

Adoption of AR/VR in Early Childhood Education: Barriers Identification, Analysis, and Prioritization

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Abstract

The adoption of Augmented Reality (AR) and Virtual Reality (VR) in early childhood education offers promising opportunities to enhance learning. However, various barriers hinder their widespread adoption. This study identifies and prioritizes these barriers using the Analytic Hierarchy Process (AHP). Based on expert input and literature review, the barriers are grouped into seven categories: Technological; Economic and Financial; Educational and Pedagogical; Social and Cultural; Privacy, Legal and Ethical; Environmental and Sustainability; and Psychological and Health. Technological barriers emerged as the most critical, with limited technological infrastructure ranked as the top obstacle. Content availability and development is another major issue under this category. Economic barriers, especially high initial implementation costs, are the second most pressing concern. Teacher training and readiness ranked high among educational and pedagogical barriers. Privacy and safety concerns also pose significant challenges. Although environmental and psychological factors are relevant, they were found to be less influential in this context. The study offers practical recommendations for stakeholders to improve infrastructure, reduce costs, and train educators effectively. These efforts can accelerate the responsible adoption of AR/VR technologies in early education. Future research should explore long-term impacts and develop strategies to address these barriers for sustainable implementation and equitable access.

Keywords : *Augmented Reality, Barriers to Technology Adoption, Early Childhood Education, Educational Technology Adoption.*

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Introduction

Background

The landscape of education is undergoing a significant transformation, driven by rapid technology advancements (Huang & Yanan, 2024). Among these innovations, AR/VR have emerged as powerful tools capable of enhancing educational experiences across various levels (Pramanik, 2024). These immersive technologies hold the potential to revolutionize the way learners engage with content, particularly in early childhood education, where children are highly impressionable and eager to learn through exploration and interaction. AR and VR present innovative opportunities to create engaging and interactive learning environments, thus enriching the educational journey for young learners (Hu-Au & Lee, 2017). AR and VR technologies offer unique pedagogical benefits that align well with the developmental needs of young children. For instance, in a science lesson, children can use AR applications to visualize complex biological processes or view 3D models of the solar system in their classrooms. This not only makes learning more engaging but also helps children grasp abstract concepts through visual representation and interaction. On the other hand, VR creates entirely new environments for exploration and discovery. It immerses learners in virtual worlds where they can conduct experiments, engage in simulations, and explore historical events or distant places without leaving the classroom. Research indicates that immersive learning experiences foster deeper cognitive engagement and retention, making AR and VR particularly beneficial in early childhood education, where experiential learning plays a key role in development. By engaging multiple senses and providing hands-on experiences, these technologies can facilitate creativity, improve critical thinking skills, and enhance social interactions among peers.

Despite the clear potential of AR and VR technologies, their adoption in early childhood education remains limited. Various barriers hinder their widespread implementation, creating a significant gap between the availability of these technologies and their actual use in classrooms (Childs et al., 2021). Understanding these barriers is crucial for educators and policymakers who aim to leverage AR and VR to enhance learning outcomes for young children. One of the most significant barriers is the high cost associated with AR and VR hardware and software (Coburn et al., 2017). The financial implications of acquiring the

necessary equipment can deter educational institutions from investing in these technologies, especially in resource-constrained environments. Moreover, the cost of maintaining and updating technology can also pose challenges for schools. Another critical factor is the lack of infrastructure (Matsika & Zhou, 2021). Many early childhood education settings may not have the technological infrastructure, such as reliable internet connectivity or adequate physical space, to support AR and VR technologies effectively. Without a stable and robust technological foundation, attempts to adopt into the curriculum may lead to frustration among educators and students alike. Pedagogical concerns also play a significant role in hindering adoption. Many educators may lack the necessary training and confidence to effectively adopt these technologies into their teaching practices. The lack of clear guidelines on how to use AR and VR in alignment with early learning standards further complicates this issue. Additionally, concerns regarding the appropriateness of screen time and the potential impact of technology on young children's development contribute to hesitation among educators and parents alike. Moreover, the social context surrounding early childhood education cannot be overlooked. Parental apprehensions regarding the effects of screen time on children's health, social skills, and overall development can lead to resistance against adopting AR and VR technologies. This apprehension is compounded by the lack of empirical evidence demonstrating the long-term benefits of these technologies for young learners.

Given these multifaceted challenges, there is a pressing need for a systematic approach to identify, analyze, and prioritize the barriers. The complexity of these barriers calls for a structured framework that can address the diverse stakeholder perspectives, including educators, parents, administrators, and technology providers.

Need for Multi-Criteria Decision-Making (MCDM)

In light of the challenges outlined above, MCDM techniques become essential tools for addressing the complexity of barrier identification and prioritization in the context of AR and VR adoption. MCDM methods allow for the evaluation of multiple conflicting criteria and facilitate informed decision-making by providing a structured approach to problem-solving (Joshi, 2024a). One of the most widely used MCDM methods is the Analytic Hierarchy Process (AHP) (Joshi & Adhaye, 2024). AHP is a powerful

decision-making tool that helps stakeholders systematically evaluate complex problems by breaking them down into a hierarchy. This method allows for a detailed analysis of criteria and sub-criteria, facilitating a more nuanced understanding of the challenges at hand. By employing AHP, this research aims to provide a comprehensive analysis of the barriers to AR and VR adoption in early childhood education, thereby offering insights that can inform educators, administrators, and policymakers.

