor their learning and refine their understanding through continuous practice (Saleem et al., 2022; Zourmpakis et al., 2023).

Despite its benefits, effective gamification design requires careful planning to ensure that game elements enhance learning rather than serve as distractions (Toda et al., 2019). While competition can increase motivation, some students may feel discouraged by frequent comparisons (Sailer et al., 2017). Therefore, educators must balance engagement strategies with meaningful educational outcomes, ensuring that gamified learning environments support diverse student needs and learning styles.

2.3 The research model and hypotheses

This study integrates key constructs from GETAMEL and PMT to examine the psychological and behavioral factors influencing science teachers' adoption of AR-G. GETAMEL focuses on cognitive and social aspects, such as perceived usefulness, ease of use, and social influence, while PMT addresses motivational factors, including perceived risks and coping mechanisms. By combining these frameworks, the model offers a comprehensive perspective on technology adoption, evaluating how

teachers' perceptions of usability, risk, and efficacy shape their adoption decisions. The hypotheses derived from this model seek to validate these relationships, providing insights into strategies that support AR-G integration in science education.

2.3.1 GETAMEL framework

The GETAMEL framework, an extension of the Technology Acceptance Model (TAM), integrates psychological, social, and contextual factors to explain teachers' adoption of digital technologies in education (Abdullah & Ward, 2016). GETAMEL assesses perceived usefulness, ease of use, and social influence, providing a comprehensive perspective on how these factors shape adoption decisions, particularly in e-learning scenarios.

A key component of GETAMEL is subjective norms, referring to the perceived expectations of peers and institutional authorities regarding technology use. Research indicates that teachers who receive support from colleagues and administrators are more likely to adopt AR-G, as institutional encouragement fosters confidence and perceived value of the technology (Eksail & Afari, 2020; Venkatesh et al., 2003). Studies show that when school leaders actively promote AR and provide training, adoption rates increase significantly (Ateş & Garzón, 2023). This highlights the importance of peer and administrative support in reducing barriers to adoption and fostering a technology-embracing culture. Therefore, we hypothesize that:

H1: Subjective norms positively affect perceived usefulness of AR-G.
H2: Subjective norms positively affect perceived ease of use of AR-G.

Experience plays a crucial role in AR-G adoption, as familiarity with similar technologies enhances teachers' confidence and perceptions of usability. Prior exposure to educational technology fosters proficiency and comfort, making teachers more likely to integrate new tools (Zhang & Yang, 2024). Research indicates that teachers with successful past interactions with digital tools perceive them as more useful and easier to adopt. For instance, science teachers who previously implemented flipped learning reported greater ease in adapting to new instructional technologies, demonstrating how positive experiences facilitate technology integration (Ateş et al., 2024). Thus, we hypothesize:

H3: Experience positively affects the perceived usefulness of AR-G.
H4: Experience positively affects the perceived ease of use of AR-G.

Perceived enjoyment plays a crucial role in AR-G adoption, as teachers who find the technology engaging are more likely to integrate it into their classrooms. Enjoyment fosters positive attitudes, increasing perceptions of both usefulness and ease of use (FakhrHosseini et al., 2024). Research shows that teachers who enjoy using digital tools are more likely to adopt them consistently. For instance, educators using mobile learning environments reported that enjoyment enhanced

their willingness to use technology, reinforcing its long-term adoption (Ateş & Garzón, 2022). Building on this understanding, we hypothesize:

H5: Perceived enjoyment positively influences teachers' perceptions of the usefulness of AR-G.
H6: Perceived enjoyment positively influences the perceived ease of use of AR-G.

Anxiety presents a significant barrier to AR-G adoption, as teachers who perceive the technology as complex or difficult to implement may be less motivated to integrate it into their teaching (Granić, 2023). Research highlights that emotional reactions to new technologies negatively impact acceptance and usage, with teachers experiencing higher anxiety levels being less likely to adopt digital tools due to fears of inadequate mastery and failure (Hopcan et al., 2024; Zhang et al., 2023). These findings emphasize the role of emotional factors in shaping technology adoption decisions. Given these considerations, the following hypotheses are proposed:

H7: Anxiety negatively influences teachers' perceptions of the ease of use of AR-G.
H8: Anxiety negatively affects teachers' perceptions of the usefulness of AR-G.

Self-efficacy, or the belief in one's ability to successfully use technology, plays a critical role in AR-G adoption (Bandura, 1982). Teachers with high self-efficacy are more likely to perceive AR-G as beneficial and manageable, increasing their readiness to integrate it into their classrooms. Research shows that teachers with greater confidence in handling technology encounter fewer barriers and report higher ease of use and perceived usefulness (Anderson & Maninger, 2007; Zhi et al., 2024). This aligns with broader findings that self-efficacy strengthens both adoption intentions and perceptions of a technology's utility. Building on these insights, the study formulates the following hypotheses:

H9: Self-efficacy positively affects teachers' perceptions of the ease of use of AR-G.
H10: Self-efficacy positively influences teachers' perceptions of the usefulness of AR-G.

The GETAMEL framework highlights that perceived ease of use enhances perceived usefulness in technology adoption (Abdullah & Ward, 2016). In educational settings, science teachers who find AR-G intuitive and easy to implement are more likely to recognize its effectiveness in improving student engagement and learning outcomes. Research confirms that ease of use significantly influences perceptions of usefulness, reinforcing the role of usability in technology adoption (Al-Adwan et al., 2024; Ateş & Yilmaz, 2024; Dahri et al., 2024; Venkatesh & Davis, 2000). Building on these theoretical underpinnings, the study proposes the following hypotheses:

H11: Perceived ease of use of AR-G positively affects its perceived usefulness among science teachers.
H12: Perceived ease of use of AR-G positively influences teachers' attitudes towards its adoption.
H13: Perceived usefulness of AR-G positively affects teachers' attitudes towards its adoption.
H14: Perceived usefulness of AR-G positively affects teachers' intentions to adopt it.
H15: Positive attitudes towards AR-G significantly influence teachers' intentions to adopt it.

2.3.2 Protection motivation theory

PMT is a key framework for exploring the psychological processes that underpin the adoption of new technologies in education (Ateş & Kölemen, 2025). This approach considers two main components:

1. **Threat appraisal**: This includes perceptions of the severity and vulnerability associated with not using AR-G. The theory posits that if the consequences of not adopting AR-G are perceived as severe, teachers may be more motivated to adopt it. For example, teachers might perceive a significant risk in falling behind in technological advancements if they do not adopt new tools like AR-G. The sense of vulnerability, or the perceived likelihood of facing these negative outcomes, also plays a crucial role. This mirrors findings in studies like those by Al-Emran et al. (2023) and Arpaci (2023), where the perceived severity of not adopting safety measures in technology was crucial for readiness to adopt.
2. **Coping appraisal**

This component evaluates three key factors that influence teachers' adoption of AR-G: self-efficacy, response efficacy, and response cost.

- Self-efficacy refers to teachers' confidence in their own ability to successfully use AR-G in their instructional practices. A teacher with high self-efficacy believes they can integrate AR-G effectively, troubleshoot issues, and adapt the technology to their classroom needs. High self-efficacy reduces anxiety and increases willingness to experiment with new technologies. Studies such as Miraja et al. (2019) have demonstrated that self-efficacy plays a crucial role in shaping teachers' engagement with educational technologies.
- Response efficacy, on the other hand, concerns teachers' beliefs about the effectiveness of AR-G in achieving desired educational outcomes. This construct is not about the teacher's ability but rather about whether the technology itself is a worthwhile tool. Teachers with high response efficacy believe that using AR-G will enhance student engagement, improve comprehension of complex concepts, and lead to better learning outcomes. Even a teacher with high self-efficacy (con-

fidence in their own ability) may hesitate to adopt AR-G if they lack response efficacy, meaning they doubt its usefulness in actual classroom settings.

- Response cost refers to the perceived barriers associated with adopting AR-G, such as the time, effort, financial investment, and technical difficulties involved. Even when teachers have high self-efficacy (confidence in their ability) and high response efficacy (belief in AR-G's effectiveness), they may still hesitate to adopt AR-G if they perceive the costs of implementation to be too high. For example, if teachers believe that using AR-G requires extensive training, expensive equipment, or additional workload, their intention to adopt it may decrease.

By evaluating both the perceived risks and the ability to manage these risks, PMT provides a comprehensive framework for understanding the complex interplay of motivations behind technology adoption in educational settings (Ateş & Kölemen, 2025). This dual perspective allows for a detailed assessment of both the challenges and supports needed for successful technology integration in schools (Arpaci, 2023). This structured approach to PMT in the context of AR-G adoption among science teachers not only sheds light on the psychological dimensions of technology adoption but also highlights potential interventions to enhance the integration of innovative technologies in education (Al-Emran et al., 2023). By understanding the specific fears and motivations of teachers, educational policymakers and administrators can better tailor support mechanisms to encourage the effective use of AR-G in enhancing science education. Since self-efficacy is a shared construct in both the GETAMEL and PMT frameworks, it is covered under hypotheses H9 and H10 to avoid repetition, as detailed in subsection 2.3.1. Meanwhile, the hypotheses concerning perceived vulnerability, perceived severity, response efficacy, and response costs are specified below:

H16: Increased perceived vulnerability to the risks associated with not adopting AR-G will enhance the intention to adopt AR-G technologies.
H17: Higher perceived severity of potential negative outcomes from not integrating AR-G into educational practices will increase the intention to adopt it.
H18: Higher response efficacy, perceived as the effectiveness of AR-G for enhancing teaching and learning outcomes, will positively influence teachers' adoption intentions.
H19: Lower response costs associated with adopting AR-G will lead to higher adoption intentions.

Figure 1 visually represents the integration of GETAMEL and PMT, illustrating how these frameworks shape science teachers' intentions to adopt AR-G. The model highlights the influence of perceived ease of use, usefulness, and social factors from GETAMEL, alongside threat and coping appraisals from PMT, providing a comprehensive view of the psychological, social, and technological factors driving adoption decisions. This diagram clarifies the interplay between cognitive and motivational factors, offering insights into the complex decision-making process behind AR-G integration in education.

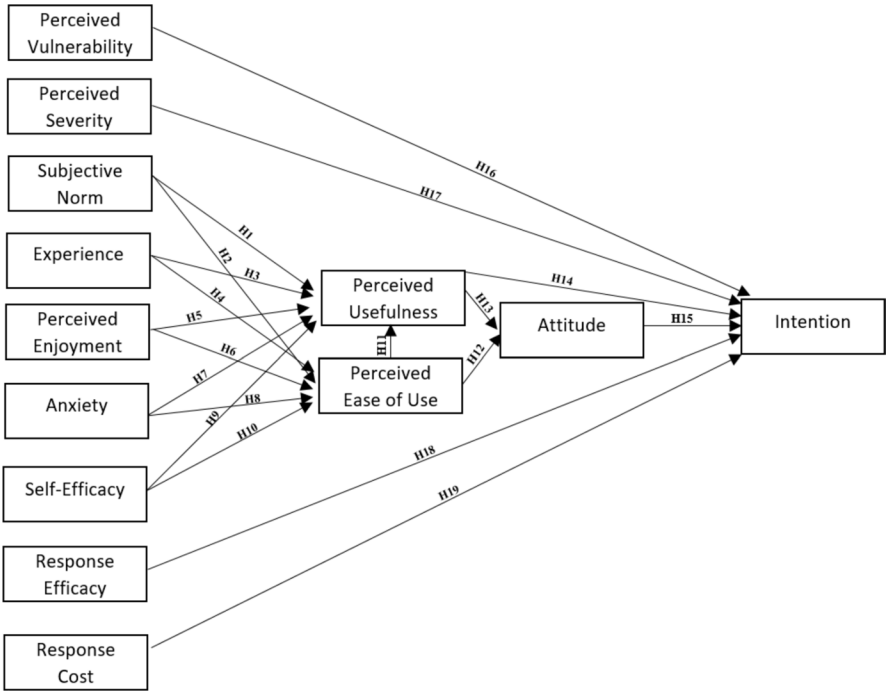


Fig. 1 Unified framework including hypotheses for AR-G adoption, incorporating GETAMEL and PMT models

3 Method

3.1 Data collection process

In this study, data collection was meticulously structured to ensure comprehensive engagement with science educators regarding the adoption of AR-G in their teaching practices. The process began with a detailed orientation session, where participants were introduced to the foundational aspects of AR-G technology. This session emphasized the practical applications of AR-G in science education. Participants were provided with comprehensive guidance on the technical requirements and operational features of AR-G, ensuring they had a clear understanding of its functionalities before engaging in hands-on activities.

Following the orientation, a series of interactive workshops and classroom-based implementation sessions were conducted. These workshops were designed not only to familiarize teachers with AR-G tools but also to provide practical training on integrating these tools into their existing curricula. Importantly, the workshops were carried out in two settings: controlled training environments where teachers experimented with AR-G individually, and dynamic classroom environments where they applied AR-G in real-time with students. This dual

approach allowed for a comprehensive examination of how AR-G is perceived both in theoretical training and in practical application.

In the classroom implementation sessions, teachers integrated AR-G activities into their lessons, allowing students to engage with the gamified augmented reality tools in an authentic learning environment. The impact of AR-G was observed in live classroom interactions, providing insights into its real-world feasibility, student engagement levels, and potential challenges in implementation. Teachers documented their experiences, noting student responses, technical challenges, and instructional benefits.

