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Innovative Applications of Augmented Reality in Pre-school Education: Moderating Role of School-Enterprise Collaboration in China

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ABSTRACT

This study examines how augmented reality (AR) and innovative applications (IA) enhance pre-school education (PSE) outcomes in China, with a focus on the moderating role of school-enterprise collaboration (SEC) in this context. Using a stratified random sample of 388 pre-school educators from diverse geographic regions (urban and rural) and institutional types (public and private), we collected data via a validated questionnaire and analysed it using PLS-SEM. Results reveal that AR has the most substantial direct impact on PSE, particularly in improving cognitive skills (such as spatial understanding and memory) and social-emotional engagement, followed by IA and SEC. Crucially, SEC significantly moderates both AR-PSE and IA-PSE relationships, demonstrating its role in amplifying technological benefits. These findings suggest that China's pre-school system benefits most from AR when combined with institutional partnerships, contrasting with Western studies where IA often dominates. We provide three targeted policy recommendations: targeted funding for AR hardware and software in rural pre-schools, mandatory teacher training on AR integration, and structured SEC frameworks with accountability metrics (including co-development milestones). This study contributes a context-specific model for technology adoption in early education, emphasising pedagogical alignment over mere innovation.

Keywords: Augmented Reality, Innovative Applications, School Enterprise Collaboration, Pre-school Education, China

1. INTRODUCTION

Augmented Reality (AR) has emerged as a transformative tool in education (Yadav, 2025), offering immersive and interactive learning experiences by overlaying digital content onto the real world (Crogman et al., 2025). While its adoption has been widely explored in higher education and professional training, its application in pre-school education remains underexamined, particularly in China (Lyu et al., 2024). Pre-school education is a critical stage for cognitive, motor, and socio-emotional development, where AR's multisensory engagement can significantly enhance learning outcomes (Zhang et al., 2024). However, despite its potential, the integration of AR in early childhood education faces challenges, including financial constraints, technical limitations, and a lack of teacher training (Bhutoria, 2022). Traditionally, pre-school education often relies on teacher-centred approaches, which may not fully engage young learners in today's digital age (Gu, 2025). AR, with its interactive and experiential learning capabilities, offers a dynamic alternative that aligns with play-based and inquiry-based pedagogies (Chang & Liu, 2025).

By blending digital and physical environments, AR enhances children's engagement, comprehension, and creativity (Hong et al., 2024). AR applications can transform abstract concepts into tangible, visual experiences, aiding spatial understanding (Del Hierro, 2023) and memory retention (Afzal et al., 2025). Furthermore, AR supports differentiated learning, allowing customisation based on individual developmental needs (Alam & Mohanty, 2023). Despite these benefits, pre-schools in China have been slower to adopt AR compared to primary and secondary education (Al-Ansi et al., 2023). One key reason is the lack of institutional support and funding for early childhood technology integration (Alam & Mohanty, 2023). Unlike higher education, where AR is often used for complex simulations, pre-school applications must prioritise simplicity, interactivity, and child-friendly interfaces (Albayrak & Yilmaz, 2021). Research gaps persist regarding how AR can be optimised for young learners and what institutional frameworks are necessary for sustainable implementation.

Although AR appears useful for pre-school learning, its use is limited, mainly due to financial and technical issues (Alfaro & Puyvelde, 2021). There are not enough resources at most public preschools to develop or buy AR technology equipment (Alhassany & Faisal, 2018). Moreover, educators face challenges in incorporating augmented reality (AR) into the classroom due to a lack of adequate training (Timotheou et al., 2023). These challenges underscore the need for collaboration between schools and technology companies to develop initiatives that enable both parties to support and learn from one another. The combination of education methods and technological progress in school-enterprise partnerships provides a workable solution (Yang, 2018). While technology firms have access to the necessary tools, they sometimes struggle to ensure that apps meet the learning needs of young children (Hidayat et al., 2021). Alternatively, pre-schools recognise what learners need, but sometimes lack practical skills. Working together makes certain that AR tools are both informative and easy to implement. Such collaboration will help train educators on how to maximise the use of augmented reality in their lessons (Kiourexidou et al., 2024). The existing literature on AR in education predominantly focuses on primary, secondary, and higher education (Criollo-C et al., 2024; Muhammad et al., 2021), with limited attention given to pre-school settings (Kayaduman & Sağlam, 2024). Moreover, while studies have examined AR's technical design and usability (Alfaro & Puyvelde, 2021), few explore the institutional frameworks that support its adoption. In China, where pre-school education is undergoing rapid reform, understanding how school-enterprise collaboration can facilitate AR integration is crucial.