Purpose of the Research

The primary objective of this research is to identify, analyze, and prioritize the barriers to the adoption of AR and VR technologies in early childhood education using the AHP method. This study aims to fill the existing gap in the literature by:

1. Developing a comprehensive list of barriers affecting the adoption of AR/VR in early childhood education through a thorough review of existing literature and expert consultations.
2. Categorizing these barriers into broader themes, such as technological, pedagogical, economic, and social factors, to create a structured understanding of the challenges faced.
3. Applying the AHP method to prioritize these barriers based on input from key stakeholders, ensuring that the analysis reflects the diverse perspectives within the educational community.
4. Providing actionable recommendations for overcoming the most critical barriers, offering valuable insights for educators, policymakers, and technology providers to facilitate the successful adoption of AR/VR technologies in early childhood education.

Methodology

The methodology utilized for prioritizing barriers was a comprehensive, multi-dimensional approach, as illustrated in Fig. 1. The process began with an extensive literature review aimed at identifying a diverse array of potential criteria and factors. This review provided a solid foundation for comprehending existing research, industry trends, and perspectives on relevant issues. Following this, to refine and substantiate the identified

criteria, a survey and interview process was conducted with industry professionals, including two teachers, two AR/VR developers, and two parents, all of whom possessed over a decade of experience in the field. These stakeholders contributed their insights on the most relevant criteria based on their expertise and practical knowledge.

The responses collected from the surveys and interviews were systematically analyzed to uncover recurring themes and to rank the criteria based on their perceived importance. To conclude the process, a consensus-building exercise was conducted, involving further discussions and deliberations among the experts to finalize the most critical criteria for inclusion in the study. This methodology facilitated a thorough and inclusive approach to identifying factors, drawing on both literature and expert opinions to develop a comprehensive list of criteria.

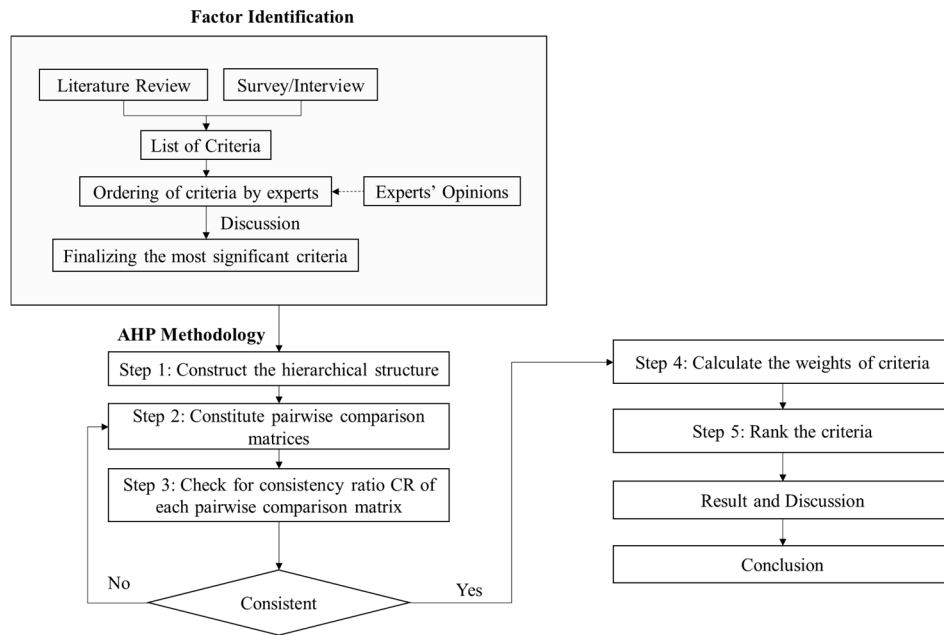


Figure 1. Research Methodology showing various research steps

The AHP methodology (Joshi, 2024b) used in this study followed a systematic process to prioritize criteria (as per Fig. 1):

Step 1: Construct the Hierarchical Structure

The hierarchical structure was constructed to organize the criteria into a logical framework. This structure consisted of a top-level criterion representing the overall objective, with subsequent levels containing sub-criteria related to different aspects.

Step 2: Constitute Pair wise Comparison Matrices

Pairwise comparison matrices were developed to capture the relative importance of criteria at each level of the hierarchy. Experts were asked to compare each criterion against every other criterion within the same level, assigning numerical values based on their perceived importance as shown in Table 1. The majority of responses were used as the basis for managing multiple responses.