To facilitate deeper learning and ensure sustainability, participants were provided with user manuals, video tutorials, and lesson plan templates that aligned with science curricula. To further support teachers, a structured feedback system was established, including surveys, focus group discussions, and post-implementation reflections. This allowed educators to share their experiences, discuss classroom-specific challenges, and suggest refinements for AR-G integration.

Moreover, case studies showcasing successful AR-G adoption in science education were shared with participants, serving as both motivational examples and practical references for overcoming barriers. To monitor the long-term feasibility of AR-G adoption, follow-up sessions were conducted, where teachers reported on their sustained use of AR-G and any modifications they had made to better suit their teaching contexts.

By incorporating both individual training and real-world classroom implementation, this study ensured that the collected data reflected both theoretical adoption intentions and practical classroom realities. This approach strengthened the validity of findings related to teachers' willingness to integrate AR-G, potential barriers in real teaching settings, and the overall effectiveness of AR-G in enhancing science education.

3.2 Gamification in AR-G implementation

This study examines the structured integration of gamification principles within Augmented Reality Gamification (AR-G) to enhance interaction and engagement in science education. The gamification elements embedded in AR-G serve as structured mechanisms to guide teachers through interactive learning tasks, reinforcing ease of use, response efficacy, and adoption feasibility. Rather than focusing on motivation, these game-based features support teachers in navigating AR-G effectively, aligning with key constructs from the GETAMEL and PMT frameworks.

3.3 Game elements integrated in AR-G

To ensure effective implementation, the AR-G platform incorporates several structured game elements that facilitate engagement, interaction, and practical adoption (Awan et al., 2022; Dreimane, 2024; Predescu & Mocanu, 2024; Λαμπρόπουλος et al., 2022):

- **Structured task progression:** Teachers engage in a step-by-step learning pathway where they progressively interact with AR-based simulations, ensuring gradual adaptation to the technology.
- **Points and unlockable features:** Teachers earn points by completing AR-driven science experiments and quizzes, progressively unlocking advanced features. This reinforces response efficacy, demonstrating the practical utility of AR-G in real classroom scenarios.
- **Scenario-based challenges:** Teachers participate in subject-specific challenges such as "Visualizing the Carbon Cycle in AR" or "Balancing Chemical Equations through Virtual Manipulation," aligning with science curriculum requirements.
- **Interactive progress tracking:** A real-time dashboard provides performance analytics, allowing teachers to monitor their AR-G integration proficiency and identify areas for improvement.
- **Collaborative lesson planning tasks:** Teachers collaborate in designing an AR-enhanced science lesson, promoting peer-supported adoption and knowledge exchange.

3.4 Tasks and challenges in AR-G implementation

The AR-G system presents structured tasks tailored to pre-service and in-service teachers, addressing technology adoption concerns such as usability, effort expectancy, and response costs. Examples include:

- **AR-driven science simulations:** Teachers interact with dynamic, immersive AR models (e.g., molecular structures, planetary systems) to explore scientific concepts in real-time.
- **Real-world teaching scenarios:** Participants engage in decision-making activities, selecting the most effective AR-G teaching strategies based on classroom dynamics and student needs.
- **Timed problem-solving missions:** AR-G presents time-sensitive challenges, such as troubleshooting an AR experiment or adapting an AR lesson for students with different learning paces.
- **Peer collaboration and reflection:** Teachers participate in a shared AR-G experience, discussing best practices, technical barriers, and instructional strategies in a structured reflection process.

3.5 Alignment with theoretical frameworks

This structured gamification-driven AR-G approach directly aligns with the study's unified GETAMEL-PMT framework:

- Perceived Ease of Use & Response Efficacy → Interactive tasks gradually enhance teachers' confidence in AR-G integration.

- Perceived Response Cost Reduction → Structured task progression minimizes complexity concerns, ensuring accessibility.
- Social Influence & Subjective Norms → Collaboration features facilitate peer-supported adoption, reinforcing subjective norms.

By embedding structured game-based elements, AR-G provides a guided, interactive pathway for teachers to engage with technology in practical classroom settings. This approach reinforces usability, reduces adoption barriers, and supports informed decision-making, aligning with the study's objectives of exploring key adoption constructs and their predictive power.

3.6 Participants

Data collection spanned four months (January–July 2024) using a structured questionnaire. We purposively sampled in-service and pre-service science teachers from diverse urban and suburban areas in Türkiye to ensure representativeness. Prior to participating, teachers received detailed information sheets and informed consent forms, outlining the purpose, procedures, and ethical considerations of the study. Participants were assured of the voluntary nature of their involvement and the confidentiality of their responses.

A total of 1,800 questionnaires were distributed, with 1,712 returned, achieving an impressive response rate of 95.1%. After data screening, 1,634 valid responses were included in the final analysis. The sample consisted of 952 in-service science teachers and 682 pre-service science teachers, ensuring a balanced representation of both experienced educators and future teaching professionals. Among the respondents, 1,022 were female and 612 were male, reflecting the gender distribution typical within education fields.

In-service teachers spanned across age ranges, with 72% falling between 30 and 45 years old. Notably, 31% held advanced degrees, and 18% had prior experience incorporating AR-based tools in their teaching. Pre-service teachers were primarily third- and fourth-year students enrolled in science education programs at various universities. Of these, 21% were male, and 74% expressed enthusiasm about adopting AR-G in their future teaching, demonstrating a progressive outlook toward educational technology. A majority (67%) indicated prior exposure to digital teaching tools through their coursework.

To support teachers' ability to integrate AR-G effectively, a professional development component was incorporated. In-service teachers participated in structured workshops conducted over three months, with bi-weekly sessions lasting 2.5 h each, totaling 15 h of training. The training included hands-on demonstrations, classroom integration strategies, and troubleshooting exercises to address teachers' concerns. Pre-service teachers received a modified version of the training embedded within their university coursework, spanning six weeks with weekly 1.5-h sessions, focusing on pedagogical applications and classroom management strategies for AR-G.

The variation in professional development duration and intensity across participant groups may have influenced the results. In-service teachers, benefiting from

more extensive training and peer collaboration, may have demonstrated higher confidence and response efficacy in adopting AR-G. Conversely, pre-service teachers, with a more limited training duration, may have exhibited greater concerns related to technical complexity and classroom implementation. Future studies should explore the long-term effects of varying professional development structures, assessing how different training models influence sustained AR-G adoption in real classroom settings.

This sample size exceeds the recommended threshold for statistical power, ensuring the robustness of our analyses. With 32 items in our survey, following Kline's (2011) guideline of 10 participants per item, a minimum of 320 participants was necessary. Our final sample of 1,634 respondents comfortably surpasses this requirement, providing a strong foundation for meaningful statistical insights.

3.7 Measures

The data collection tools for this study were meticulously developed by integrating constructs from both the GETAMEL and the PMT, ensuring comprehensive measurement of the factors influencing teachers' intentions to adopt AR-G in science education. The construction process began with an in-depth review of the relevant literature to identify validated scales aligned with the conceptual frameworks (e.g., Abdullah et al., 2016; Al-Emran et al., 2023; Ateş & Kölemen, 2025; Ateş et al., 2024; Davis, 1989). Each item was designed or adapted to reflect the specific educational context of AR-G adoption, capturing both cognitive and motivational drivers. To ensure content validity and contextual alignment, the preliminary version of the instrument was evaluated by five domain experts—representing science education, instructional technology, and educational psychology. The feedback received prompted minor modifications to the wording of certain items, enhancing their clarity and applicability for teachers in Türkiye. To further validate the items, the questionnaire was translated from English to Turkish using a double-blind translation-back-translation method (Esfandiar et al., 2020), ensuring semantic equivalence across languages.

The instrument underwent a pilot study involving 270 in-service and 120 pre-service science teachers. This phase was essential for testing reliability and internal consistency. The pilot results yielded strong Cronbach's alpha values demonstrating high reliability across constructs. Problematic items were refined or removed based on statistical feedback to enhance the overall robustness of the instrument.

The final questionnaire integrated constructs from both GETAMEL and PMT, capturing cognitive, social, and motivational factors influencing AR-G adoption.

- GETAMEL constructs focused on cognitive and usability aspects, including perceived ease of use (how simple AR-G is to use), perceived usefulness (its expected benefits), perceived enjoyment (the pleasure derived from using it), subjective norms (social influence), experience (prior exposure to technology), anxiety (concerns about using AR-G), and self-efficacy (confidence in personal ability).

- PMT constructs addressed motivational and risk-related perceptions, including perceived severity (importance of adopting AR-G), perceived vulnerability (risk of falling behind without it), response efficacy (belief that AR-G improves learning outcomes), and response cost (time, effort, and resources needed for adoption).

All items were measured on a 7-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (7), enabling the assessment of teachers' agreement with each statement. In total, the instrument included 32 items, distributed equally across the constructs from the GETAMEL and PMT frameworks. These items were designed to capture both cognitive and motivational factors influencing teachers' intentions to adopt AR-G in science teaching. For example, items under Perceived Ease of Use included: "*I find AR-G easy to use for teaching science*" and "*It is easy for me to become skilled in using AR-G for science teaching*". Similarly, Perceived Usefulness was assessed with statements such as "*Using AR-G for science teaching is useful for my instructional goals.*" and "*Integrating AR-G enhances my teaching effectiveness.*". Motivational constructs from PMT were also included. For instance, Perceived Severity featured items like: "*I believe that not using AR-G may hinder students' engagement in science education.*". Perceived Vulnerability explored statements such as "*There is a risk of missing out on innovative teaching practices without AR-G*". Response Efficacy assessed teachers' belief in AR-G's benefits with items like "*The use of AR-G can prevent disengagement and improve student performance*", while Response Costs included statements such as "*Implementing AR-G requires significant time and effort*". For further details, see the full list of constructs and their items in Table 1.

3.8 Data analysis

The data analysis for this study was conducted using SPSS version 27 for descriptive statistics and reliability testing, along with AMOS version 24 for structural equation modeling (SEM) to evaluate the theoretical model comprehensively. The analysis commenced with a preliminary exploration of the descriptive statistics, examining the mean, standard deviation, and response distribution across the dataset. This helped identify patterns in the data, allowing for a better understanding of participants' perceptions regarding AR-G adoption in science education.

Next, a confirmatory factor analysis (CFA) was carried out using AMOS to assess the measurement model's structure, ensuring that the observed items appropriately reflected the latent constructs within the GETAMEL and PMT frameworks. Reliability analysis was conducted by calculating Cronbach's alpha for each construct, yielding values between 0.79 and 0.89, surpassing the threshold of 0.70, thereby indicating strong internal consistency.

To further validate the instrument, we assessed convergent validity. Composite reliability (CR) values ranged between 0.79 and 0.90, while factor loadings exceeded the recommended minimum of 0.60. The average variance extracted (AVE) values for all constructs ranged from 0.58 to 0.75, exceeding the minimum threshold of

Table 1 Constructs and items for assessing teachers' intentions to use AR-G in science education

Constructs and items	FL	AVE	CR	α	M	SD
Perceived Ease of Use (Davis, 1989; Nikou & Economide, 2017)		0.66	0.85	0.80	4.82	1.15
I find AR-G easy to use for teaching science	0.83					
It is easy for me to become skilled in using AR-G for science teaching	0.79					
My interactions with AR-G during science teaching are clear and understandable	0.81					
Perceived Usefulness (Davis, 1989; Nikou & Economide, 2017)		0.72	0.88	0.81	4.90	1.21
Using AR-G for science teaching is useful for my instructional goals	0.85					
Integrating AR-G enhances my teaching effectiveness	0.82					
AR-G improves my students' engagement and learning outcomes	0.87					
Perceived Enjoyment (Lu et al., 2009; Moon & Kim, 2001)		0.69	0.87	0.89	4.95	1.14
I find using AR-G for science teaching enjoyable	0.86					
Using AR-G makes science teaching more fun for me	0.83					
Teaching with AR-G makes me feel happy and fulfilled	0.81					
Anxiety (Zhai & Ma, 2022)		0.58	0.81	0.85	4.65	1.18
I feel apprehensive about using AR-G for science teaching	0.78					
It worries me that I might make mistakes I cannot correct while using AR-G	0.75					
The idea of using AR-G for science teaching feels somewhat intimidating	0.76					
Experience (Abdullah et al., 2016)		0.69	0.87	0.87	5.10	1.19
I enjoy using AR-G in my teaching activities	0.84					
I feel comfortable incorporating AR-G into science lessons	0.82					
I am comfortable using technology when applying AR-G for science teaching	0.83					
Self-efficacy (Salloum et al., 2019)		0.75	0.90	0.87	5.00	1.20
I feel confident using AR-G for science teaching, even without assistance	0.88					
I have sufficient skills to integrate AR-G into my science lessons	0.85					
I am confident in my ability to effectively use AR-G for teaching science	0.87					
Attitude (Lu et al., 2009; Taylor & Todd, 1995)		0.68	0.87	0.86	4.85	1.17
Using AR-G for science teaching is a good idea	0.83					

Table 1 (continued)