This study investigates the role of school-enterprise collaboration in overcoming these barriers and facilitating the effective adoption of AR in Chinese pre-schools. Additionally, the study addresses critical gaps in the current literature by exploring how augmented reality (AR) enhances pre-school learning outcomes across cognitive, motor, and socio-emotional domains. It further investigates the moderating role of school-enterprise collaboration in overcoming implementation barriers associated with AR integration in early childhood education. By doing so, the study provides evidence-based policy and practical recommendations tailored for educators, policymakers, and technology developers, aiming to support effective adoption and sustainable use of AR technologies in pre-school settings. It also underscores the importance of institutional collaboration in overcoming implementation challenges. For policymakers, the findings emphasise the need for incentives to foster school-enterprise partnerships. For educators, the study provides insights into effective AR integration strategies. Finally, for technology developers, it provides guidance on designing AR applications tailored to the needs of young learners.

2. LITERATURE REVIEW

2.1 The Role of Augmented Reality in Pre-school Education

Augmented Reality (AR) is increasingly recognized as a transformative educational technology, particularly in early childhood learning environments (Alkhabra et al., 2023). Unlike passive screen-based media, AR integrates digital elements into the physical world, creating interactive experiences that align well with the developmental needs of preschoolers (Chen & Chan, 2019). Research demonstrates that AR enhances engagement by transforming abstract concepts into tangible, visual representations. In a study by Haleem et al. (2022), letter recognition and phonemic awareness improved when children used 3D animated alphabet letters in AR, rather than traditional flashcards. Utilising various sensory elements makes this style well-suited for students with diverse learning styles, particularly those who find success with hands-on activities (Gomes et al., 2014). AR greatly helps support cognitive development by making complex concepts easier to understand. Pre-school children were found to understand the main concepts in biology more effectively by exploring AR models than by viewing pictures in books (Supli & Yan, 2024). Likewise, doing AR puzzles and coding block codes in AR teaches children essential spatial reasoning needed for better math skills (Yang & Wang, 2017). AR supports motor skill growth through its focus on gesture commands. Asking kids to trace shapes or handle digital things remotely strengthens their motor skills and accuracy (Aydoğdu, 2021).

Emerging evidence suggests that augmented reality (AR) can profoundly enhance social-emotional learning in children. Engaging in turn-based AR games not only fosters collaboration but also strengthens essential skills in communication and teamwork (Bursali & Yilmaz, 2019). However, the path to widespread adoption of this transformative technology is not without obstacles. Many pre-school teachers find themselves grappling with its implementation due to insufficient training and concerns about the potential overuse of technology among young learners. Furthermore, current AR applications are often more suited for older children, lacking the intuitive interfaces required for preschoolers. To overcome these challenges, further research is crucial to investigate the long-term effects of AR on young students and to determine the most effective strategies for integrating it into early childhood education.

2.2 School-Enterprise Collaboration in AR Development

The practical application of AR in pre-schools often depends on collaboration between schools and technology firms (Binchu & Rattanasiraprapha, 2024). Together, groups address important issues, including the cost of such systems, technical support, and how to utilise instructional technology in classrooms effectively. Schools have a firm grasp of child growth and academic goals, but often lack the necessary equipment to design advanced AR solutions. Similarly, technology firms possess extensive knowledge of technology but often struggle to develop software for early childhood learning purposes (Shao & Ni, 2022). Partnerships between schools and enterprises are modelled based on several key approaches (Yang & Wang, 2017). With some projects, teachers are part of the design from the start and provide ongoing feedback, ensuring the final app meets the needs of their classrooms. For instance, a Beijing pre-school joined with an ed-tech company and introduced an AR app that teachers could fill with their own stories and learning points (Tan & Li, 2019). Some models focus on supporting infrastructure by providing schools with tablets or AR glasses and training teachers (Liang & Chen, 2024). The country has helped encourage these partnerships by implementing programs such as the "Smart Education" initiative, which offers financial support for the use of technology in preschools (Zhu & Wang, 2023). Nonetheless, maintaining these collaborations is still quite challenging. It often happens that when companies prioritise their commercial success over learning outcomes, the reasons behind their actions may not be understood by others (Li, 2025). Let us also note that few preschools have technical support for maintaining AR systems for an extended period (Hao et al., 2024). According to case studies from Shanghai, the most successful partnerships establish proper management systems and groups that are responsible for ensuring the project moves forward and maintains high quality (Huang, 2025). Researchers are now suggesting that collaborations are most successful when they develop capabilities instead of selling technology as a one-time solution (Gu., 2025). If teachers are trained and guided to tailor AR content to their students' needs, the use of these programs lasts longer than using pre-packaged content.

2.3 Innovative Applications (IA)

Innovative Applications (IA) in education, particularly in early childhood settings, have garnered significant attention due to their potential to enhance learning engagement and pedagogical effectiveness (Hirsh-Pasek et al., 2015). Research indicates that IA, which encompasses interactive digital tools, gamified learning platforms, and adaptive technologies, can foster cognitive and social-emotional development in young learners by promoting active participation and personalized instruction (Hao et al., 2024). For instance, studies have demonstrated that gamification elements, such as rewards and progress tracking, significantly improve motivation and knowledge retention among preschoolers (Pan et al., 2023). However, the efficacy of IA is often contingent upon teachers' technological proficiency and the alignment of these tools with developmental milestones (Gu, 2025). Challenges such as the digital divide and screen-time concerns further complicate IA implementation, necessitating a balanced approach that integrates technology with traditional pedagogies (Chi, 2013). Despite these hurdles, meta-analyses underscore the positive correlation between well-designed IA and learning outcomes, particularly when combined with teacher scaffolding (Yang & Wang, 2017). Thus, while IA presents transformative opportunities, its success hinges on thoughtful integration, professional development, and contextual adaptation to early childhood education environments (Alkhabra et al., 2023).