Table 1. *Linguistic measures of importance*

Degree of Preference	Score Index (SI)
Absolutely more importance(AM)	9
Very high importance(VH)	7
High importance(HI)	5
Slightly more importance(SM)	3
Equal importance(EI)	1
Slightly lower importance(SL)	1/3
Low importance(LI)	1/5
Very low importance(VL)	1/7
Absolutely low importance(AL)	1/9

Step 3: Calculate the Weights of Criteria

Using the validated pairwise comparison matrices, the weights of criteria were calculated through the AHP algorithm using eq(1) and eq(2). These weights represented the relative importance of each criterion in achieving the overall objective.

$$GM_i = (\prod_{i=1}^A x_i)^{\frac{1}{A}} \quad (1)$$

Where, GM_i represents the geometric mean, x_i are the individual values of alternatives, A is the total number of factors/alternatives.

$$\text{Weight}_i = \frac{GM_i}{\sum_{i=1}^A GM} \quad (2)$$

Step 4: Rank the Criteria

Based on their calculated weights, the criteria were ranked in order of importance. This ranking provided valuable insights into which criteria were considered most critical for addressing barriers and facilitating the transition to a CE.

Step 5: Check for Consistency Ratio (CR)

To ensure the reliability of the pairwise comparisons, CRs were calculated for each matrix using eq(3). If the CR fell within an acceptable range (10%), indicating reasonable consistency in the judgments, the comparisons were deemed valid and proceeded to the next step.

$$CR = \frac{CI}{RI} \quad (3)$$

The Consistency Index (CI) is calculated as follows using eq(4):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (4)$$

Where, the maximum Eigenvalue of the matrix, denoted as $\lambda_{\max}$, is used in conjunction with the number of criteria (n) in the calculation. The Random Index (RI) used in eq(3) is determined by considering the number of criteria utilized in the research study.

By following this structured AHP methodology, the study was able to systematically prioritize criteria and provide actionable recommendations for stakeholders.

Results and Discussion

Barriers to the Adoption of AR and VR in Early Childhood Education

Despite the advantages offered by AR and VR, their adoption in early childhood

education is often hindered by various barriers. The hierarchical structure of identified barriers is shown in Fig. 2. These barriers are broadly categorized into technological, economic, pedagogical, and social factors etc. These barriers are detailed as follows:

Technological Barriers (B₁)

- **Limited Technological Infrastructure (B₁₁)** – Many educational institutions lack the essential hardware and software infrastructure to support AR and VR technologies. Limited access to devices such as VR headsets, high-performance computers, and AR-compatible tablets restricts the ability to incorporate these innovative tools into the curriculum. Without the proper infrastructure, schools cannot fully leverage the potential of AR and VR to enhance learning experiences for young children (Adelana et al., 2023).
- **Content Availability and Development (B₁₂)** – The scarcity of high-quality, age-appropriate content tailored for AR and VR applications poses a significant challenge. While there are some existing AR and VR educational resources, they may not align with specific learning objectives or the developmental needs of young learners. Additionally, the creation of custom content can be resource-intensive, requiring expertise that many educational institutions may lack. This limitation can result in missed opportunities for immersive learning experiences (Al-Ansi et al., 2023).
- **Technical Challenges (B₁₃)** – Integrating AR and VR technologies can be fraught with technical challenges. Software bugs, compatibility issues, and difficulties in installation can disrupt the learning experience. Educators may encounter frustrations when dealing with unforeseen technical problems, which can deter them from using these technologies. A lack of reliable technical support further exacerbates these challenges, making it difficult for educators to implement AR and VR seamlessly into their teaching practices (Basumatary & Maity, 2023).
- **Dependency on Internet Connectivity (B₁₄)** – Many AR and VR applications rely on stable internet connections to function effectively, particularly those that utilize cloud-based content or real-time data. Inadequate or inconsistent internet access can hinder the effectiveness of these technologies in the classroom, leading to interruptions during lessons. Educational institutions in rural or underfunded areas

may face greater challenges regarding internet connectivity, further limiting their ability to adopt AR and VR.

- **Short Product Lifecycles and Obsolescence (B₁₅)** – The rapid pace of technological advancement results in short product lifecycles for AR and VR hardware and software. Educational institutions may struggle to keep up with the latest developments, leading to the obsolescence of existing technologies. As new models and updates are released frequently, schools may find it challenging to allocate resources for continuous upgrades, creating a barrier to long-term investment in AR and VR solutions.
- **Immature Software Ecosystem (B₁₆)** – A lack of well-developed, age-appropriate AR/VR educational software for early childhood may hinder the adoption of these technologies (Li et al., 2020).
- **Technical Skills Gap among IT Support Staff (B₁₇)** – A lack of skilled IT support staff can hinder the effective implementation of AR and VR technologies (Lee, 2012). Many educational institutions may not have personnel with the technical expertise required to troubleshoot problems, maintain equipment, and provide adequate training to educators. This skills gap can lead to downtime and frustration, ultimately affecting the successful adoption of AR and VR in the classroom.
- **Usability for Young Children (B₁₈)** – Usability concerns related to AR and VR applications designed for young children also pose significant barriers (Tuli&Mantri, 2021). Not all AR and VR interfaces are intuitively designed for young learners, which can impact their engagement and overall learning experience. If children find the technology difficult to navigate or understand, it may lead to disengagement, undermining the intended educational benefits of these immersive technologies.