Constructs and items	FL	AVE	CR	α	M	SD
I like the idea of using AR-G to teach science	0.81					
Teaching with AR-G would be enjoyable and rewarding for me	0.84					
Subjective Norm (Ajzen, 2006; Lu et al., 2009; Taylor & Todd, 1995)		0.65	0.79	0.79	4.72	1.23
People who are important to me think that I should use AR-G for science teaching	0.79					
People who influence my behavior encourage me to use AR-G in my science classes	0.82					
Perceived Severity (Al-Emran et al., 2023; Ateş & Kölemen, 2025)		0.61	0.83	0.88	4.80	1.15
I believe that not using AR-G may hinder students' engagement in science education	0.77					
I think the absence of AR-G in my teaching might lead to less effective learning	0.78					
Not adopting AR-G could reduce the overall effectiveness of my science instruction	0.80					
Perceived Vulnerability (Al-Emran et al., 2023; Ateş & Kölemen, 2025)		0.62	0.83	0.87	4.76	1.16
I feel my teaching effectiveness could decline if I don't integrate AR-G	0.76					
I believe my students might fall behind without exposure to AR-G-based learning	0.79					
There is a risk of missing out on innovative teaching practices without AR-G	0.81					
Response Efficacy (Al-Emran et al., 2023; Ateş & Kölemen, 2025)		0.72	0.89	0.86	4.92	1.20
I am confident that AR-G will significantly enhance my teaching outcomes	0.84					
The use of AR-G can prevent disengagement and improve student performance	0.85					
AR-G offers the most effective solution for enhancing science education	0.86					
Response Cost (Al-Emran et al., 2023; Ateş & Kölemen, 2025)		0.60	0.82	0.85	4.70	1.22
Implementing AR-G requires significant time and effort investments	0.77					
The cost of using AR-G in science teaching is reasonable considering the benefits	0.79					
Upgrading resources to use AR-G may pose financial challenges	0.76					
Intention to Use AR-G (Ajzen, 2006; Davis, 1989; Nikou & Economide, 2017)		0.72	0.89	0.89	5.05	1.18
I will use AR-G for teaching science in the future	0.85					
I plan to integrate AR-G into my science lessons	0.84					
I intend to experiment with AR-G to enhance my science teaching practices	0.86					

FL Factor loadings; *AVE* Average variance extracted; *CR* Composite reliability; *α* Cronbach alpha; *M* Mean; *SD* Standard deviation

0.50. This indicates that the constructs accounted for a significant proportion of the variance in the data, demonstrating adequate convergent validity (Fornell & Larcker, 1981; Ruvio et al., 2008). Discriminant validity was verified by ensuring that the square root of the AVE for each construct was greater than the correlations between the constructs, following the Fornell and Larcker (1981) criterion.

The structural model was tested using SEM to evaluate the relationships between constructs within the integrated framework. Multiple fit indices were employed to assess the model's goodness-of-fit, including the Chi-square to degrees of freedom ratio (χ^2/df = 2.31), Comparative Fit Index (CFI = 0.95), Tucker-Lewis Index (TLI = 0.94), Goodness of Fit Index (GFI = 0.93), and Root Mean Square Error of Approximation (RMSEA = 0.048). These values indicated an acceptable fit of the model to the data (Browne & Cudek, 1992; Hair et al., 1986).

Detailed results and statistical outputs are presented in Tables 1 and 2, offering a comprehensive view of the relationships between constructs, as outlined in the unified framework presented in Fig. 1.

4 Findings

4.1 Evaluating model fit and predictive strength of the integrated framework

This study integrates constructs from GETAMEL and PMT to explore science teachers' intentions to adopt AR-G in science education. Both frameworks contribute uniquely to the explanation of behavioral intention, with GETAMEL offering

Table 2 Descriptive statistics and discriminant validity for science teachers

Constructs	1	2	3	4	5	6	7	8	9	10	11	12	13
1. PEOU	**0.81**												
2. PU	0.52	**0.85**											
3. PE	0.45	0.48	**0.83**										
4. ANX	0.41	0.42	0.44	**0.76**									
5. EXP	0.39	0.50	0.51	0.47	**0.83**								
6. SE	0.47	0.53	0.50	0.48	0.56	**0.87**							
7. ATT	0.48	0.51	0.49	0.45	0.54	0.58	**0.82**						
8. SN	0.50	0.49	0.52	0.46	0.55	0.56	0.59	**0.81**					
9. PS	0.43	0.44	0.46	0.42	0.47	0.52	0.50	0.53	**0.78**				
10. PV	0.44	0.46	0.47	0.45	0.48	0.51	0.52	0.55	0.56	**0.79**			
11. RE	0.42	0.43	0.44	0.41	0.46	0.53	0.50	0.54	0.55	0.56	**0.85**		
12. RC	0.40	0.42	0.45	0.43	0.44	0.49	0.48	0.50	0.52	0.51	0.53	**0.77**	
13. INT	0.50	0.51	0.53	0.47	0.49	0.54	0.55	0.56	0.57	0.55	0.56	0.54	**0.85**

The bold values represent $\sqrt{\text{AVE}}$ ($p < 0.01$). *PEOU* Perceived ease of use; *PU* Perceived usefulness; *PE* Perceived enjoyment; *ANX* Anxiety; *EXP* Experience; *SE* Self-efficacy; *ATT* Attitude; *SN* Subjective norm; *PS* Perceived severity; *PV* Perceived vulnerability; *RE* Response efficacy; *RC* Response cost; *INT* Intention to use AR-G

insights into cognitive and usability factors, and PMT emphasizing psychological and motivational aspects. Combining these frameworks into a unified model provides a more holistic perspective on AR-G adoption.

To determine the effectiveness of the models, we compared the explanatory power of three: the GETAMEL model, the PMT model, and the integrated model encompassing both frameworks. SEM was employed to assess model fit, with results indicating that all three models achieved acceptable indices based on the standards proposed by Bagozzi and Yi (2012) and Browne and Cudeck (1993). However, the integrated model outperformed the individual models. Specifically, the integrated framework displayed the best χ^2/df ratio (χ^2/df = 2.43), surpassing the GETAMEL model (χ^2/df = 2.66) and the PMT model (χ^2/df = 2.71).

The integrated model also exhibited stronger predictive power, with an R^2 value of 0.54, compared to 0.46 for the GETAMEL model and 0.41 for the PMT model. This suggests that the combination of cognitive, social, and motivational factors provides a more nuanced understanding of science teachers' intentions to adopt AR-G. By capturing both the ease of use and perceived usefulness alongside motivational constructs such as response efficacy and vulnerability, the integrated model offers a well-rounded framework for analyzing technology adoption in educational settings. A detailed comparison of the model fit and predictive strength is provided in Table 3.

4.2 Path analysis and hypothesis testing in AR-G adoption

This section presents the results of the path analysis conducted to assess the theoretical relationships outlined in the GETAMEL and PMT frameworks. The path analysis aimed to explore the factors influencing science teachers' intentions to adopt AR-G in their teaching practices.

4.2.1 Path analysis for GETAMEL

The findings reveal that Subjective Norm exert a positive influence on both Perceived Usefulness ($\beta = 0.39$, $p < 0.01$) and Perceived Ease of Use ($\beta = 0.37$, $p < 0.01$). These results underscore the importance of social influence from peers and administrators in shaping teachers' perceptions of AR-G's value and ease of integration. Teachers are more inclined to view AR-G positively when they feel socially supported in their use of the technology. The study also highlights the role of Experience, showing a significant positive impact on both Perceived Usefulness ($\beta = 0.32$, $p < 0.01$) and Perceived Ease of Use ($\beta = 0.35$, $p < 0.01$). Prior exposure to similar technologies fosters comfort and confidence, making teachers more likely to perceive AR-G as both useful and manageable in their teaching practices. Similarly, Perceived Enjoyment was found to positively influence Perceived Usefulness ($\beta = 0.37$, $p < 0.01$) and Perceived Ease of Use ($\beta = 0.36$, $p < 0.01$). Teachers who find AR-G enjoyable are more motivated to adopt it, perceiving the technology as both valuable and easy to use. Conversely, Anxiety was negatively associated with Perceived Ease of Use ($\beta = -0.33$, $p < 0.01$) and Perceived Usefulness ($\beta = -0.29$, $p < 0.01$). Teachers with

Table 3 Comparison of model fit indices and predictive strength

Model	χ^2/df	R^2	χ^2	df	NFI	IFI	TLI	CFI	RMSEA	SRMR
Integrated Model	2.43	0.54	395.42	163	0.95	0.94	0.93	0.96	0.05	0.04
GETAMEL Model	2.66	0.46	412.35	155	0.92	0.91	0.92	0.93	0.06	0.06
PMT Model	2.71	0.41	450.12	166	0.91	0.90	0.90	0.91	0.07	0.06

higher levels of anxiety toward AR-G are more likely to see it as challenging to use and less effective in improving learning outcomes. The analysis further indicates that Self-Efficacy positively influences both Perceived Ease of Use ($\beta = 0.43$, $p < 0.01$) and Perceived Usefulness ($\beta = 0.40$, $p < 0.01$). Teachers with high self-efficacy are more confident in their ability to use AR-G, which strengthens their perception of the technology's usability and effectiveness. Moreover, Perceived Ease of Use was found to have a significant effect on both Perceived Usefulness ($\beta = 0.46$, $p < 0.01$) and Attitude ($\beta = 0.44$, $p < 0.01$). Teachers who find AR-G straightforward to use are more likely to develop positive attitudes and view it as beneficial for their teaching. Additionally, Perceived Usefulness significantly influenced Attitude ($\beta = 0.50$, $p < 0.01$) and Intention to Use AR-G ($\beta = 0.51$, $p < 0.01$). This indicates that teachers who perceive AR-G as useful are more inclined to develop favorable attitudes and intentions toward its adoption. Finally, Attitude was found to have a strong positive effect on Intention to Use AR-G ($\beta = 0.52$, $p < 0.01$). Teachers with positive attitudes are more likely to integrate AR-G into their instructional practices. The relationships among these constructs are visually summarized in Fig. 2.

4.2.2 Path analysis for PMT

The findings show that Perceived Vulnerability positively influences teachers' Intention to Use AR-G ($\beta = 0.37$, $p < 0.01$). Teachers who feel that their instructional effectiveness could decline without adopting AR-G are more motivated to integrate the technology. This suggests that teachers are aware of the risks of falling behind without incorporating innovative tools into their teaching practices. Similarly, Perceived Severity was found to have a significant positive impact on Intention to Use AR-G ($\beta = 0.39$, $p < 0.01$). Teachers who believe that the absence of AR-G in their science classrooms could negatively affect student learning outcomes are more likely to adopt the technology. These findings emphasize the role of risk perception in motivating technology adoption. The analysis also indicates that Response Efficacy exerts a strong positive influence on Intention to Use AR-G ($\beta = 0.46$, $p < 0.01$). Teachers who are confident that AR-G will enhance student engagement and improve learning outcomes are more inclined to adopt it. This highlights the importance of demonstrating the educational benefits of AR-G to increase teachers' confidence in its effectiveness. In contrast, Response Costs show a negative association with Intention to Use AR-G ($\beta = -0.32$, $p < 0.01$). Teachers who perceive that the time, effort, or financial investments required to implement AR-G are manageable are more likely to adopt the technology. Finally, self-efficacy has a strong influence on Intention to Use AR-G ($\beta = 0.41$, $p < 0.01$).

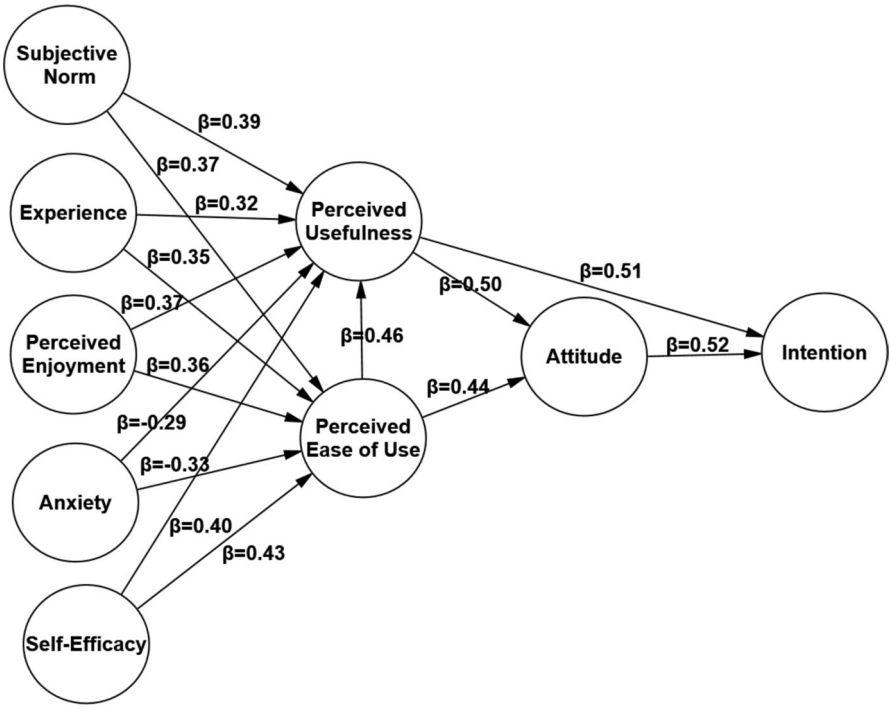


Fig. 2 Path Analysis Results of the GETAMEL Framework

These results reveal key differences in how cognitive and motivational factors drive AR-G adoption. Perceived Vulnerability and Perceived Severity emphasize the role of risk awareness, as teachers are primarily motivated by concerns about the potential negative consequences of not integrating AR-G into their instructional practices. Teachers who perceive themselves as vulnerable to falling behind in technological advancements or who believe that the absence of AR-G could negatively impact student learning outcomes are more likely to adopt the technology. Similarly, Response Efficacy and Self-Efficacy both contribute to confidence-building, but they differ in their focus. Self-Efficacy pertains to a teacher's personal belief in their ability to use AR-G effectively, including their skills and capacity to integrate it into teaching. In contrast, Response Efficacy refers to teachers' belief in AR-G's effectiveness as an educational tool, specifically its potential to enhance student engagement and improve learning outcomes. Even teachers with high self-efficacy may hesitate to adopt AR-G if they lack confidence in its overall impact on teaching and learning. On the other hand, Response Cost acts as a barrier to adoption by influencing teachers' cost–benefit perceptions. Even if teachers recognize AR-G as beneficial, they may be discouraged from using it if they perceive the required time, effort, or financial investment as excessive. High implementation costs, technological complexity, or resource constraints can limit the likelihood of AR-G adoption, even among those who view it as effective. Overall, these findings suggest that a combination of risk perception, confidence, and cost–benefit considerations influences

teachers' willingness to adopt AR-G. While risk awareness and confidence encourage adoption, perceived costs may act as deterrents. The relationships among these constructs and their contributions to the adoption of AR-G are visually represented in Fig. 3.