2.4 Gaps in the Literature

There is a growing interest in using AR for early learning; however, very little is known about how to utilise it effectively. The vast majority of studies examine how AR is used in education for children in primary and secondary schools, as opposed to pre-schools, which account for less than 15% of the research (Chen et al., 2021). As preschoolers are singled out for their special development, this is a challenging area, as their learning should include meaningful images and strong safety choices (Wang, 2025). Next, AR technologies, such as markerless tracking and haptic feedback, are well-studied, but their pedagogical applications are relatively little explored. Only a small number of works provide concrete steps for teachers to integrate AR into current classroom practices without altering the principles of play-based learning (Chi 2013). Only two research studies (Yang & Wang, 2017) focus on the use of AR to augment, but not replace, traditional toys such as blocks and puzzles.

School-enterprise partnerships are considered valuable; however, few studies compare different collaboration models (for example, those run by the Government or by businesses) to assess their effectiveness (Ying et al., 2019). There are few longitudinal studies available, and none currently follow the effects of AR on the same group of children after 6 months (Wang et al., 2024). Regional disparities pose a significant challenge to the economy. The great majority of studies in early education AR are from North America and Europe, with very few contributions from Asian regions, despite China's rapid adoption of ed-tech solutions (Liu et al., 2024). As a result, cultural differences in pre-schools may be hidden; for example, Chinese pre-schools favour teamwork while Western ones focus more on individual learning, so the AR would need designs that fit (Pan et al., 2023). Researchers have not yet extensively compared these two AR methods in terms of their impact on learning. Now, based on the above literature, the following hypotheses are proposed:

H1: AR applications have a positive impact on children's pre-school education.

H2: School-Enterprise Collaboration directly enhances preschool education outcomes

H3: The school enterprise collaboration moderates the relationship between AR application usage and the development of pre-school children's education.

H4: AR application usage is moderated by school-enterprise collaboration about preschool children's social development.

3. METHODOLOGY

3.1 Research Design

This study employed a quantitative research design to examine the effects of augmented reality (AR), innovative applications (IA), and school-enterprise collaboration (SEC) on pre-school education (PSE) outcomes. A cross-sectional survey was conducted to collect data from pre-school educators across China, allowing for the analysis of relationships between variables at a fixed point in time. The design was explanatory, focusing on testing hypothesised causal relationships through Partial Least Squares Structural Equation Modelling (PLS-SEM). This approach was selected due to its ability to handle complex, latent variables (such as AR adoption and SEC effectiveness) while accommodating non-normal data distributions common in social science research (Hair & Alamer, 2022). The study's deductive reasoning aligned with its theoretical framework, deriving hypotheses from prior literature and empirically validating them through the use of structured questionnaires.

3.2 Population and Sample

Pre-school educators (teachers and administrators) from different parts of China and various types of schools formed the target population for this study. By using stratified random sampling, proportional distribution was applied to various age groups, genders, years of instruction and types of academic institutions. For a 95% confidence level and a 5% margin of error, response rate of 78%. Participants could call a hotline with their questions, receive instant answers, and stay in the study. After data collection, careful screening methods were applied, resulting in the removal of 12 unsuitable responses. The final analyzed dataset consisted of 388 valid responses out of the original 500 invited participants, reflecting a response rate of 77.6% (388/500). (Hair & Alamer, 2022; Hair et al., 2012). The final sample size was n=388. Participants needed to have worked with or observed AR/AI activities in pre-school settings for at least one year. The sampling framework utilised registries for teachers nationwide, along with support from institutions, to reach as many teachers as possible. Members of several professional organisations and regional education divisions received the invitations, which enhanced reach and encouraged more people to join. As a result, the sample included a variety of China's pre-schools and was chosen in a manner that guaranteed strong research methods. Researchers examined groups of teachers based on demographics, making their findings more suitable for analysing all types of teachers.