Economic and Financial Barriers (B₂)

The adoption of AR/VR is also hampered by several economic and financial barriers. These issues can significantly affect schools' ability to adopt and sustain AR/VR technologies in their curricula. The key economic and financial barriers are outlined below:

- **High Initial Cost of Implementation (B₂₁)** – The upfront investment required to implement AR and VR technologies in educational institutions is one of the most significant economic barriers (Machala et al., 2022). This expense includes the

procurement of hardware, such as VR headsets, AR-compatible devices, and high-performance computers, as well as necessary software licenses and applications. In addition, schools need to invest in peripheral equipment, such as motion sensors, controllers, and specialized learning spaces that can accommodate AR/VR activities. For many educational institutions, particularly those with limited budgets, the high initial outlay for these technologies is a major deterrent. Schools must weigh the benefits of AR/VR adoption against the costs, which can prevent many from exploring these innovative solutions.

- **Cost-benefit Analysis and ROI Uncertainty (B₂₂)** – Schools often struggle to justify the costs of adopting AR/VR technologies due to uncertainty about the return on investment (ROI). With limited data available on the long-term benefits and impact of AR/VR in education, administrators face difficulties in conducting a thorough cost-benefit analysis. This uncertainty can make it harder to commit significant resources to these technologies.
- **Limited Financial Resources for Schools (B₂₃)** – Many schools, particularly in underfunded regions, face financial constraints that limit their ability to adopt new technologies (Alalwan et al., 2020). Educational institutions must prioritize essential needs, such as staffing, infrastructure, and basic educational tools, leaving little room for investments in AR/VR, which can be seen as non-essential or luxury items.
- **Unproven ROI and Financial Sustainability (B₂₄)** – Even if initial funds are secured for AR/VR implementation, concerns about financial sustainability remain. The cost of maintaining and upgrading the hardware and software, as well as providing training for staff, poses long-term financial challenges. Without a clear demonstration of ROI, schools may be reluctant to allocate ongoing resources, making it difficult to sustain AR/VR initiatives in the long run.
- **Equity and Inclusion Challenges (B₂₅)** – The high costs of AR/VR can widen the digital divide, with wealthier schools having access to the technology while underfunded schools struggle, leading to disparities in educational opportunities for students.

Educational and Pedagogical Barriers (B₃)

- **Teacher Training and Readiness (B₃₁)** – The successful adoption of AR/VR in early childhood education requires well-trained teachers who are comfortable using these technologies (Rudnik, 2022). Many educators lack the necessary training and support to effectively implement AR/VR in the classroom, which can hinder adoption and reduce the potential benefits of these tools. Comprehensive teacher training programs are essential to bridge this gap.
- **Pedagogical Fit (B₃₂)** – One key concern is whether AR/VR aligns with early childhood educational pedagogy (Bertrand et al., 2024). The effectiveness of these technologies depends on their ability to support age-appropriate learning strategies. If AR/VR tools are not well-adopted into the existing curriculum or do not complement developmental needs, their impact may be limited.
- **Short Attention Span of Young Learners (B₃₃)** – Young children generally have shorter attention spans (Musthafa, 2010), which may affect their ability to engage with AR/VR technologies for extended periods. If not used effectively, AR/VR might cause distractions rather than enhancing focus, thereby limiting its educational effectiveness in early childhood settings.
- **Lack of Long-Term Research on Learning Outcomes (B₃₄)** – There is limited long-term research on the impact of AR/VR on learning outcomes in early childhood education. This creates uncertainty about how these technologies influence cognitive development, social skills, and overall educational growth. Without clear evidence, educators may be reluctant to adopt AR/VR at scale.
- **Unbalanced Focus on Technology over Learning (B₃₅)** – There is a risk that the novelty of AR/VR technologies could overshadow core educational goals, with more emphasis placed on the technology itself rather than on how it enhances learning. A well-balanced approach is needed to ensure that the focus remains on pedagogical outcomes rather than simply using technology for its own sake.
- **Unclear Classroom Management Models (B₃₆)** – AR/VR introduces new challenges in classroom management, particularly with younger learners. Teachers may struggle with keeping students on task while using immersive technologies, managing device usage, and ensuring equitable participation. The lack of established classroom

management models for AR/VR further complicates implementation.

- **Insufficient Incentives for AR Developers to Focus on Early Education (B₃₇)** – Many AR/VR developers are more focused on markets like gaming or higher education, leaving a gap in the availability of customized content for early childhood education. This lack of dedicated resources and incentives for developers means that AR/VR tools may not be optimized for the needs of young learners, limiting their effectiveness in early education settings.
- **Limited Evidence of Customization for Individual Learning Styles (B₃₈)** – Every child learns differently, and while AR/VR has the potential to offer personalized learning experiences, there is currently limited evidence of how well these technologies can be tailored to accommodate individual learning styles. Without proper customization, AR/VR may not fully support differentiated instruction, which is critical for young learners.