4.2.3 Path analysis for integrated model

The integrated model, which combines constructs from both the GETAMEL and PMT frameworks, offers a comprehensive analysis of the factors influencing science teachers' intentions to adopt AR-G. This section presents the results of the path analysis testing all 19 hypotheses simultaneously, demonstrating the enhanced explanatory power and predictive strength of the integrated model over the individual frameworks. The results indicate that Subjective Norms positively affect both Perceived Usefulness ($\beta = 0.43$, $p < 0.01$) and Perceived Ease of Use ($\beta = 0.41$, $s < 0.01$), confirming H1 and H2. Teachers feel encouraged by colleagues and administrators to use AR-G, perceiving it as both valuable and easy to implement. Additionally, Experience positively influences Perceived Usefulness ($\beta = 0.37$, $p < 0.01$) and Perceived Ease of Use ($\beta = 0.39$, $p < 0.01$), supporting H3 and H4. Familiarity with similar technologies enhances teachers' comfort and belief in the practicality of AR-G. Perceived Enjoyment also plays a significant role, positively impacting Perceived Usefulness ($\beta = 0.40$, $p < 0.01$) and Perceived Ease of Use ($\beta = 0.38$, $p < 0.01$), validating H5 and H6. Teachers who enjoy using AR-G perceive it as both beneficial and manageable. Conversely, Anxiety negatively influences Perceived Usefulness ($\beta = -0.36$, $p < 0.01$) and Perceived Ease of Use ($\beta = -0.31$, $p < 0.01$), confirming H7 and H8. This suggests that reducing anxiety is crucial for promoting AR-G adoption. The findings further reveal that Self-Efficacy positively affects both Perceived Usefulness ($\beta = 0.47$, $p < 0.01$) and Perceived Ease of Use ($\beta = 0.45$, $p < 0.01$), supporting H9 and H10. Teachers with high self-confidence are more inclined to see AR-G as easy to use and effective in achieving educational goals. Moreover, Perceived Ease of Use has a strong influence on Perceived Usefulness ($\beta = 0.50$, $p < 0.01$) and Attitude ($\beta = 0.48$, $p < 0.01$), confirming H11 and H12. Teachers who find AR-G easy to use develop positive attitudes toward its adoption. The analysis also confirms the relationships between Perceived Usefulness, Attitude, and Intention to Use AR-G. Perceived Usefulness significantly influences both Attitude ($\beta = 0.53$, $p < 0.01$) and Intention ($\beta = 0.55$, $p < 0.01$), validating H13 and H14. Furthermore, Attitude has a substantial positive effect on Intention to Use AR-G ($\beta = 0.57$, $p < 0.01$), supporting H15. Teachers with favorable attitudes are more likely to integrate AR-G into their teaching practices. From the PMT framework, Perceived Vulnerability positively influences Intention to Use AR-G ($\beta = 0.41$, $p < 0.01$), confirming H16. Teachers who feel their effectiveness may decline without adopting AR-G are more motivated to use it. Similarly, Perceived Severity has a positive impact on Intention ($\beta = 0.44$, $p < 0.01$), validating H17. Teachers who recognize the negative outcomes of not using AR-G are more inclined to adopt the technology. Response Efficacy significantly affects Intention ($\beta = 0.49$, $p < 0.01$), supporting H18. Teachers who believe in the effectiveness of AR-G to enhance learning outcomes are more motivated to integrate it. Conversely, Response Costs show a negative association with Intention

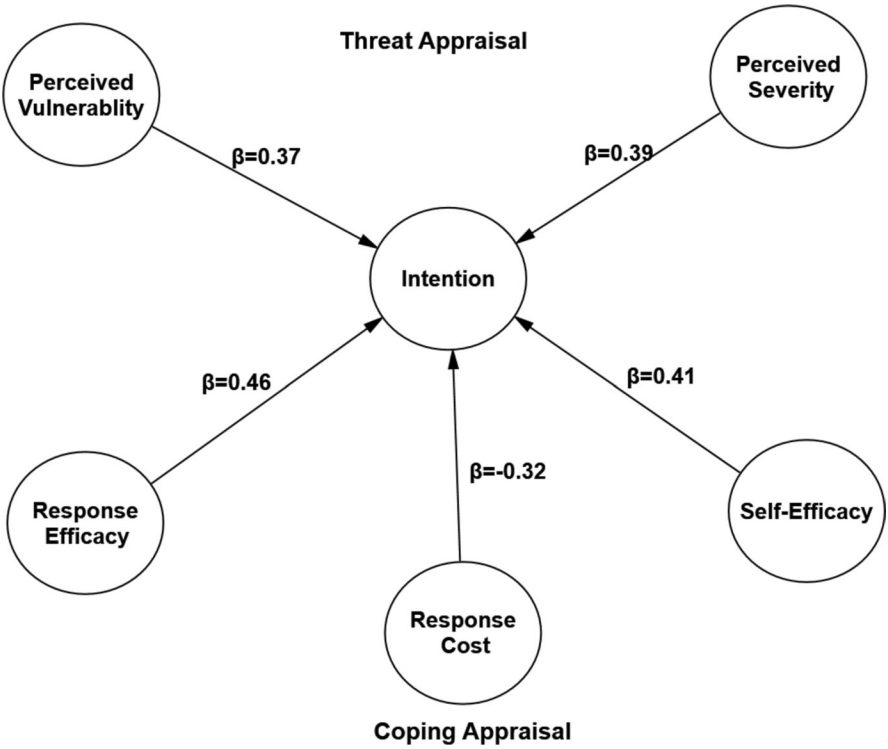


Fig. 3 Path analysis results of the PMT framework

to Use AR-G ($\beta = -0.35$, $p < 0.01$), confirming H19. Teachers who perceive fewer obstacles in terms of time, effort, or financial resources are more likely to adopt the technology. The integrated model exhibits the highest explanatory power, with an R^2 value of 0.54, surpassing both the GETAMEL model ($R^2 = 0.46$) and the PMT model ($R^2 = 0.41$).

The findings of the integrated model highlight the interplay between cognitive, social, and motivational factors in shaping teachers' adoption of AR-G. Social influences, such as Subjective Norms, play a key role in fostering Perceived Usefulness and Perceived Ease of Use, showing that encouragement from colleagues and administrators enhances teachers' confidence in AR-G. Similarly, Experience with related technologies improves teachers' comfort with AR-G, reinforcing their belief in its usability and effectiveness. On the emotional side, Anxiety acts as a barrier to adoption by reducing perceptions of usefulness and ease of use, whereas Self-Efficacy strengthens these perceptions by increasing confidence in using AR-G. Teachers who feel competent in their technological abilities are more likely to integrate AR-G into their teaching. Perceived Enjoyment also plays a role, suggesting that teachers who find AR-G engaging and enjoyable are more inclined to use it. Attitude toward AR-G emerges as a critical factor influencing Intention to Use, reinforcing the idea that positive perceptions lead to stronger adoption intentions. Within the PMT framework, Perceived Vulnerability and Perceived Severity highlight the role

of risk perception, with teachers who fear negative consequences from not adopting AR-G being more motivated to integrate it. In contrast, Response Efficacy and Self-Efficacy both relate to confidence but differ in their focus—Self-Efficacy pertains to teachers' belief in their own ability to use AR-G, while Response Efficacy refers to their belief in AR-G's effectiveness as a teaching tool. Meanwhile, Response Cost acts as an adoption inhibitor, suggesting that even when teachers acknowledge AR-G's benefits, high perceived costs in terms of time, effort, or financial investment can discourage them from integrating it into their teaching practices. Overall, these findings indicate that AR-G adoption is not solely driven by cognitive or social factors, but rather by a combination of usability perceptions, emotional influences, and cost–benefit evaluations. Teachers are more likely to adopt AR-G when they find it useful, easy to use, socially supported, and aligned with their teaching goals. However, perceived costs and anxiety may limit adoption, even when these other conditions are met. Addressing these barriers through professional development, institutional support, and user-friendly technology design can enhance the likelihood of successful AR-G implementation. Table 4 and Fig. 4 visually summarize these relationships, emphasizing the distinct yet interconnected influences of cognitive, motivational, and social factors on AR-G adoption.

Table 4 Path analysis results for hypotheses testing in the integrated model

Hypotheses	Hypothesized relationship	β value	t-value	*p*-value	Confirmed
H1	SN → PU	0.43	9.78	< 0.01	Yes
H2	SN → PEOU	0.41	8.96	< 0.01	Yes
H3	EXP → PU	0.37	7.43	< 0.01	Yes
H4	EXP → PEOU	0.39	8.00	< 0.01	Yes
H5	PE → PU	0.40	8.47	< 0.01	Yes
H6	PE → PEOU	0.38	7.61	< 0.01	Yes
H7	ANX → PU	−0.36	−7.05	< 0.01	Yes
H8	ANX → PEOU	−0.31	−6.02	< 0.01	Yes
H9	SE → PU	0.47	10.70	< 0.01	Yes
H10	SE → PEOU	0.45	10.11	< 0.01	Yes
H11	PEOU → PU	0.50	11.63	< 0.01	Yes
H12	PEOU → ATT	0.48	10.95	< 0.01	Yes
H13	PU → ATT	0.53	12.45	< 0.01	Yes
H14	PU → INT	0.55	12.58	< 0.01	Yes
H15	ATT → INT	0.57	12.96	< 0.01	Yes
H16	PV → INT	0.41	9.02	< 0.01	Yes
H17	PS → INT	0.44	9.85	< 0.01	Yes
H18	RE → INT	0.49	11.31	< 0.01	Yes
H19	RC → INT	−0.35	−6.75	< 0.01	Yes

SN Subjective norm; *PU* Perceived usefulness; *PEOU* Perceived ease of use; *EXP* Experience; *PE* Perceived enjoyment; *ANX* Anxiety; *SE* Self-efficacy; *ATT* Attitude; *INT* Intention to use AR-G; *PV* Perceived vulnerability; *PS* Perceived severity; *RE* Response efficacy; *RC* Response cost

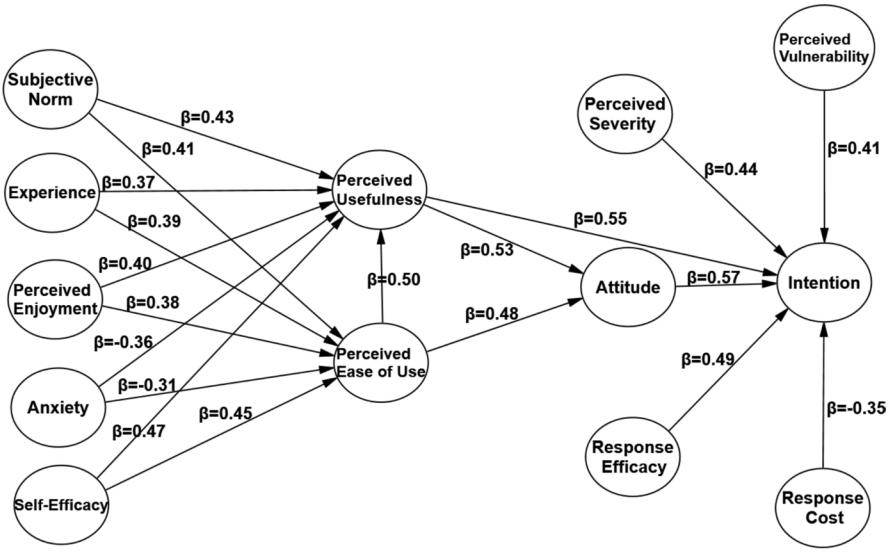


Fig. 4 Path analysis results of the unified framework of GETAMEL and PMT

4.2.4 Mediating analysis

This section explores the mediating effects within the integrated model, focusing on the roles of Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Attitude (ATT) in shaping science teachers' Intention to Use AR-G (INT). The analysis reveals the complex interplay between cognitive and motivational constructs, demonstrating both partial and full mediation paths, which highlights the nuanced nature of AR-G adoption. The mediation analysis, using the bootstrapping method with 5,000 resamples, confirmed several indirect relationships. For instance, PU emerged as a key mediator between Experience (EXP) and Intention (INT). Teachers with prior exposure to similar technologies tend to find AR-G more useful, which in turn strengthens their intention to adopt it. The indirect effect from EXP → PU → INT was 0.21 ($p < 0.01$), with the direct effect of EXP on INT dropping from 0.35 to 0.14 ($p < 0.05$), confirming partial mediation. Similarly, PU also mediated the relationship between Subjective Norms (SN) and INT, indicating that social influence shapes perceived usefulness, which subsequently affects teachers' adoption intentions. The indirect effect for SN → PU → INT was 0.18 ($p < 0.01$), with the direct effect of SN on INT reduced from 0.30 to 0.12 ($p < 0.05$), reinforcing the presence of partial mediation. The analysis also identified PEOU as a significant mediator in several relationships. Specifically, PEOU mediated the impact of Self-Efficacy (SE) on Attitude (ATT), suggesting that teachers with higher self-efficacy tend to perceive AR-G as easier to use, which fosters more favorable attitudes toward its adoption. The indirect effect of SE → PEOU → ATT was 0.24 ($p < 0.01$), while the direct effect of SE on ATT declined from 0.32 to 0.10 ($p < 0.05$), confirming partial mediation. Furthermore, the results demonstrate a chain mediation from PEOU → PU → ATT → INT, highlighting that ease of use influences

intention both directly and through its effects on perceived usefulness and attitudes. The chain mediation effect was 0.28 ($p < 0.01$). The mediating role of ATT was also prominent in the integrated model. Specifically, PU indirectly influenced INT through ATT, with an indirect effect of 0.31 ($p < 0.01$). The direct effect of PU on INT decreased from 0.55 to 0.24 ($p < 0.05$), confirming partial mediation. Notably, ATT fully mediated the relationship between Perceived Vulnerability (PV) and INT. The indirect effect of PV → ATT → INT was 0.19 ($p < 0.01$), and the direct effect of PV on INT became non-significant ($p > 0.05$), suggesting that the perceived vulnerability drives intention primarily through its impact on attitudes (see Table 5).