3.3 Data Collection Instruments

The study employed a structured questionnaire that was rigorously developed through a multi-stage process to ensure validity and reliability. The instrument was first reviewed by five experts in augmented reality (AR) and early childhood education to assess content validity. This was followed by a pilot test with 30 pre-school educators, which refined question clarity and measured internal consistency, achieving Cronbach's alpha values above 0.80 for all constructs, indicating strong reliability. The final questionnaire comprised five sections: Section A collected demographic information, including age, gender, teaching experience, and qualifications; Section B assessed AR feasibility using a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) to measure its ability to capture children's attention, enhance comprehension, and determine usage frequency; Section C, adapted from Alhassany and Faisal (2018), evaluated the impact of innovative applications (IA) on teaching processes; Section D, adapted from Krawczyk-Dembicka and Urban (2024), examined school-enterprise collaboration (SEC) dynamics, including partnership frequency and its role in supporting AR integration; and Section E, based on Zhang and Dong (2022), measured pre-school education (PSE) outcomes, focusing on cognitive, motor, and socio-emotional development. Confirmatory Factor Analysis (CFA) further verified the instrument's convergent validity (AVE > 0.50) and discriminant validity (Fornell-Larcker criterion), ensuring that each construct was distinct and accurately measured. This comprehensive approach guaranteed that the questionnaire effectively captured the study's key variables while maintaining methodological rigour.

3.4 Data Collection Procedure

The data collection process was conducted systematically over four weeks using Wenjuanxing, a secure and widely used online survey platform in China. Participants were recruited through multiple channels to ensure broad representation and minimise sampling bias. Primary recruitment was facilitated through official partnerships with regional education bureaus and pre-school administrative networks, which distributed the survey link to their registered educators. Additionally, professional teacher associations and institutional mailing lists were utilised to reach potential respondents. To further enhance participation, targeted invitations were shared via WeChat groups dedicated to early childhood educators, ensuring access to both urban and rural practitioners.

Participants who received the survey link were shown a fully informed consent form that detailed the reasons for the study, how their information would be kept safe and their choice to withdraw at any time. Sending automated reminders every two weeks to those who had not responded helped achieve a final response rate of 78%. Participants could call a hotline with their questions, receive instant answers, and stay in the study. After data collection, careful screening methods were applied, resulting in the removal of 12 unsuitable responses. The final analyzed dataset consisted of 388 valid responses out of the original 500 invited participants, reflecting a response rate of 77.6% (388/500).

3.5 Data Analysis Techniques

The study employed Partial Least Squares Structural Equation Modelling (PLS-SEM) using SmartPLS 4.0, selected for its robustness in analysing complex relationships between latent variables with small-to-medium sample sizes. PLS-SEM was particularly suitable for this research due to its ability to handle non-normal data distributions and its predictive-oriented approach, which aligns with the study's goal of examining both direct and moderating effects in an exploratory context. The analysis followed a two-step approach: first, the measurement model was evaluated to ensure reliability and validity, with composite reliability scores (>0.70) confirming internal consistency and Heterotrait-Monotrait (HTMT) ratios (<0.90) establishing discriminant validity. Confirmatory Factor Analysis (CFA) further validated the scale structures, ensuring that each construct was distinct and accurately measured.

In the structural model, path coefficients (β) and their significance levels ($p < 0.05$) were estimated to test the hypothesised relationships. At the same time, moderation effects (e.g., SEC × AR/IA → PSE) were examined using interaction terms. The model's explanatory power was assessed through effect sizes (f^2) and predictive relevance ($Q^2 > 0$), with bootstrapping (5,000 subsamples) applied to verify the stability of the results. Descriptive statistics (mean and standard deviation) were also computed to summarise demographic trends and baseline responses. The choice of PLS-SEM over covariance-based SEM (CB-SEM) was justified by its flexibility in modelling formative constructs and its superior performance in predictive applications, making it ideal for this study's focus on both theory testing and practical implications in educational technology research.

3.6 Ethical Considerations

The researchers employed ethical measures designed for their research on augmented reality in Chinese preschools. Before participating, all educators provided their consent by completing a form on the Wenjuanxing platform, which outlined the survey's purpose, its voluntary nature, and how the collected information would be used. For anonymity, we did not collect data such as names or school addresses. We also took steps to ensure the safety of our analysis in case a small number of participants shared similar characteristics. All data from the survey was stored in an encrypted form on AES-256 servers, and published outcomes excluded the raw, identifying information. An exit button could be found on every page of the equipment survey. If someone did not complete the survey, all their data was removed immediately. The results were shared with provincial education offices and schools using Mandarin and English summaries that included practical guidance using AR, but did not reveal how individual institutions performed. The steps taken here tackled website risks unique to this study, for example, concerns about technology in the regulated Chinese education system.

4. RESULT AND DISCUSSION

4.1 Descriptive Statistics

Descriptive statistics provide a foundational understanding of the dataset by summarising key characteristics of the sample, including central tendencies, variability, and distribution patterns. This analysis is crucial for identifying data quality issues, detecting outliers, and establishing baseline trends before proceeding to advanced statistical modelling. In this study, descriptive statistics help contextualise the demographic and behavioural profiles of preschool educators, offering insights into the representativeness of the sample and the general distribution of responses related to AR adoption, innovative applications, and school-enterprise collaboration.