Social and Cultural Barriers (B₄)

- **Resistance to Change (Educators and Parents) (B₄₁)** – Both educators and parents may resist the adoption of AR/VR technologies into early childhood education due to unfamiliarity or skepticism about their benefits (Jalo & Pirkkalainen, 2024). Some may prefer traditional teaching methods and are hesitant to embrace new, technology-driven approaches. This resistance can slow down the adoption of AR/VR in classrooms, as schools must work to build trust and confidence in these tools.
- **Parental Concerns over Screen Time (B₄₂)** – Parents often express concerns about the amount of screen time their children are exposed to, particularly at a young age (Farooqui et al., 2023). The introduction of AR/VR in education, which increases digital interactions, can exacerbate these worries. Parents may fear that prolonged use of AR/VR devices could have negative effects on their children's physical health, cognitive development, or social skills.
- **Cultural and Regional Differences (B₄₃)** – The adoption of AR/VR technologies can be influenced by cultural and regional attitudes toward technology and education. In some areas, there may be a strong emphasis on traditional educational practices, making it difficult to introduce innovative technologies like AR/VR. Additionally,

access to AR/VR technologies may vary significantly between regions, further widening the gap in educational opportunities.

- **Competing Educational Priorities (B₄₄)** – Schools often face competing educational priorities, such as meeting core curriculum requirements, addressing resource limitations, and improving teacher-student ratios (Alalwan et al., 2020). The introduction of AR/VR may be seen as a secondary or non-essential initiative, which may delay its adoption in favor of more pressing educational concerns.
- **Social Acceptance of AR for Young Children (B₄₅)** – The general social perception of using advanced technologies like AR for young children can vary. Some parents and educators may view these technologies as too advanced or unnecessary for early childhood education, believing that traditional methods better support child development. Social acceptance plays a key role in whether AR/VR technologies can be successfully adopted into classrooms.

Privacy, Legal, and Ethical Barriers (B₅)

- **Privacy and Safety Concerns (B₅₁)** – As AR/VR technologies collect and process personal data, there are concerns over the safety and privacy of young learners (Kaur et al., 2024). The risk of data breaches or misuse of sensitive information poses a significant barrier to adoption. Schools and parents must be assured that students' data will be protected and that the technologies are safe to use.
- **Data Privacy and Security (B₅₂)** – Data security is a critical issue when implementing AR/VR in education, as these systems often collect user data to enhance experiences. Safeguarding this data, particularly for young children, is vital. Schools must adopt strict data protection measures to safeguard student information and avoid potential legal issues.
- **Fragmented or Inconsistent Regulatory Guidelines (B₅₃)** – The regulatory landscape surrounding AR/VR use in education is often fragmented, with inconsistent guidelines across different regions or countries. This lack of standardization creates uncertainty for schools and developers about how to comply with local privacy and data protection laws, further complicating the adoption process.
- **Ethical Concerns Regarding Data Collection (B₅₄)** – The collection and analysis of

data from young learners through AR/VR technologies raise ethical concerns, especially regarding informed consent and the potential exploitation of data for commercial purposes (Steele et al., 2020). Schools need to be transparent with parents and students about what data is being collected and how it will be used, ensuring ethical practices are followed.

- **Legal Concerns and Compliance with Standards (B₅₅)** – Educational institutions adopting AR/VR technologies must navigate complex legal frameworks, including compliance with regulations like the Children’s Online Privacy Protection Act (COPPA) or the General Data Protection Regulation (GDPR). Schools need to ensure that they are fully compliant with these laws to avoid legal risks, while also protecting students' rights and privacy.

Environmental and Sustainability Barriers (B₆)

- **Sustainability and Environmental Concerns (B₆₁)** – The adoption of AR/VR technologies raises questions about their sustainability. The production, use, and disposal of hardware, such as headsets and related equipment, contribute to electronic waste. Educational institutions may face challenges aligning the use of AR/VR with their sustainability goals, as these technologies often have short lifecycles, requiring frequent upgrades and replacements.
- **Environmental Impact of AR Hardware (B₆₂)** –The manufacturing of AR/VR hardware involves the use of non-renewable resources and energy-intensive processes, leading to a significant carbon footprint. Additionally, the disposal of outdated or malfunctioning devices contributes to e-waste, creating environmental risks. Schools adopting AR/VR technologies must consider these environmental impacts when planning for implementation and disposal.

Psychological and Health Barriers (B₇)

- **Potential Overstimulation of Young Learners (B₇₁)** – AR and VR can be highly immersive, which may lead to sensory overload for young children. Overstimulation can impact concentration, resulting in decreased focus on learning objectives and potentially causing anxiety or stress in young learners who may struggle to process

the influx of sensory information (Jones et al., 2023).

- **Health and Ergonomic Concerns (B₇₂)** – Extended use of AR/VR devices raises health concerns, including eye strain, headaches, and posture-related issues due to the ergonomic design of headsets and other hardware. The discomfort experienced by young children during prolonged use can limit the effective use of these technologies in education.
- **Screen Time and Physical Effects (B₇₃)** – Increased screen time due to AR/VR activities adds to concerns about the physical effects on young children, including the risk of eye fatigue, disrupted sleep patterns, and reduced physical activity (Singh, 2022). Balancing the use of AR/VR with traditional learning methods is essential to mitigate these negative health impacts.