4.2.5 Moderating effects of professional status on augmented reality-based gamification adoption

This section investigates the moderating role of professional status—specifically comparing pre-service and in-service teachers—in the adoption of AR-G for science education. The sample comprises 682 pre-service and 952 in-service science teachers, reflecting diverse teaching experiences and contexts. This distinction allows us to explore whether professional background influences the relationships between key constructs and adoption intentions.

Measurement invariance testing was conducted to assess differences across the two groups. A non-restricted model was initially established, demonstrating acceptable model fit for pre-service ($\chi^2 = 1800.32$, df = 720, RMSEA = 0.041, CFI = 0.92, IFI = 0.93, TLI = 0.92) and in-service teachers ($\chi^2 = 1835.74$, df = 712, RMSEA = 0.042, CFI = 0.92, IFI = 0.93, TLI = 0.92). The next step involved testing full-metric invariance, which also yielded good fit indices for ($\chi^2 = 1855.12$, df = 750, RMSEA = 0.040, CFI = 0.92, IFI = 0.91, TLI = 0.91).

The chi-square difference test comparing the non-restricted and full-metric invariance models indicated no significant differences between the two groups ($\Delta\chi^2(30) = 35.42$, $p > 0.05$). This result supports the comparability of the structural relationships across professional status groups. Subsequently, a baseline model integrating all hypothesized relationships was developed, with good fit indices ($\chi^2 = 2205.83$, df = 780, RMSEA = 0.045, CFI = 0.91, IFI = 0.91, TLI = 0.90).

The nested model comparison revealed significant differences in specific paths across the two groups. Notably, the path from Attitude to Intention displayed a stronger influence among in-service teachers ($\Delta\chi^2(1) = 5.12$, $p < 0.05$). Similarly, differences were found in the paths from Perceived Vulnerability and Response Efficacy to Intention, with these constructs showing a more pronounced effect for in-service teachers ($\Delta\chi^2(1) = 5.95$, $p < 0.05$ and $\Delta\chi^2(1) = 6.10$, $p < 0.05$, respectively). In addition, the relationship between Response Cost and Intention was stronger among in–service teachers ($\Delta\chi^2(1) = 6.23$, $p < 0.05$), suggesting that this group is more sensitive to perceived barriers in adopting AR-G.

These results imply that professional status moderates the relationships between various constructs and teachers' intentions to use AR-G. In-service teachers, with their greater teaching experience, appear more responsive to motivational and efficacy-related factors while also being mindful of the costs associated with adoption. Detailed moderation results are provided in Table 6.

Table 5 Summary of mediating effects

Mediating path	Indirect effect	Direct effect before mediation	Direct effect after mediation	Mediation type	*p*-value
EXP → PU → INT	0.21	0.35	0.14	Partial Mediation	< 0.01
SN → PU → INT	0.18	0.30	0.12	Partial Mediation	< 0.01
SE → PEOU → ATT	0.24	0.32	0.10	Partial Mediation	< 0.01
PEOU → PU → ATT → INT	0.28	–	–	Chain Mediation	< 0.01
PU → ATT → INT	0.31	0.55	0.24	Partial Mediation	< 0.01
PV → ATT → INT	0.19	0.22	Non-significant	Full Mediation	< 0.01

Table 6 Moderation results by professional status for augmented reality-based gamification adoption

Groups	Models	χ^2	df	RMSEA	CFI	IFI	TLI	$\Delta\chi^2$	Full-metric invariance
Pre-service and in-service teachers	Non-restricted model	1800.32	720	0.041	0.92	0.93	0.92	$\Delta\chi2(30) = 35.42$, $p > 0.01$ (Insignificant)	Supported
	Full-metric invariance	1835.74	712	0.042	0.92	0.93	0.92		
Paths	Pre-service teachers ($n = 682$)		In-service teachers ($n = 952$)		Baseline model				Nested model
	β	t-values	β	t-values					
SN → PU	0.39	8.45	0.42	8.98	χ^2 (780) = 2205.83				χ^2 (781) = 2206.12 [a]
SN → PEOU	0.35	7.15	0.38	7.68	χ^2 (780) = 2205.83				χ^2 (781) = 2203.85 [b]
EXP → PU	0.38	7.85	0.40	8.30	χ^2 (780) = 2205.83				χ^2 (781) = 2203.75 [c]
EXP → PEOU	0.39	8.15	0.42	8.60	χ^2 (780) = 2205.83				χ^2 (781) = 2207.32 [d]
PE → PU	0.37	7.45	0.40	8.12	χ^2 (780) = 2205.83				χ^2 (781) = 2206.85 [e]
PE → PEOU	0.35	7.05	0.38	7.85	χ^2 (780) = 2205.83				χ^2 (781) = 2207.25 [f]
ANX → PU	−0.34	−6.85	−0.36	−7.05	χ^2 (780) = 2205.83				χ^2 (781) = 2202.40 g
ANX → PEOU	−0.30	−5.90	−0.32	−6.15	χ^2 (780) = 2205.83				χ^2 (781) = 2206.50 h
SE → PU	0.46	10.60	0.49	10.95	χ^2 (780) = 2205.83				χ^2 (781) = 2205.35 [i]
SE → PEOU	0.44	10.05	0.47	10.55	χ^2 (780) = 2205.83				χ^2 (781) = 2204.70 [j]
PEOU → PU	0.49	11.30	0.52	11.80	χ^2 (780) = 2205.83				χ^2 (781) = 2207.85 k
PEOU → ATT	0.46	10.85	0.49	11.25	χ^2 (780) = 2205.83				χ^2 (781) = 2207.40 l
PU → ATT	0.52	12.30	0.55	12.75	χ^2 (780) = 2205.83				χ^2 (781) = 2205.80 m
PU → INT	0.54	12.45	0.57	12.95	χ^2 (780) = 2205.83				χ^2 (781) = 2208.30 [n]
ATT → INT	0.52	12.25	0.63	13.75	χ^2 (780) = 2205.83				χ^2 (781) = 2.200,71[o]
PV → INT	0.37	7.40	0.45	10.05	χ^2 (780) = 2205.83				χ^2 (781) = 2.199,88 [p]
PS → INT	0.43	9.50	0.46	9.95	χ^2 (780) = 2205.83				χ^2 (781) = 2206.95 [r]
RE → INT	0.44	10.10	0.54	12.25	χ^2 (780) = 2205.83				χ^2 (781) = 2.199,73 s
RC → INT	−0.30	−5.85	−0.40	−8.95	χ^2 (780) = 2205.83				χ^2 (781) = 2.199,6 [t]

Results of chi-square difference test:[a] $\Delta\chi^2(1) = \mathbf{0.29}$, $p > 0.05$ (insignificant)[b] $\Delta\chi^2(1) = \mathbf{1.98}$, $p > 0.05$ (insignificant)[c] $\Delta\chi^2(1) = \mathbf{2.08}$, $p > 0.05$ (insignificant)[d] $\Delta\chi^2(1) = \mathbf{1.49}$, $p < 0.05$ (insignificant)[e] $\Delta\chi^2(1) = \mathbf{1.02}$, $p < 0.05$ (insignificant)[f] $\Delta\chi^2(1) = \mathbf{1.42}$, $p < 0.05$ (insignificant)[g] $\Delta\chi^2(1) = \mathbf{3.43}$, $p > 0.05$ (insignificant)[h] $\Delta\chi^2(1) = \mathbf{0.67}$, $p > 0.05$ (insignificant)[i] $\Delta\chi^2(1) = \mathbf{0.48}$, $p > 0.05$ (insignificant[j] $\Delta\chi^2(1) = \mathbf{1.13}$, $p > 0.05$ (insignificant)[k] $\Delta\chi^2(1) = \mathbf{2.02}$, $p < 0.05$ (insignificant)[l] $\Delta\chi^2(1) = \mathbf{1.57}$, $p < 0.05$ (insignificant)[m] $\Delta\chi^2(1) = \mathbf{-0.03}$, $p > 0.05$ (insignificant)[n] $\Delta\chi^2(1) = \mathbf{2.47}$, $p < 0.05$ (insignificant)[o] $\Delta\chi^2(1) = \mathbf{5.12}$, $p < 0.05$ (significant)[p] $\Delta\chi^2(1) = \mathbf{5.95}$, $p < 0.05$ (significant)[r] $\Delta\chi^2(1) = \mathbf{1.12}$, $p < 0.05$ (insignificant)[s] $\Delta\chi^2(1) = \mathbf{6.10}$, $p < 0.05$ (significant)[t] $\Delta\chi^2(1) = \mathbf{6.23}$, $p < 0.05$ (significant)

5 Discussion

5.1 Summary of results

The study integrated constructs from the GETAMEL and PMT to explore the factors influencing science teachers' adoption of AR-G. The integrated model provided comprehensive insights, demonstrating that both cognitive and motivational factors are crucial in shaping teachers' intentions to adopt AR-G. GETAMEL elements such as perceived ease of use and usefulness were validated, indicating that teachers' perceptions of AR-G as a user-friendly and effective tool enhance their willingness to adopt it. The importance of social influences, highlighted by the positive effects of subjective norms, suggests that peer and administrative support are significant enablers of AR-G adoption. From the PMT perspective, the study confirmed that teachers' perceptions of potential risks and their efficacy in using AR-G significantly affect their adoption intentions. Teachers who recognized high response efficacy of AR-G tended to show stronger intentions to adopt, driven by their belief in the technology's capacity to enhance teaching and learning outcomes. Moreover, the findings underscored that perceived vulnerabilities and severity concerning the risks of not adopting AR-G also play a crucial role, as these perceptions push teachers towards adopting AR-G to avoid negative outcomes in their teaching effectiveness. Overall, the integration of GETAMEL and PMT into a unified model effectively captures the complex interplay of factors that influence science teachers' decisions to adopt AR-G, providing a robust framework for understanding and enhancing technology adoption in educational settings.

5.2 Implications

5.2.1 Theoretical implications

This study offers valuable theoretical contributions by integrating two well-established frameworks, GETAMEL and PMT, to explore the adoption of AR-G among science teachers. While prior research has separately applied these models in educational technology adoption (e.g., Chou et al., 2017; Zhang & Yang, 2024), the present study fills a gap by merging cognitive, motivational, and social dimensions to form a more comprehensive theoretical framework. GETAMEL, with its focus on ease of use, usefulness, and enjoyment, provides insights into teachers' cognitive assessments of AR-G. PMT, on the other hand, contributes by emphasizing science teachers' risk perceptions and coping strategies, which have often been overlooked in traditional technology adoption models. By combining these models, the integrated framework extends the theoretical landscape, revealing the nuanced interplay between cognitive factors such as perceived ease of use and motivational constructs like response efficacy and vulnerability. This dual perspective enables a deeper understanding of how cognitive evaluations and emotional responses together shape teachers' intentions to adopt AR-G. Furthermore, this framework addresses a critical limitation of earlier studies by accounting for non-volitional factors such as anxiety,

response costs, and external pressures, which influence adoption behaviors in educational settings. The empirical validation of the unified model demonstrates its superiority over individual frameworks, indicating that integrating multiple theoretical perspectives leads to stronger explanatory power. This highlights the importance of combining behavioral, motivational, and social theories to capture the complexity of technology adoption in education (Abdullah & Ward, 2016). The findings underscore that educational technology adoption is not only a matter of cognitive evaluations but also shaped by emotional and motivational dynamics (Racero et al., 2020). This theoretical advancement aligns with and builds upon prior research, suggesting that multi-faceted frameworks provide a more robust understanding of the adoption process (e.g., Ateş & Gündüzalp, 2024; Buabeng-Andoh et al., 2020). Moreover, this study's findings open avenues for future research by suggesting that this integrated framework can be adapted to other emerging technologies in education. The results contribute to advancing knowledge in technology adoption literature by offering a flexible and comprehensive model that can be extended to different educational technologies beyond AR-G. While this study primarily focuses on science teachers in Türkiye, the underlying psychological and motivational constructs examined—such as self-efficacy, response efficacy, and perceived cost—are widely applicable to educational technology adoption across disciplines and cultural settings. Teachers in fields such as humanities, social sciences, and vocational education encounter similar usability and risk-related concerns when integrating digital tools. Although subject-specific factors may shape adoption preferences, the interplay of cognitive evaluations and motivational influences remains fundamental in determining technology adoption behaviors. Additionally, the factors influencing adoption—such as institutional support, perceived usefulness, and motivational drivers—are relevant across different educational systems globally.