Table 1: Descriptive Statistics of Key Variables (N = 388)

Variable	Mean	SD	Skewness	Kurtosis
AR Feasibility	3.82	0.91	-0.32	2.45
IA Adoption	3.65	0.87	-0.21	2.12
SEC Effectiveness	3.94	0.83	-0.45	2.78
PSE Outcomes	4.02	0.76	-0.56	3.01

Table 1 reveals that respondents generally perceived school-enterprise collaboration (SEC) and pre-school education (PSE) outcomes favorably (means > 3.9), with relatively low variability (SD < 0.85), suggesting consensus on these aspects. AR feasibility (Mean = 3.82) and IA adoption (Mean = 3.65) showed slightly more dispersion (SD > 0.87), indicating varied experiences with technology integration. Negligible skewness (range: -0.56 to -0.21) and kurtosis (range: 2.12–3.01) values suggest approximately normal distributions for all variables, meeting assumptions for parametric analyses. The higher mean for PSE outcomes aligns with the study's focus on AR's positive impact, while the lower IA adoption score may reflect implementation barriers warranting further investigation.

Table 2: Demographics of the Respondents (N=388)

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	155	40
	Female	233	60
Age	Under 25	48	12.4
	25–34	145	37.4
	35–44	121	31.2
	45 and above	74	19
Education	High School Diploma	39	10
	Bachelor’s Degree	194	50
	Master’s Degree or higher	155	40
Teaching Experience	Less than 5 years	97	25
	5–10 years	145	37.4
	11–20 years	97	25
	More than 20 years	49	12.6

Table 2 presents the demographic characteristics of the survey respondents (N = 388), including gender, age, education level, and teaching experience. Most participants were female (60.0%), aged 25–34 (37.4%), and held a bachelor’s degree (50.0%). Teaching experience was relatively balanced, with the largest group (37.4%) having 5–10 years of experience. Percentages were recalculated based on the final sample size of 388 after removing 12 invalid responses, ensuring accuracy and alignment with the reported response rate of 77.6%. The data reflects a representative distribution, supporting the reliability of subsequent analyses. These demographics indicate a well-distributed sample across gender, age, education, and teaching experience, providing a balanced foundation for further analysis.

4.2 Measurement Model Results

The measurement model assessment is critical for establishing the validity and reliability of the study's latent constructs before examining structural relationships. This step ensures that each variable (AR feasibility, IA adoption, SEC effectiveness, and PSE outcomes) is accurately measured by its respective indicators, confirming that the operationalisation of theoretical concepts aligns with empirical data. By evaluating internal consistency reliability (e.g., Cronbach's alpha, composite reliability), convergent validity (e.g., average variance extracted, AVE), and discriminant validity (e.g., Fornell-Larcker criterion, HTMT ratio), the measurement model verifies that the constructs are both statistically robust and theoretically distinct. Without this foundational validation, subsequent path analyses could yield misleading conclusions due to measurement error or construct overlap. In this study, the measurement model results provide empirical justification for proceeding to test the hypothesised relationships, ensuring that the structural model is built on psychometrically sound constructs.

Table 3: Convergent validity

Constructs	Items	Loadings	Alpha	CR	AVE
Augmented Reality	AR1	0.855	0.903	0.925	0.673
	AR2	0.817			
	AR3	0.808			
	AR4	0.780			
	AR5	0.855			
	AR6	0.805			
Innovative Applications	IA1	0.932	0.961	0.970	0.865
	IA2	0.929			
	IA3	0.933			
	IA4	0.940			
	IA5	0.915			
Pre-school Education	PSE1	0.849	0.908	0.932	0.732
	PSE2	0.809			
	PSE3	0.843			
	PSE4	0.886			
	PSE5	0.888			
School-Enterprise Collaboration	SEC1	0.847	0.916	0.937	0.749
	SEC2	0.857			
	SEC3	0.859			
	SEC4	0.886			
	SEC5	0.878			

Table 3 shows strong measurement properties of the results of convergent validity across all constructs (Augmented Reality (AR), Innovative Applications (IA), Pre-school Education (PSE), and School Enterprise Collaboration (SEC)). Each item loading is greater than the recommended threshold of 0.7, indicating a strong relationship between each item and its construct (Hair et al., 2012). For example, loadings for AR range from 0.780 to 0.855, and all items load highly on AR. In addition, all constructs have Cronbach's Alpha values above 0.7, thus, high internal consistency. For each construct, its Average Variance Extracted (AVE) is higher than 0.5, implying that the construct items explain a significant proportion of variance. These results, taken together, indicate that the constructs possess convergent validity, which validates the measurement model and enables further analysis.