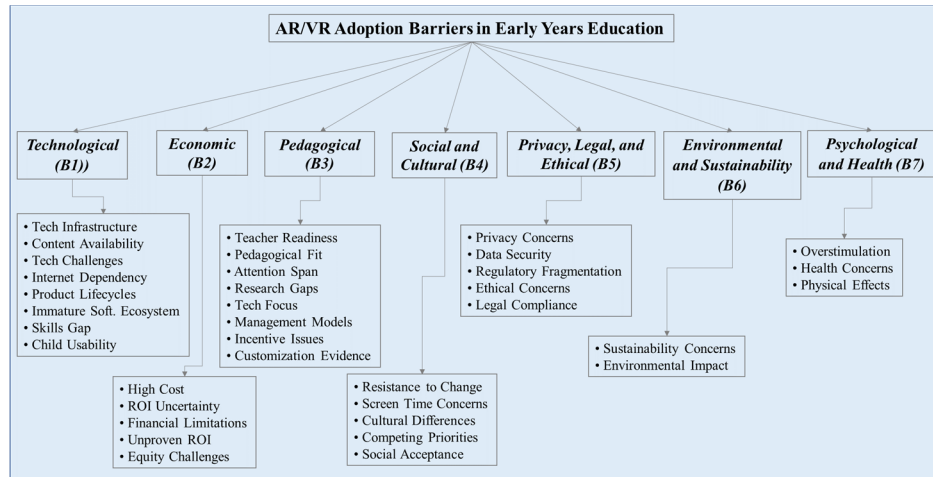


Figure 2. Hierarchical structure of factors affecting AR/VR adoption

Analysis of Barriers

The analysis of barriers to the adoption of AR/VR yielded significant insights. The findings illustrate a prioritized list of barriers categorized into technological, economic, educational, social, privacy, legal, environmental, and psychological dimensions. The pairwise comparison matrix for main and subcategories categories is given in Table 2 and Table 3. On the other hand, global weights and rank of each factor in consideration is given in Table 4.

Table 2. *Pairwise Comparison Matrix for main categories*

Barriers	B1	B2	B3	B4	B5	B6	B7	Weight
Technological (B1)	1.00	2.00	3.00	5.00	3.00	4.00	6.00	0.338
Economic & Financial (B2)	0.50	1.00	2.00	4.00	2.00	3.00	5.00	0.223
Educational & Pedagogical (B3)	0.33	0.50	1.00	3.00	2.00	2.00	4.00	0.152
Social & Cultural (B4)	0.20	0.25	0.33	1.00	0.50	2.00	3.00	0.073
Privacy, Legal, & Ethical (B5)	0.33	0.50	0.50	2.00	1.00	3.00	2.00	0.113
Environmental & Sustainability (B6)	0.25	0.33	0.50	0.50	0.33	1.00	2.00	0.061
Psychological & Health (B7)	0.17	0.20	0.25	0.33	0.50	0.50	1.00	0.040

Table 3. *Pairwise Comparison Matrix for subcategories*

Technological Barriers (B1)									
	B11	B12	B13	B14	B15	B16	B17	B18	Weight
B11	1.00	3.00	4.00	2.00	5.00	6.00	3.00	7.00	0.32
B12	0.33	1.00	3.00	2.00	4.00	5.00	2.00	6.00	0.21
B13	0.25	0.33	1.00	3.00	2.00	4.00	2.00	5.00	0.14
B14	0.50	0.50	0.33	1.00	3.00	5.00	2.00	4.00	0.13
B15	0.20	0.25	0.50	0.33	1.00	2.00	3.00	4.00	0.08
B16	0.17	0.20	0.25	0.20	0.50	1.00	2.00	3.00	0.05
B17	0.33	0.50	0.50	0.50	0.33	0.50	1.00	3.00	0.06
B18	0.14	0.17	0.20	0.25	0.25	0.33	0.33	1.00	0.03
Economic and Financial Barriers (B2)									
	B21	B22	B23	B24	B25	Weight			
B21	1.00	2.00	3.00	2.00	4.00	0.38			
B22	0.50	1.00	2.00	2.00	3.00	0.25			
B23	0.33	0.50	1.00	0.50	2.00	0.12			
B24	0.50	0.50	2.00	1.00	2.00	0.17			
B25	0.25	0.33	0.50	0.50	1.00	0.08			
Educational & Pedagogical (B3)									
	B31	B32	B33	B34	B35	B36	B37	B38	Weight
B31	1.00	2.00	3.00	4.00	3.00	2.00	3.00	2.00	0.26
B32	0.50	1.00	2.00	3.00	2.00	2.00	2.00	1.00	0.17
B33	0.33	0.50	1.00	2.00	2.00	1.00	2.00	1.00	0.12
B34	0.25	0.33	0.50	1.00	2.00	0.50	1.00	0.50	0.07
B35	0.33	0.50	0.50	0.50	1.00	0.33	0.50	0.33	0.05