The findings of this study validate several key hypotheses from the integrated model, reinforcing the importance of combining cognitive, social, and motivational constructs to understand science teachers' intentions to adopt AR-G. Consistent with the TAM and GETAMEL framework (Abdullah et al., 2016), Subjective Norms were found to positively influence both Perceived Usefulness and Perceived Ease of Use (H1, H2), highlighting the critical role of social influence. This aligns with prior studies that suggest that teachers who feel encouraged by colleagues or administrators are more likely to perceive a new technology as valuable and easy to implement (Eksail & Afari, 2020; Huang & Teo, 2021). Social endorsement not only increases teachers' confidence in the technology but also enhances their willingness to experiment with it, emphasizing the need for supportive professional environments in fostering innovation (Al-Rahmi et al., 2021; Konukman & Filiz, 2024). Similarly, Experience was shown to have a significant positive impact on both Perceived Usefulness and Perceived Ease of Use (H3, H4). This finding aligns with TAM studies that suggest prior exposure to similar technologies enhances users' comfort and reduces the learning curve associated with new tools (Abdullah & Ward, 2016; Davis, 1989). Teachers with experience using related digital tools are more likely to see AR-G as both beneficial and manageable, reinforcing that professional development initiatives should include hands-on experiences with emerging technologies (Ateş & Gündüzalp, 2024). The role of Perceived Enjoyment in influencing both

Perceived Usefulness and Perceived Ease of Use (H5, H6) further underscores the intrinsic motivational elements highlighted in prior research (Sun & Gao, 2020). Teachers who find enjoyment in using AR-G are more inclined to adopt it, as enjoyment fosters positive attitudes toward the technology and promotes sustained use. This supports the notion that emphasizing the enjoyable aspects of AR-G can motivate teachers to engage more actively with it, as seen in similar educational technology studies (Şahin & Şahin, 2022; Sharma & Srivastava, 2020). Conversely, Anxiety was found to negatively impact both Perceived Ease of Use and Perceived Usefulness (H7, H8), echoing previous research suggesting that higher anxiety toward a technology can hinder adoption by creating psychological barriers (Henderson & Corry, 2021; Wang et al., 2021). This highlights the importance of providing adequate support and training to reduce anxiety and build teachers' confidence. Consistent with self-efficacy theory (Bandura, 1982), Self-Efficacy emerged as a strong predictor, positively influencing both Perceived Ease of Use and Perceived Usefulness (H9, H10). Teachers with high self-efficacy are more likely to feel capable of using AR-G effectively, resulting in more positive perceptions of the technology's value and ease of integration. This aligns with studies by Ateş et al. (2024) and Zhi et al. (2024), which emphasize the role of self-efficacy in technology adoption, suggesting that enhancing teachers' confidence through training programs can improve adoption rates. The integrated model also highlights the impact of Perceived Ease of Use on both Perceived Usefulness and Attitude (H11, H12). This is consistent with the TAM framework, where users who find a technology easy to use are more likely to view it as useful and develop positive attitudes toward it (Davis, 1989). The results confirm that teachers who perceive AR-G as easy to implement are more likely to hold favorable attitudes toward its use, facilitating smoother integration into their teaching practices. Moreover, Perceived Usefulness was found to significantly influence both Attitude and Intention to Use AR-G (H13, H14). This aligns with previous findings indicating that when teachers recognize the educational benefits of a technology, they are more likely to develop positive attitudes and stronger intentions to adopt it (Al-Adwan et al., 2024). Attitude was also shown to have a significant positive effect on Intention to Use AR-G (H15), underscoring the importance of fostering positive attitudes to encourage adoption. This finding supports the TPB model, which emphasizes that favorable attitudes are critical in shaping behavioral intentions (Ajzen, 1991).

From the PMT perspective, Perceived Vulnerability and Perceived Severity were both found to positively influence Intention to Use AR-G (H16, H17). This aligns with prior research suggesting that when teachers perceive potential risks or negative outcomes associated with not adopting a technology, they are more motivated to integrate it into their practices (Ateş & Kölemen, 2025). The findings also confirm that Response Efficacy plays a crucial role, positively impacting Intention to Use AR-G (H18). Teachers who believe in the effectiveness of AR-G to enhance student engagement are more likely to adopt it, which mirrors the results of previous studies on the role of response efficacy in technology adoption (Kumar et al., 2023). Conversely, Response Costs were found to negatively influence Intention to Use AR-G (H19), indicating that teachers who perceive the time, effort, or financial burden of adopting AR-G as manageable are more likely to integrate it into their practices.

This finding aligns with prior research highlighting the importance of minimizing perceived barriers related to the costs of technology to facilitate its adoption (Tseng et al., 2022). Reducing these perceived burdens—whether financial, time-related, or effort-based—can significantly enhance teachers' willingness to integrate innovative technologies into their practices (Ateş & Garzón, 2023).

The moderator analysis offers valuable theoretical insights by demonstrating the impact of professional status on the adoption of AR-G among science teachers. The findings reveal nuanced differences between pre-service and in-service teachers, which extend the theoretical understanding of how professional background influences the cognitive and motivational processes underlying technology adoption. Consistent with previous studies (e.g., Ateş & Kölemen, 2025), in-service teachers showed a stronger influence of motivational factors such as response efficacy and perceived vulnerability on their intention to adopt AR-G. This highlights that experienced teachers, who are more familiar with traditional teaching methods, respond more strongly to motivational cues that emphasize the potential risks of non-adoption and the benefits of AR-G. In addition, in-service teachers were found to be more sensitive to response costs, aligning with prior research suggesting that perceived barriers—such as time, effort, and financial burden—play a crucial role in shaping the adoption behaviors of experienced educators (Tseng et al., 2022). This suggests that reducing perceived obstacles through targeted interventions could facilitate AR-G adoption among in-service teachers. The positive impact of attitude on intention was also more pronounced among in-service teachers, reinforcing the notion that experienced educators are more likely to develop favorable intentions when they hold positive attitudes toward the technology (Kumar et al., 2023). These findings are aligned with the TAM, which posits that attitudes play a crucial role in predicting behavioral intentions (Davis, 1989). Overall, the moderator analysis underscores the importance of tailoring strategies to address the distinct needs and concerns of pre-service and in-service teachers.

5.2.2 Practical implications

The study's findings emphasize the importance of tailored professional development programs to support AR-G adoption among teachers. Pre-service teachers, who may have limited experience with educational technologies, require hands-on workshops and structured training to build confidence and address concerns about time, effort, and technical complexity. In-service teachers, on the other hand, benefit from advanced training focused on enhancing response efficacy and leveraging their existing teaching experience to integrate AR-G effectively. Schools and training institutions should ensure that professional development initiatives cater to these distinct needs to maximize AR-G adoption and effectiveness.

Institutional support plays a crucial role in shaping teachers' perceptions of AR-G and their willingness to adopt it. Schools should foster a collaborative environment where teachers receive peer support and encouragement from administrators. Recognizing and rewarding educators who successfully implement AR-G can further reinforce a culture of innovation and inspire broader adoption. Additionally, policymakers can enhance adoption rates by allocating funding for AR-G infrastructure,

providing financial incentives for teacher training, and establishing guidelines for technology integration in science curricula. Industry partnerships with educational institutions can also ensure that teachers have access to updated AR-G tools and ongoing technical support, facilitating a smoother transition into technology-enhanced instruction.

The study also highlights the importance of addressing psychological and financial barriers that hinder AR-G adoption. Anxiety about using new technologies can negatively affect teachers' willingness to integrate AR-G into their classrooms. To mitigate this, schools and technology developers should ensure that AR-G tools feature user-friendly interfaces, and institutions should provide continuous technical support to build teacher confidence. Reducing response costs is another critical factor in increasing adoption rates, particularly for pre-service teachers who may have limited resources. Financial incentives, such as subsidies for AR-G software or government-backed funding programs, could make the technology more accessible, while providing ready-to-use lesson plans and AI-assisted content creation tools can help alleviate the burden of lesson preparation.

The study underscores the role of enjoyment in sustaining AR-G adoption. Teachers who enjoy AR-G are more likely to use it long-term. Collaboration between educators and developers ensures AR-G remains pedagogically effective and engaging. Incorporating gamification elements, such as progress tracking, achievement badges, and interactive challenges, can enhance the overall experience and encourage consistent use. By making AR-G engaging and easy to use, teachers will be more inclined to explore innovative teaching methods that improve student outcomes.

Furthermore, mentorship and experience-sharing are essential for encouraging AR-G adoption, particularly among pre-service teachers. Institutions should incorporate AR-G into teacher education programs, allowing pre-service teachers to gain early exposure and hands-on practice with the technology. In-service teachers who have successfully implemented AR-G can play a mentoring role by sharing best practices, success stories, and classroom strategies, fostering a supportive network for new adopters. This collaborative approach can help address uncertainties and accelerate the integration of AR-G across different educational settings.

To ensure the sustainability of AR-G implementation, institutions must regularly evaluate its impact on both student engagement and teacher experiences. Creating feedback loops where teachers can share challenges, propose improvements, and discuss their experiences will help refine AR-G applications in the classroom. Additionally, continuous assessment of how AR-G influences student learning outcomes will provide data-driven insights for refining policies and training programs. Schools should remain flexible in their implementation strategies, allowing teachers to adapt AR-G usage to their specific teaching contexts while receiving the necessary support.

The study also highlights the importance of differentiated professional development strategies tailored to the distinct needs of pre-service and in-service teachers. Pre-service teachers, who are still in training and may have limited exposure to classroom dynamics, often require structured learning pathways that introduce AR-G in a step-by-step manner. Integrating AR-G into teacher education curricula, offering simulated teaching experiences, and providing pre-designed lesson plans

can help them develop confidence in using AR-G before they enter the workforce. On the other hand, in-service teachers, who are already experienced but may be resistant to change due to workload constraints or perceived complexity, benefit from peer-led mentorship programs, real-world classroom integration examples, and hands-on advanced workshops that demonstrate how AR-G can be seamlessly incorporated into their existing teaching methods. Additionally, as in-service teachers are more sensitive to response costs, reducing technical barriers, offering institutional incentives, and providing on-demand support can encourage greater adoption. By aligning professional development initiatives with these distinct needs, schools and policymakers can foster widespread and sustainable AR-G integration across diverse teaching contexts.

By addressing these practical considerations, this study provides actionable recommendations for educators, school leaders, and policymakers to support and sustain AR-G adoption in science education. Ensuring institutional support, reducing barriers, fostering enjoyment, and maintaining long-term evaluation strategies will maximize the benefits of AR-G for both teachers and students.

To provide a concise summary of the key findings and their implications for educators, administrators, and policymakers, Table 7 presents an overview of the most significant factors influencing AR-G adoption and actionable strategies to enhance its implementation.

5.3 Limitation and suggestions for future studies

While this study provides valuable insights into the adoption of AR-G among science teachers, it has several limitations that should be addressed in future research.

First, the study relies on self-reported data, which may introduce biases such as social desirability or inaccuracies in respondents' perceptions. Future studies could complement self-reported data with classroom observations, usage logs, or longitudinal studies to assess actual AR-G adoption patterns over time. Additionally, incorporating experimental studies where teachers receive structured AR-G training and their performance is tracked in real classroom settings could provide practical insights into how training quality impacts adoption.

Second, this study focuses solely on science teachers in Türkiye, limiting the generalizability of the findings to other disciplines and cultural contexts. While science education benefits from AR-based tools, the psychological and motivational constructs examined—such as self-efficacy, response efficacy, and perceived cost—are relevant across various educational disciplines. Future research should explore AR-G adoption in non-STEM subjects, such as mathematics, social sciences, or language education, to determine whether similar cognitive, motivational, and contextual factors influence adoption intentions. Additionally, expanding the study to different countries or conducting cross-cultural comparisons would provide a deeper understanding of how cultural, institutional, and technological differences impact technology adoption behaviors.