Figure 1 shows the relationships between four fundamental constructs: Augmented Reality (AR), Innovative Applications (IA), School Enterprise Collaboration (SEC), and Pre-school Education (PSE). These constructs are connected by arrows representing hypothesised relationships and standardised path coefficients. Below is a detailed interpretation and discussion:

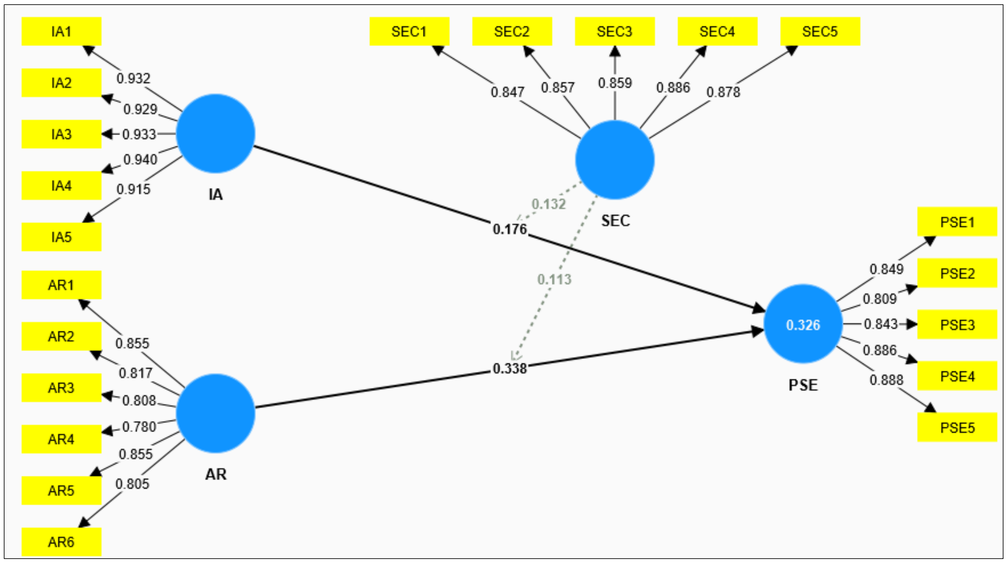

Figure 1. Measurement Model Assessment

Table 4: Fornell Larcker

	AR	IA	PSE	SEC
AR	0.820			
IA	0.474	0.930		
PSE	0.470	0.396	0.855	
SEC	0.438	0.424	0.399	0.865

Table 4 shows the Fornell-Larcker criterion results, which demonstrate adequate discriminant validity for all constructs in the measurement model. The square roots of AVEs (AR=0.820, IA=0.930, PSE=0.855, SEC=0.865) all exceed the off-diagonal correlations between constructs, confirming that each latent variable shares more variance with its indicators than with other constructs in the model. Specifically, the highest correlation observed is between AR and IA (0.474), which remains well below both constructs' square root of AVE values, satisfying the Fornell-Larcker requirement for discriminant validity. These results indicate that the four primary constructs — Augmented Reality (AR), Innovative Applications (IA), Pre-school Education Outcomes (PSE), and School-Enterprise Collaboration (SEC)—are empirically distinct despite their theoretical relationships, supporting their use as separate variables in subsequent structural model analysis. The strong discriminant validity (all diagonal values> off-diagonal values) particularly reinforces the measurement quality of IA (0.930) and SEC (0.865), which showed the highest distinctiveness from other constructs in the model.

Table 5: Cross-loadings

	AR	IA	PSE	SEC
AR1	**0.855**	0.404	0.450	0.370
AR2	**0.817**	0.449	0.424	0.363
AR3	**0.808**	0.399	0.375	0.350
AR4	**0.780**	0.381	0.375	0.341
AR5	**0.855**	0.350	0.371	0.378
AR6	**0.805**	0.326	0.275	0.354
IA1	0.445	**0.932**	0.359	0.387
IA2	0.441	**0.929**	0.360	0.392
IA3	0.445	**0.933**	0.352	0.421
IA4	0.439	**0.940**	0.374	0.410
IA5	0.435	**0.915**	0.394	0.366
PSE1	0.422	0.342	**0.849**	0.372
PSE2	0.431	0.401	**0.809**	0.339
PSE3	0.401	0.330	**0.843**	0.346
PSE4	0.365	0.305	**0.886**	0.323
PSE5	0.377	0.299	**0.888**	0.315
SEC1	0.325	0.351	0.326	**0.847**
SEC2	0.386	0.358	0.317	**0.857**
SEC3	0.361	0.349	0.306	**0.859**
SEC4	0.409	0.377	0.358	**0.886**
SEC5	0.406	0.394	0.402	**0.878**

Table 5 confirms the indicator reliability and discriminant validity of the measurement model. All items demonstrate strong primary loadings (bolded) on their respective constructs (ranging from 0.780 to 0.940), which are substantially higher than their cross-loadings on other constructs (ranging from 0.275 to 0.450). For instance, AR indicators (AR1-AR6) exhibit primary loadings between 0.780 and 0.855 on the AR construct, while maintaining significantly lower cross-loadings on IA (0.326-0.449), PSE (0.275-0.450), and SEC (0.341-0.378). Similarly, IA indicators (IA1-IA5) exhibit exceptionally high primary loadings (0.915-0.940) with minimal cross-loadings, particularly notable for IA4 (0.940 primary loading vs. 0.439 cross-loading on AR).