Table 3. *Pairwise Comparison Matrix for subcategories**(continued)*

Educational & Pedagogical (B3)									
	B31	B32	B33	B34	B35	B36	B37	B38	Weight
B36	0.50	0.50	1.00	2.00	3.00	1.00	2.00	1.00	0.13
B37	0.33	0.50	0.50	1.00	2.00	0.50	1.00	0.50	0.07
B38	0.50	1.00	1.00	2.00	3.00	1.00	2.00	1.00	0.14
Social and Cultural Barriers (B4)									
	B41	B42	B43	B44	B45	Weight			
B41	1.00	2.00	3.00	4.00	3.00	0.40			
B42	0.50	1.00	2.00	3.00	2.00	0.24			
B43	0.33	0.50	1.00	2.00	2.00	0.16			
B44	0.25	0.33	0.50	1.00	2.00	0.10			
B45	0.33	0.50	0.50	0.50	1.00	0.09			
Privacy, Legal, & Ethical (B5)									
	B51	B52	B53	B54	B55	Weight			
B51	1.00	2.00	3.00	4.00	3.00	0.40			
B52	0.50	1.00	2.00	3.00	2.00	0.24			
B53	0.33	0.50	1.00	2.00	2.00	0.16			
B54	0.25	0.33	0.50	1.00	2.00	0.10			
B55	0.33	0.50	0.50	0.50	1.00	0.09			
Environmental & Sustainability (B6)									
	B61	B62	Weight						
B61	1.00	2.00	0.67						
B62	0.50	1.00	0.33						
Psychological and Health Barriers (B7)									
	B71	B72	B73	Weight					
B71	1.00	2.00	3.00	0.54					
B72	0.50	1.00	2.00	0.30					
B73	0.33	0.50	1.00	0.16					

The Technological Barriers (B1) emerged as the most critical category, with a class weight of 0.338. Within this category, Limited Technological Infrastructure (B11) ranked highest, with an individual weight of 0.317 and a global weight of 0.107, underscoring the necessity for foundational technology in educational settings. Content Availability and Development (B12) and High Initial Cost of Implementation (B21) followed closely, reflecting the importance of not only technological readiness but also financial considerations

Table 4. *Global weights and Rank*

Classification	Class weight	Barrier	Global Weight	Rank
Technological Barriers (B1)	0.338	Limited Technological Infrastructure (B11)	0.107	1
		Content Availability and Development (B12)	0.070	3
		Technical Challenges (B13)	0.047	5
		Dependency on Internet Connectivity (B14)	0.043	7
		Short Product Lifecycles and Obsolescence (B15)	0.026	14
		Immature Software Ecosystem (B16)	0.017	25
		Technical Skills Gap among IT Support Staff (B17)	0.020	19
		Usability for Young Children (B18)	0.009	32
Economic and Financial Barriers (B2)	0.223	High Initial Cost of Implementation (B21)	0.084	2
		Cost-benefit Analysis and ROI Uncertainty (B22)	0.055	4
		Limited Financial Resources for Schools (B23)	0.027	13
		Unproven ROI and Financial Sustainability	0.039	10
		Equity and Inclusion Challenges (B25)	0.018	22
Educational and Pedagogical Barriers (B3)	0.152	Teacher Training and Readiness (B31)	0.039	9
		Pedagogical Fit (B32)	0.025	15
		Short Attention Span of Young Learners (B33)	0.017	24
		Lack of Long-Term Research on Learning Outcomes (B34)	0.010	30
		Unbalanced Focus on Technology over Learning (B35)	0.008	33
		Unclear Classroom Management Models (B36)	0.019	20
		Insufficient Incentives for AR Developers to Focus on Early Education (B37)	0.011	29
		Limited Evidence of Customization for Individual Learning Styles (B38)	0.021	17
Social and Cultural Barriers (B4)	0.073	Resistance to Change (Educators and Parents)	0.030	11
		Parental Concerns over Screen Time (B42)	0.018	21
		Cultural and Regional Differences (B43)	0.012	28
		Competing Educational Priorities (B44)	0.008	34
		Social Acceptance of AR for Young Children (B45)	0.007	35
Privacy, Legal, and Ethical Barriers (B5)	0.113	Privacy and Safety Concerns (B51)	0.045	6
		Data Privacy and Security (B52)	0.028	12
		Fragmented or Inconsistent Regulatory Guidelines (B53)	0.018	23
		Ethical Concerns Regarding Data Collection (B54)	0.012	27
		Legal Concerns and Compliance with Standards (B55)	0.010	31
Environmental and Sustainability Barriers (B6)	0.061	Sustainability and Environmental Concerns (B61)	0.041	8
		Environmental Impact of AR Hardware (B62)	0.020	18
Psychological and Health Barriers (B7)	0.040	Potential Overstimulation of Young Learners (B71)	0.022	16
		Health and Ergonomic Concerns (B72)	0.012	26
		Screen Time and Physical Effects (B73)	0.007	36

in the effective adoption of AR/VR.

Economic and Financial Barriers (B2), with a class weight of 0.223, highlighted significant challenges related to High Initial Costs of Implementation (B21) and Cost-benefit Analysis and ROI Uncertainty (B22), indicating that financial constraints could hinder widespread adoption. The priority given to these economic factors suggests that decision-makers need to address funding and resource allocation to support the adoption of AR/VR technologies.

In the Educational and Pedagogical Barriers (B3) category, Teacher Training and Readiness (B31) and the Pedagogical Fit (B32) were notable factors affecting implementation, with individual weights of 0.258 and 0.165, respectively. These findings emphasize the need for comprehensive training and a strong alignment of AR/VR tools with educational goals.