Third, the cross-sectional design of this study captures data at a single point in time, limiting the ability to track changes in teachers' attitudes, intentions, and

Table 7 Summary of key findings and their practical implications

Key finding	Explanation	Practical implication
Perceived ease of use and usefulness significantly impact adoption	Teachers who perceive AR-G as easy to use and beneficial are more likely to integrate it into their teaching	Training programs should focus on usability and demonstrate the practical educational benefits of AR-G through real-life classroom applications. Additionally, simplified interfaces and user-friendly design should be prioritized to minimize technical challenges
Subjective norms play a crucial role in adoption	Support from colleagues, school leaders, and institutional encouragement enhances teachers' adoption intentions	Schools should foster a culture of collaboration, provide peer mentorship programs, and recognize teachers who successfully implement AR-G through incentives, awards, or professional development credits
Anxiety negatively affects adoption	Teachers with high anxiety levels may hesitate to adopt AR-G due to concerns over technical difficulties and classroom management challenges	Institutions should offer continuous technical support, hands-on workshops, and troubleshooting resources to reduce teachers' concerns. Establishing a teacher support network where educators can share best practices and resolve issues collaboratively can further alleviate anxiety
Enjoyment enhances adoption	Teachers who find AR-G engaging and enjoyable are more likely to continue using it in their teaching practices	AR-G tools should incorporate gamified elements, progress tracking, and interactive features that enhance engagement for both teachers and students. Encouraging teachers to experiment with creative lesson designs using AR-G can further increase adoption rates
Response costs hinder adoption	High perceived costs in terms of time, effort, and financial investment discourage teachers from integrating AR-G	Schools should provide financial incentives, reduce workload burdens through ready-to-use lesson plans, and support teachers with dedicated AR-G integration time in their schedules. Access to open-source or subsidized AR-G platforms can further minimize response costs
Professional status moderates adoption	In-service teachers are more influenced by motivational factors such as response efficacy, while pre-service teachers are more concerned with perceived barriers	Pre-service teachers benefit from structured learning pathways integrated into teacher education curricula, simulated teaching experiences, and pre-designed lesson plans. In-service teachers need flexible professional development, peer-led mentoring, and practical classroom implementation strategies. Addressing response costs through time-saving resources and institutional incentives is particularly crucial for in-service teachers

adoption behaviors. Future research could employ longitudinal designs to investigate how teachers' perceptions evolve over time, particularly in response to technological advancements, training programs, or institutional policy changes. Conducting pre- and post-intervention studies where teachers participate in structured AR-G professional development and their attitudes are measured over time would offer practical recommendations for improving professional training programs.

Fourth, while this study integrates GETAMEL and PMT, additional theoretical perspectives could further enhance understanding. Future research could explore alternative models, such as UTAUT, to assess the role of performance expectancy, effort expectancy, and facilitating conditions in AR-G adoption. Additionally, incorporating teacher motivation theories, such as Self-Determination Theory (SDT), could provide deeper insights into how intrinsic and extrinsic motivations influence technology adoption in educational settings. Exploring how autonomy, competence, and relatedness affect teachers' willingness to integrate AR-G could lead to practical recommendations on how to design motivational training programs that encourage sustainable use.

Moreover, the study examines professional status (pre-service vs. in-service teachers) as a moderator, but other demographic and institutional factors may also influence technology adoption behaviors. Future research could explore the impact of age, teaching experience, school type, or digital literacy levels to identify additional barriers and facilitators of AR-G adoption. Understanding these factors would allow education policymakers to develop differentiated training strategies tailored to specific teacher profiles. Investigating the interactions between these variables may yield a more nuanced understanding of the conditions that enhance or inhibit AR-G integration.

Additionally, while this study focuses on psychological and motivational barriers such as anxiety and response costs, it does not directly examine practical constraints, including infrastructure challenges, administrative support, and institutional policies, which can also influence AR-G adoption. Teachers' ability to integrate AR-G effectively may depend on factors such as hardware availability, internet connectivity, funding for educational technology, and professional development support provided by schools. Future research should examine how these factors influence adoption and explore institutional interventions, such as providing dedicated AR-G classrooms, integrating AR-G tools into national curricula, and establishing IT support teams within schools to assist teachers.

While GETAMEL and PMT effectively capture individual adoption motivations, future research could incorporate organizational change theories to better understand institutional and infrastructural influences on AR-G implementation. Conducting cross-institutional studies comparing resource-rich and resource-limited schools would offer further insights into how external barriers impact adoption decisions and guide practical interventions to bridge the gap in AR-G accessibility.

Finally, while this study focuses on teachers' perspectives, it does not incorporate students' views on AR-G adoption, which are crucial for understanding its educational impact. Future studies should include student feedback to assess how AR-G influences learning engagement, comprehension, and academic performance.

Additionally, long-term studies could evaluate the sustained effects of AR-G integration on student learning outcomes, providing a more comprehensive assessment of its pedagogical value. Understanding student perspectives would allow educators to refine AR-G teaching strategies, making them more effective and engaging.

By addressing these limitations, future research can contribute to a broader and more globally applicable understanding of AR-G adoption in education, ensuring that findings extend beyond specific subjects, national contexts, or methodological constraints. More importantly, providing practical recommendations tailored to different teacher profiles and institutional settings will enhance AR-G's real-world applicability in education.

6 Conclusion

This study explores the factors shaping science teachers' intentions to adopt AR-G. By integrating the GETAMEL and PMT frameworks, the research offers a comprehensive theoretical model that captures the cognitive, motivational, and social dimensions shaping adoption decisions. Self-efficacy, perceived ease of use, usefulness, and response efficacy drive teachers' AR-G adoption. Additionally, the role of subjective norms and professional status highlights the importance of the social context in encouraging technology adoption. The results demonstrate that teachers who feel confident in their ability to use AR-G and recognize its benefits are more likely to integrate the technology into their teaching practices. However, the study also reveals that perceived barriers, such as anxiety and response costs, can hinder adoption, underscoring the need for institutional support and targeted interventions. These insights suggest that both individual and contextual factors must be addressed to foster the successful integration of AR-G in educational settings. The practical implications of this research highlight the importance of providing teachers with adequate training, resources, and ongoing support to build their confidence and reduce perceived challenges. Encouraging collaborative environments where teachers feel socially supported by their peers and administrators can further enhance their willingness to adopt AR-G. Educational policymakers and leaders can use these findings to design targeted strategies that address both motivational and cognitive barriers, facilitating smoother technology adoption. The study also provides a valuable foundation for future research by suggesting that the integrated model of GETAMEL and PMT can be adapted to investigate other emerging technologies in education. As the rapid pace of technological advancements continues to reshape education, this research offers timely insights into the complex dynamics involved in technology adoption. By bridging the gaps between individual motivation, social influence, and practical barriers, the study contributes to the development of more effective strategies for integrating AR-G into science education. Ultimately, this research aims to empower educators to embrace innovative technologies, enhancing both teaching effectiveness and student learning experiences in an increasingly digital educational landscape.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK). This research received no external funding.

Data availability The datasets generated and analyzed during the current study are not publicly available due to privacy and ethical considerations but are available from the corresponding author on reasonable request and subject to necessary approvals.

Declarations

Conflict of interest disclosure The authors declare no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Abdullah, F., & Ward, R. (2016). Developing a general extended technology acceptance model for e-learning (GETAMEL) by analysing commonly used external factors. *Computers in Human Behavior, 56*, 238–256.

Abdullah, F., Ward, R., & Ahmed, E. (2016). Investigating the influence of the most commonly used external variables of TAM on students' Perceived ease of use (PEOU) and perceived usefulness (PU) of e-portfolios. *Computers in Human Behavior, 63*, 75–90.

Ajzen, I. (1991). The Theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Ajzen, I. (2006). *Constructing a theory of planned behavior questionnaire*. http://people.umass.edu/~aizen/pdf/tpb.measurement.pdf

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20*, 1–11.

Al-Adwan, A. S., Meet, R. K., Anand, S., Shukla, G. P., Alsharif, R., & Dabbaghia, M. (2024). Understanding continuous use intention of technology among higher education teachers in emerging economy: evidence from integrated TAM, TPACK, and UTAUT model. *Studies in Higher Education*, 1–20.

Al-Emran, M., Al-Nuaimi, M. N., Arpaci, I., Al-Sharafi, M. A., & Anthony Jnr, B. (2023). Towards a wearable education: Understanding the determinants affecting students' adoption of wearable technologies using machine learning algorithms. *Education and Information Technologies, 28*(3), 2727–2746.

Al-Emran, M., Granić, A., Al-Sharafi, M. A., Ameen, N., & Sarrab, M. (2021). Examining the roles of students' beliefs and security concerns for using smartwatches in higher education. *Journal of Enterprise Information Management, 34*(4), 1229–1251.

Almufareh, M. (2021). The impact of gamification and individual differences on second language learning among first-year female university students in Saudi Arabia. *Simulation & Gaming, 52*(6), 715–734.

Alptekin, M., & Temmen, K. (2020). Gamification in an augmented reality based virtual preparation laboratory training. In *The Challenges of the Digital Transformation in Education: Proceedings of the 21st International Conference on Interactive Collaborative Learning (ICL2018)-Volume 1* (pp. 567–578). Springer International Publishing.

Al-Rahmi, W. M., Yahaya, N., Alamri, M. M., Alyoussef, I. Y., Al-Rahmi, A. M., & Kamin, Y. B. (2021). Integrating innovation diffusion theory with technology acceptance model: Supporting students' attitude towards using a massive open online courses (MOOCs) systems. *Interactive Learning Environments, 29*(8), 1380–1392.

Altmeyer, K., Kapp, S., Thees, M., Malone, S., Kuhn, J., & Brünken, R. (2020). The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses—Theoretical background and empirical results. *British Journal of Educational Technology, 51*(3), 611–628.

Anderson, S. E., & Maninger, R. M. (2007). Preservice teachers' abilities, beliefs, and intentions regarding technology integration. *Journal of Educational Computing Research, 37*(2), 151–172.

Arici, F., & Yilmaz, M. (2023). An examination of the effectiveness of problem-based learning method supported by augmented reality in science education. *Journal of Computer Assisted Learning, 39*(2), 446–476.

Arpaci, I. (2023). A multi-analytical SEM-ANN approach to investigate the social sustainability of AI chatbots based on cybersecurity and protection motivation theory. *IEEE Transactions on Engineering Management, 71*, 1714–1725.

Ateş, H. (2024). Integrating augmented reality into intelligent tutoring systems to enhance science education outcomes. *Education and Information Technologies*, 1–36.

Ateş, H., & Garzón, J. (2022). Drivers of teachers' intentions to use mobile applications to teach science. *Education and Information Technologies, 27*(2), 2521–2542.

Ateş, H., & Garzón, J. (2023). An integrated model for examining teachers' intentions to use augmented reality in science courses. *Education and Information Technologies, 28*(2), 1299–1321.

Ateş, H., Garzón, J., & Lampropoulos, G. (2024). Evaluating science teachers' flipped learning readiness: A GETAMEL approach test. *Interactive Learning Environments, 32*(10), 6283–6300.

Ateş, H., & Gündüzalp, C. (2024). A unified framework for understanding teachers' adoption of robotics in STEM education. *Education and Information Technologies, 29*, 13437–13463.

Ateş, H., & Kölemen, C. Ş. (2025). Integrating theories for insight: An amalgamated model for gamified virtual reality adoption by science teachers. *Education and Information Technologies, 30*, 2123–2153.

Ateş, H., & Yilmaz, R. M. (2024). A comprehensive model explaining teachers' intentions to use mobile-based assessment. *Interactive Learning Environments, 32*(8), 4063–4087.

Aw, J. K., Boellaard, K. C., Tan, T. K., Yap, J., Loh, Y. P., Colasson, B., ... & Fung, F. M. (2020). Interacting with three-dimensional molecular structures using an augmented reality mobile app, *Journal of Chemical Education, 97*, 3877−3881.

Awan, A., Lombardi, D., Ruffino, P., & Agkathidis, A. (2022). *Efficacy of gamification on introductory architectural education: A literature review.* https://doi.org/10.52842/conf.ecaade.2022.2.553

Bagozzi, R. P., & Yi, Y. (2012). Specification, evaluation, and interpretation of structural equation models. *Journal of the Academy of Marketing Science, 40*(1), 8–34.

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist, 37*(2), 122–147.

Barhorst, J. B., McLean, G., Shah, E., & Mack, R. (2021). Blending the real world and the virtual world: Exploring the role of flow in augmented reality experiences. *Journal of Business Research, 122*, 423–436.

Browne, M. W., & Cudeck, R. (1992). Alternative ways of assessing model fit. *Sociological Methods & Research, 21*(2), 230–258.

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. A. Bollen & J. S. Long (Eds.), *Testing Structural Equation Models* (pp. 136–162). Sage.

Buabeng-Andoh, C., & Baah, C. (2020). Pre-service teachers' intention to use learning management system: An integration of UTAUT and TAM. *Interactive Technology and Smart Education, 17*(4), 455–474.

Chang, C. T., Hajiyev, J., & Su, C. R. (2017). Examining the students' behavioral intention to use e-learning in Azerbaijan? The general extended technology acceptance model for e-learning approach. *Computers & Education, 111*, 128–143.

Chen, S. Y., & Liu, S. Y. (2020). Using augmented reality to experiment with elements in a chemistry course. *Computers in Human Behavior, 111*, 106418.

Chou, H. L., & Sun, J. C. Y. (2017). The moderating roles of gender and social norms on the relationship between protection motivation and risky online behavior among in-service teachers. *Computers & Education, 112*, 83–96.

Crandall, P. G., Engler, R. K., III., Beck, D. E., Killian, S. A., O'Bryan, C. A., Jarvis, N., & Clausen, E. (2015). Development of an augmented reality game to teach abstract concepts in food chemistry. *Journal of Food Science Education, 14*(1), 18–23.

Dahri, N. A., Yahaya, N., Al-Rahmi, W. M., Aldraiweesh, A., Alturki, U., Almutairy, S., ... & Soomro, R. B. (2024). Extended TAM based acceptance of AI-Powered ChatGPT for supporting metacognitive self-regulated learning in education: A mixed-methods study. *Heliyon*, *10*(8), e29317. https://doi.org/10.1016/j.heliyon.2024.e29317.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MISQuarterly,* 319–340.