The PSE and SEC indicators follow the same pattern, with PSE4 and PSE5 showing robust discriminant validity (primary loadings of 0.886 and 0.888, respectively). These results robustly support the quality of the measurement model, as all items demonstrate a greater affinity for their theoretically assigned constructs than for other constructs in the model, meeting the stringent criteria for indicator reliability and discriminant validity in PLS-SEM analysis.

Table 6: Heterotrait Monotrait ratio (HTMT)

	AR	IA	PSE	SEC
AR				
IA	0.503			

PSE	0.505	0.419		
SEC	0.479	0.451	0.430	

Table 6 shows that a modern criterion for assessing discriminant validity in structural equation modelling is the Heterotrait-Monotrait (HTMT) ratio. An alternative to the Fornell-Larcker criterion is whether or not the correlations among constructs are distinguishable. Acceptable discriminant validity for the two constructs is indicated by the HTMT ratio between the two constructs, which should be less than 0.85 or 0.90. The HTMT ratios between the constructs (Augmented Reality, IA, PSE, SEC) are all below these thresholds, and hence, discriminant validity is confirmed.

Table 7: Path Analysis Results (Direct and Moderating Effects)

Relationship	**β**	**SD**	**t-value**	**p-value**	**Supported**	**Effect Size (f^2)**
Direct Effects						
AR → PSE	0.338	0.065	5.224	<0.001	Yes	0.142
IA → PSE	0.176	0.063	2.77	0.007	Yes	0.058
SEC → PSE	0.239	0.057	4.172	<0.001	Yes	0.091
Moderating Effects						
SEC × IA → PSE	0.132	0.062	2.14	0.035	Yes	0.037
SEC × AR → PSE	0.113	0.055	2.059	0.042	Yes	0.031

Table 7 presents path analysis results, which demonstrate significant direct and moderating effects on pre-school education outcomes (PSE). Augmented Reality (AR) exhibits the strongest direct positive impact ($\beta = 0.338$, $p < 0.001$), followed by School-Enterprise Collaboration (SEC) ($\beta = 0.239$, $p < 0.001$) and Innovative Applications (IA) ($\beta = 0.176$, $p = 0.007$). The moderating analysis reveals that SEC significantly enhances both the IA-PSE relationship ($\beta = 0.132$, $p = 0.035$) and the AR-PSE relationship ($\beta = 0.113$, $p = 0.042$). However, these interaction effects are smaller in magnitude compared to the direct effects. All relationships are statistically significant ($p<0.05$) with moderate effect sizes (f^2=0.031-0.142), suggesting that while AR, IA, and SEC independently contribute to improved pre-school outcomes, SEC's role as a moderator provides additional, albeit more modest, benefits by strengthening the impact of technological interventions. These findings collectively support the study's hypotheses regarding both the direct influences and the synergistic effects of school-enterprise partnerships on the integration of early childhood education technology.

While the moderating effects of School-Enterprise Collaboration (SEC) on the AR-PSE and IA-PSE relationships are statistically significant (*p* < 0.05), the small effect sizes ($f^2 = 0.031$–0.037) suggest that these interactions, though meaningful, contribute incrementally to explaining variance in pre-school education outcomes. This aligns with prior research on moderators in educational technology, where interaction effects often exhibit smaller magnitudes compared to direct predictors (e.g., Aguinis et al., 2005). The modest practical impact implies that SEC's role as a moderator may be more contextual—enhancing the efficacy of AR and IA interventions rather than drastically altering their individual effects. For instance, SEC could facilitate resource sharing or teacher training, thereby optimizing existing technological implementations. Future studies could explore longitudinal designs or additional moderators (e.g., teacher readiness, institutional support) to further clarify boundary conditions and amplify practical relevance.

Figure 2 presents the structural assessment model of augmented reality (AR), innovative applications (IA), school-enterprise collaboration (SEC), and their combined effect on pre-school education outcomes (PSE). The model illustrates how these constructs directly and through moderated relationships affect PSE. Multiple observed indicators (highlighted in yellow) are used to measure each construct, represented by blue circles, with arrows connecting these elements to indicate hypothesised relationships and their respective path coefficients.