Social and Cultural Barriers (B4) and Privacy, Legal, and Ethical Barriers (B5), with class weights of 0.073 and 0.113 respectively, revealed challenges related to Resistance to Change (Educators and Parents) and Privacy and Safety Concerns. The emphasis on social acceptance and regulatory frameworks indicates that addressing perceptions and ethical considerations is vital for successful AR/VR adoption. Lastly, Environmental and Sustainability Barriers (B6) and Psychological and Health Barriers (B7) had lower weights, highlighting that while important; they may not be the foremost concerns at this stage. Nonetheless, barriers such as Potential Overstimulation of Young Learners (B71) and Sustainability and Environmental Concerns (B61) remain areas for ongoing monitoring and research.

The top-ranking barriers-particularly Limited Technological Infrastructure and High Initial Costs-suggest that without addressing these foundational issues, the potential benefits of AR/VR technologies may remain untapped. This aligns with existing literature, which indicates that infrastructural deficiencies can significantly hinder the effective implementation of new educational technologies.

The significant emphasis on Teacher Training and Readiness reinforces the notion that educators must be equipped not only with the necessary skills to utilize AR/VR technologies but also with pedagogical frameworks that enhance student learning outcomes. The lack of preparation and training for educators has been cited as a common barrier in previous studies.

Moreover, the findings regarding Resistance to Change reflect broader cultural attitudes toward technology in education. Fostering a supportive culture for technological adoption requires addressing educators' and parents' concerns, particularly regarding screen time and the balance of educational priorities (Blum-Ross & Livingstone, 2016).

The substantial weight given to Privacy and Safety Concerns underlines the importance of developing robust guidelines and best practices for data usage in educational settings. As regulatory environments continue to evolve, it will be critical for AR/VR developers and educators to ensure compliance with established standards and to prioritize student safety (Kaur et al., 2024).

While lower-ranking barriers such as Environmental Impact and Psychological Effects may not be immediate priorities, they warrant attention as AR/VR technologies become more adopted into educational contexts. Continuous research in these areas is necessary to mitigate potential negative outcomes associated with prolonged use of AR/VR technologies among young learners.

Guidelines and Policy Implications

- **Infrastructure Investment:** Policymakers and educational institutions should prioritize investments in the technological infrastructure necessary for effective AR/VR implementation. This includes ensuring adequate hardware, software, and internet connectivity to facilitate seamless use of these technologies.
- **Financial Support and Incentives:** Financial models need to be developed that provide clear benefits and return on investment (ROI) for schools adopting AR/VR technologies. Exploring funding opportunities and partnerships can alleviate financial burdens on educational institutions.
- **Comprehensive Teacher Training:** Developing robust training programs that equip educators with the necessary skills and knowledge for effective AR/VR use in the classroom is essential. Ongoing professional development should focus on pedagogical strategies that enhance learning outcomes through technology adoption.
- **Stakeholder Engagement:** Involving parents, educators, and community members in discussions about the benefits and challenges of AR/VR technologies can foster a supportive environment. Addressing concerns about screen time and educational

priorities will be crucial for promoting acceptance.

- **Ethical and Regulatory Frameworks:** Establishing clear guidelines for data privacy and safety concerning AR/VR technologies in educational settings is imperative. Educators and developers should collaborate to ensure compliance with legal standards while prioritizing the well-being of young learners.
- **Sustainability Practices:** As AR/VR technologies are adopted into education, considerations for environmental sustainability should be factored into their development and usage. Ongoing evaluation of the environmental impact of AR/VR hardware is recommended.
- **Research and Monitoring:** Continuous research on the psychological effects of AR/VR technologies and their long-term impact on learning outcomes should be prioritized. Educational stakeholders should monitor usage patterns to ensure that potential overstimulation or negative health effects are mitigated.

Conclusion

The study provides valuable insights into the multifaceted challenges that hinder the effective implementation of AR and VR technologies in early childhood education. Through a systematic approach utilizing the Analytic Hierarchy Process, we identified and ranked various barriers across technological, economic, educational, social, privacy, environmental, and psychological dimensions. The findings revealed that limited technological infrastructure, high initial costs, and privacy concerns are the most significant barriers to the adoption of AR/VR in early education settings. Addressing these barriers requires a collaborative effort from educators, policymakers, and technology developers to create a conducive environment for adopting AR/VR technologies in early learning.

The study's findings may be influenced by the limited number of experts consulted. Increasing the sample size and including diverse stakeholders from various educational contexts could yield a more holistic view of the barriers. The research primarily reflects perspectives from specific regions or countries, which may not be generalizable to other contexts with different educational systems and technological landscapes. The rapid

evolution of AR/VR technologies may result in the emergence of new barriers or changes in the significance of existing barriers over time. Ongoing research is necessary to keep up with these developments. Future research may extend the present AHP-based prioritization by adopting hybrid MCDM frameworks that capture both uncertainty and causal interdependencies among barriers. Techniques such as Fuzzy AHP can better model the vagueness inherent in expert judgments, while DEMATEL-based or integrated AHP–DEMATEL approaches can reveal cause–effect relationships among technological, economic, and pedagogical barriers, similar in spirit to ISM/MICMAC analysis. Such methods would enable researchers to distinguish driving barriers from dependent ones, offering deeper structural insights beyond ranking alone. Expanding expert panels, incorporating longitudinal evidence, and conducting cross-context comparisons would further strengthen the explanatory and policy relevance of future studies.

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