Deci, E. L., & Ryan, R. M. (1985). The general causality orientations scale: Self-determination in personality. *Journal of Research in Personality, 19*(2), 109–134.

Dreimane, S. (2024). *A gamified learning process model.* In *Proceedings of the 2024 High-Tech and Quality Education Conference* (pp. 88–100). https://doi.org/10.22364/htqe.2024.07

Durukan, Ü. G., Turan Güntepe, E., & Dönmez Usta, N. (2023). Evaluation of the effectiveness of augmented reality-based teaching material: The solar system. *International Journal of Human-Computer Interaction, 39*(12), 2542–2556.

Eksail, F. A. A., & Afari, E. (2020). Factors affecting trainee teachers' intention to use technology: A structural equation modeling approach. *Education and Information Technologies, 25*(4), 2681–2697.

Esfandiar, K., Dowling, R., Pearce, J., & Goh, E. (2020). Personal norms and the adoption of pro-environmental binning behaviour in national parks: An integrated structural model approach. *Journal of Sustainable Tourism, 28*(1), 10–32.

Fakhr Hosseini, S., Chan, K., Lee, C., Jeon, M., Son, H., Rudnik, J., & Coughlin, J. (2024). User adoption of intelligent environments: A review of technology adoption models, challenges, and prospects. *International Journal of Human-Computer Interaction, 40*(4), 986–998.

Fiş Erümit, S. E. M. R. A., & Karakuş Yılmaz, T. (2022). Gamification design in education: What might give a sense of play and learning? *Technology, Knowledge and Learning, 27*(4), 1039–1061.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*(1), 39–50.

García-López, I. M., Acosta-Gonzaga, E., & Ruiz-Ledesma, E. F. (2023). Investigating the impact of gamification on student motivation, engagement, and performance. *Education Sciences, 13*(8), 813. https://doi.org/10.3390/educsci13080813

Granić, A. (2023). Technology acceptance and adoption in education. In *Handbook of open, distance and digital education* (pp. 183–197). Singapore: Springer Nature Singapore.

Hair, J. F., Jr., Anderson, R. E., & Tatham, R. L. (1986). *Multivariate data analysis with readings*. Macmillan Publishing Co., Inc.

Henderson, J., & Corry, M. (2021). Teacher anxiety and technology change: A review of the literature. *Technology, Pedagogy and Education, 30*(4), 573–587.

Hidayat, R., & Wardat, Y. (2024). A systematic review of augmented reality in science, technology, engineering and mathematics education. *Education and Information Technologies, 29*(8), 9257–9282.

Hopcan, S., Türkmen, G., & Polat, E. (2024). Exploring the artificial intelligence anxiety and machine learning attitudes of teacher candidates. *Education and Information Technologies, 29*(6), 7281–7301.

Huang, F., & Teo, T. (2021). Examining the role of technology-related policy and constructivist teaching belief on English teachers' technology acceptance: A study in Chinese universities. *British Journal of Educational Technology, 52*(1), 441–460.

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education, 123*, 109–123.

Iqbal, M. Z., Mangina, E., & Campbell, A. G. (2019, October). Exploring the use of augmented reality in a kinesthetic learning application integrated with an intelligent virtual embodied agent. In *2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)* (pp. 12–16). IEEE.

Iqbal, M. Z., Mangina, E., & Campbell, A. G. (2022). Current challenges and future research directions in augmented reality for education. *Multimodal Technologies and Interaction, 6*(9), 75. https://doi.org/10.3390/mti6090075

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A. I. (2021). Gamification in science education. A systematic review of the literature. *Education Sciences*, *11*(1), 22.

Kline, P. (2011). *Principles and practice of structural equation modeling* (3rd ed.). The Guilford Press.

Konukman, F., & Filiz, B. (2024). Turkish Physical Education Teachers' Use of Technology: Application and Diffusion of Technological Innovations. *Education Sciences, 14*(6), 616.

Koumpouros, Y. (2024). Revealing the true potential and prospects of augmented reality in education. *Smart Learning Environments, 11*(2), 1–62.

Kumar, K., Liu, D., & Carter, L. (2023). Understanding the adoption of digital conferencing tools: Unpacking the impact of privacy concerns and incident response efficacy. *Computers & Security, 132*, 103375.

Lampropoulos, G., Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2022). Augmented reality and gamification in education: A systematic literature review of research, applications, and empirical studies. *Applied Sciences, 12*(13), 6809.

Lampropoulos, G., Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2023). Integrating augmented reality, gamification, and serious games in computer science education. *Education Sciences, 13*(6), 618.

Lampropoulos, G., & Kinshuk. (2024). Virtual reality and gamification in education: A systematic review. *Educational Technology Research and Development, 72*, 1691–1785. https://doi.org/10.1007/s11423-024-10351-3

Lu, Y., & Zhou, T. (2009). Exploring Chinese users' acceptance of instant messaging using the theory of planned behav-ior, the technology acceptance model, and the flow theory. *Computers in Human Behavior, 25*(1), 29–39. https://doi.org/10.1016/j.chb.2008.06.002

Maddux, J. E., & Rogers, R. W. (1983). Protection motivation and self-efficacy: A revised theory of fear appeals and attitude change. *Journal of Experimental Social Psychology, 19*(5), 469–479.

Mahmud, A., Yusoff, M. N., & Husin, M. H. (2023). Generation Z's adoption of IoT: Protection motivation theory as the underlying model and gender as a moderator. *Journal of Systems and Information Technology, 25*(2), 133–159.

Milne, S., Sheeran, P., & Orbell, S. (2000). Prediction and intervention in health-related behavior: A meta-analytic review of protection motivation theory. *Journal of Applied Social Psychology, 30*(1), 106–143.

Miraja, B., Persada, S., Prasetyo, Y., Belgiawan, P., & Redi, A. A. N. (2019). Applying protection motivation theory to understand Generation Z students intention to comply with educational software anti piracy law. *International Journal of Emerging Technologies in Learning (iJET), 14*(18), 39–52.

Möller, J., Thürmer, J. L., Tulis, M., Reiss, S., & Jonas, E. (2022). Exploring higher education pathways for coping with the threat of COVID-19: Does parental academic background matter? *Frontiers in Psychology, 12*, 768334.

Moon, J. W., & Kim, Y. G. (2001). Extending the TAM for a world-wide-web context. *Information and Management, 38*(4), 217–230. https://doi.org/10.1016/S0378-7206(00)00061-6

Nikou, S. A., & Economides, A. A. (2017). Mobile-based assessment: Investigating the factors that influence behavioral intention to use. *Computers and Education, 109*, 56–73. https://doi.org/10.1016/j.compedu.2017.02.005

Noreikis, M., Savela, N., Kaakinen, M., Xiao, Y., & Oksanen, A. (2019). Effects of gamified augmented reality in public spaces. *IEEE Access, 7*, 148108–148118.

Ozcelik, E., Cagiltay, N. E., & Ozcelik, N. S. (2013). The effect of uncertainty on learning in game-like environments. *Computers & Education, 67*, 12–20.

Perifanou, M., Economides, A. A., & Nikou, S. A. (2022). Teachers' views on integrating augmented reality in education: Needs, opportunities, challenges and recommendations. *Future Internet, 15*(1), 20.

Pirker, J., & Gütl, C. (2015). Educational gamified science simulations. In T. Reiners & L. C. Wood (Eds.), *Gamification in education and business* (pp. 253–275). Springer International Publishing. https://doi.org/10.1007/978-3-319-10208-5_13

Predescu, A., & Mocanu, M. (2024). Gamification in real-world applications: Interactive maps and augmented reality. *In InTechOpen Book Series on Emerging Technologies*. https://doi.org/10.5772/intechopen.1004870

Putz, L. M., Hofbauer, F., & Treiblmaier, H. (2020). Can gamification help to improve education? Findings from a longitudinal study. *Computers in Human Behavior, 110*, 106392.

Racero, F. J., Bueno, S., & Gallego, M. D. (2020). Predicting students' behavioral intention to use open source software: A combined view of the technology acceptance model and self-determination theory. *Applied Sciences, 10*(8), 2711.

Ratinho, E., & Martins, C. (2023). The role of gamified learning strategies in student's motivation in high school and higher education: A systematic review. *Heliyon, 9*(8), e19033. https://doi.org/10.1016/j.heliyon.2023.e19033

Rogers, R. W. (1975). A protection motivation theory of fear appeals and attitude change. *The Journal of Psychology, 91*(1), 93–114.

Ruvio, A., Shoham, A., & Brenčič, M. M. (2008). Consumers' need for uniqueness: Short-form scale development and cross-cultural validation. *International Marketing Review, 25*(1), 33–53.

Sáez-López, J. M., Cózar-Gutiérrez, R., González-Calero, J. A., & Gómez Carrasco, C. J. (2020). Augmented reality in higher education: An evaluation program in initial teacher training. *Education Sciences, 10*(2), 26.

Şahin, F., & Şahin, Y. L. (2022). Drivers of technology adoption during the COVID-19 pandemic: The motivational role of psychological needs and emotions for pre-service teachers. *Social Psychology of Education, 25*(2), 567–592.

Sailer, M., Hense, J., Mandl, H., & Klevers, M. (2017). *Fostering development of work competencies and motivation via gamification* (pp. 795–818). Springer International Publishing.

Saleem, A. N., Noori, N. M., & Ozdamli, F. (2022). Gamification applications in E-learning: A literature review. *Technology, Knowledge and Learning, 27*(1), 139–159.

Salloum, S. A., Alhamad, A. Q. M., Al-Emran, M., Monem, A. A., & Shaalan, K. (2019). Exploring students' acceptance of e-learning through the development of a comprehensive technology acceptance model. *IEEE Access, 7*, 128445–128462. https://doi.org/10.1109/ACCESS.2019.2939467

Scaravetti, D., & François, R. (2021). Implementation of augmented reality in a mechanical engineering training context. *Computers, 10*(12), 163.

Sharma, L., & Srivastava, M. (2020). Teachers' motivation to adopt technology in higher education. *Journal of Applied Research in Higher Education, 12*(4), 673–692.

Srisawasdi, N., & Panjaburee, P. (2019). Implementation of game-transformed inquiry-based learning to promote the understanding of and motivation to learn chemistry. *Journal of Science Education and Technology, 28*, 152–164.

Sun, Y., & Gao, F. (2020). An investigation of the influence of intrinsic motivation on students' intention to use mobile devices in language learning. *Educational Technology Research and Development, 68*(3), 1181–1198.

Taylor, S., & Todd, P. A. (1995). Understanding information technology usage: A test of competing models. *Information Systems Research, 6*(2), 144–176. https://doi.org/10.1287/isre.6.2.144

Toda, A. M., & do Carmo, R. M., da Silva, A. P., Bittencourt, I. I., & Isotani, S. (2019). An approach for planning and deploying gamification concepts with social networks within educational contexts. *International Journal of Information Management, 46*, 294–303.

Tseng, T. H., Lin, S., Wang, Y. S., & Liu, H. X. (2022). Investigating teachers' adoption of MOOCs: The perspective of UTAUT2. *Interactive Learning Environments, 30*(4), 635–650.

Uz Bilgin, C., & Gul, A. (2020). Investigating the effectiveness of gamification on group cohesion, attitude, and academic achievement in collaborative learning environments. *Tech Trends, 64*(1), 124–136.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 46*(2), 186–204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 425–478.

Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. *MIS Quarterly*, 157–178.

Wang, Y. (2022). Effects of augmented reality game-based learning on students' engagement. *International Journal of Science Education, Part B, 12*(3), 254–270.

Wang, Y., Liu, C., & Tu, Y. F. (2021). Factors affecting the adoption of AI-based applications in higher education. *Educational Technology & Society, 24*(3), 116–129.

Wen, Y. (2021). Augmented reality enhanced cognitive engagement: Designing classroom-based collaborative learning activities for young language learners. *Educational Technology Research and Development, 69*(2), 843–860.

Witte, K., & Allen, M. (2000). A meta-analysis of fear appeals: Implications for effective public health campaigns. *Health Education & Behavior, 27*(5), 591–615.

Zhai, N., & Ma, X. (2022). Automated writing evaluation (AWE) feedback: A systematic investigation of college students' acceptance. *Computer Assisted Language Learning, 35*(9), 2817–2842. https://doi.org/10.1080/09588221.2021.1897019

Zhang, C., Schießl, J., Plößl, L., Hofmann, F., & Gläser-Zikuda, M. (2023). Acceptance of artificial intelligence among pre-service teachers: A multigroup analysis. *International Journal of Educational Technology in Higher Education, 20*(49), 1–22.

Zhang, P., & Yang, H. (2024). The GETAMEL Model: Features of the Adaptation of Teachers in the Transition to On-Line Learning. *International Journal of Human–Computer Interaction*, 1–13.

Zhi, R., Wang, Y., & Wang, Y. (2024). The role of emotional intelligence and self-efficacy in EFL teachers' technology adoption. *The Asia-Pacific Education Researcher, 33*(4), 845–856.

Zourmpakis, A. I., Kalogiannakis, M., & Papadakis, S. (2023). Adaptive gamification in science education: An analysis of the impact of implementation and adapted game elements on students' motivation. *Computers, 12*(7), 143.

Λαμπρόπουλος, Γ, Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2022). Augmented reality and gamification in education: A systematic literature review of research, applications, and empirical studies. *Applied Sciences, 12*(13), 6809. https://doi.org/10.3390/app12136809

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.