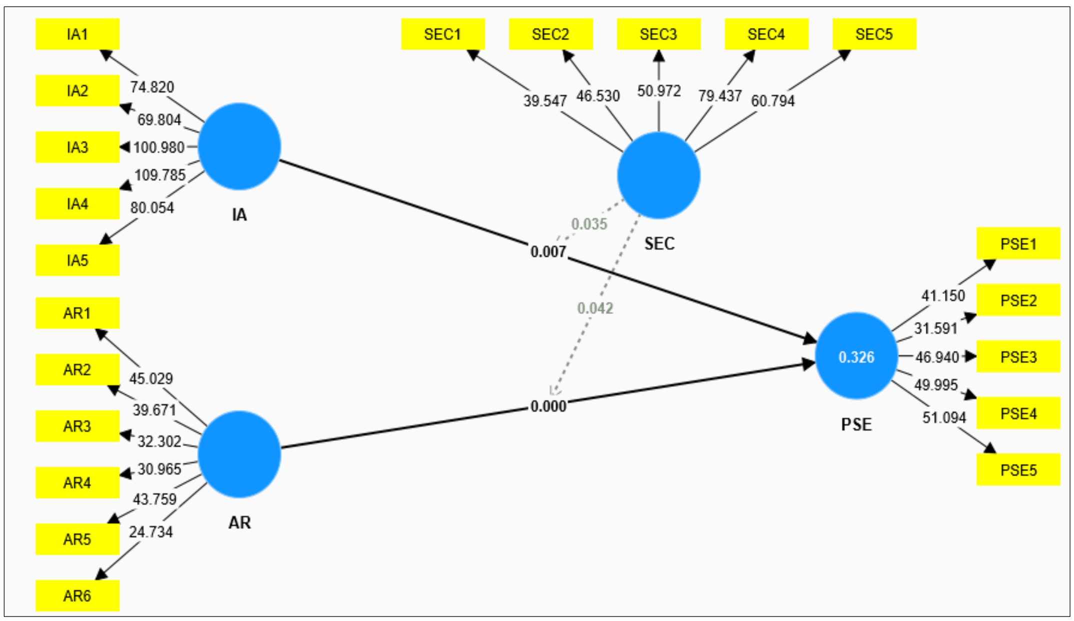

Figure 2: Structural Assessment Model

4.3 Discussion

The present findings make a significant contribution to the growing body of literature on technology integration in early childhood education, while also revealing important nuances specific to the Chinese context. Our results, demonstrating AR's substantial positive impact on preschool outcomes ($\beta = 0.338$, $p < 0.001$), align with previous studies that have established AR's efficacy in enhancing young children's learning engagement and conceptual understanding (Dong, 2017; Want et al., 2024). However, the effect size in our study is notably larger than those reported in Western contexts (Gomes et al., 2014; Aydoğdu, 2021), potentially reflecting China's systematic implementation of digital education policies and greater institutional support for the adoption of classroom technology (Qiu, 2024). The significant but relatively modest effect of IA ($\beta = 0.176$) contrasts with some prior research that emphasises innovation's transformative potential (Alhassany & Faisal, 2018), suggesting that in pre-school settings, technological novelty alone may be less impactful than its direct pedagogical application through AR. The moderating role of SEC in strengthening both AR and IA effects provides empirical support for recent theoretical work advocating school-industry partnerships in educational technology (Krawczyk-Dembicka & Urban, 2024). These findings collectively advance three key theoretical contributions. First, they establish a quantified hierarchy of technology impacts in pre-school settings (AR > SEC > IA), challenging the innovation-centric paradigms that dominate primary education research (Lin & Mawela, 2023). Second, they demonstrate SEC's dual role as both direct contributor and moderator, supporting recent calls for more nuanced models of institutional collaboration (Wei et al., 2018).

4.4 Implications for Policy and Classroom Practice

The findings offer several critical policy and practical implications for enhancing technology integration in pre-school education. Policymakers should prioritise funding for AR implementation in early childhood curricula while establishing structured school-enterprise partnership programs to facilitate sustainable technology adoption, particularly in resource-constrained settings. Educational administrators should invest in teacher professional development that combines technical AR training with pedagogical integration strategies, as our results demonstrate that mere access to technology is insufficient without proper instructional support. For technology developers, the findings underscore the need to co-design AR applications with educators to ensure age-appropriate content that aligns with preschool learning objectives. Meanwhile, enterprises should move beyond one-time technology donations toward ongoing collaborative partnerships that include teacher training and curriculum support. At the institutional level, pre-schools should establish technology integration committees to systematically evaluate AR applications and foster communities of practice for sharing implementation experiences, as the moderating effect of SEC suggests that structured collaboration mechanisms significantly enhance educational outcomes.

5. CONCLUSION AND RECOMMENDATIONS

The integration of augmented reality (AR) and innovative applications (IA) in pre-school education has shown significant potential to improve preschoolers' learning outcomes through interactive and immersive elements that align with their mental development. The implications of this study for early childhood education are that it provides insight into the importance of AR as a new way to make abstract concepts more engaging and concrete, and how this approach will both develop the cognitive and social skills of children's learning. However, IA has a definite role as it increases motivation and engagement at least as much as AR, albeit with less impact. In addition, school-enterprise collaboration (SEC) and partnerships between schools and technology enterprises cannot be ignored in their moderating effect on the implementation of these technologies. At the same time, schools benefit from the SEC by gaining access to the latest and most advanced AR and IA resources and expertise, which helps make these tools pedagogically aligned and scalable for broader use. It emphasises factors that should be considered when curating a program that integrates digital tools in pre-school education, with the SEC as an enabler of realising the full potential of AR and IA in promoting better educational outcomes.

Ethical Statement: This study did not require formal ethical approval from an Institutional Review Board (IRB) as it involved anonymous surveys and/or interviews with participants who provided informed consent. No personal or

sensitive data was collected, and all responses were treated confidentially for research purposes only. Participation was voluntary, and respondents were informed of the study's objectives before providing their input.

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