

How Should Immersive Learning Spaces Be Designed? Formalising the Intersection Between School Design and XR Technologies

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Abstract

In recent years, the design of learning spaces has increasingly gained traction in school contexts, capturing the attention of scholars, architects, and educational communities. Following a long period of standstill in the condition of school buildings, European countries have undertaken significant efforts to renovate and modernise their school facilities through new policies and design guidelines. At the same time, a major trend in education has emerged: the adoption of eXtended Reality (XR) technologies to support and enhance learning experiences. However, despite the proliferation of research and practical implementations in both fields, physical space design and immersive learning experiences, there remains a lack of an integrated theoretical framework linking the two. Therefore, this study aims at creating a unified theoretical framework to represent and describe how virtual environments supporting learning experiences should be designed, outlining first practical indications on how the various key principles to design physical spaces can be translated into virtual environments. Using thematic analysis, the research examines key international documents and guidelines to identify the core design features and pedagogical principles on both fronts. These are then intertwined through the construction of a correlation matrix that highlights alignments and points of translation between physical and virtual design strategies. While the qualitative findings of this study require further analyses such as ethnographic techniques or quantitative assessments, this work represents a first step towards bridging the fields of educational architecture and immersive learning in that it provides preliminary design guidelines for XR learning environments.

Keywords: school design, immersive learning environments, XR

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Introduction

For much of the twentieth century, the spatial configuration of classrooms remained largely unchanged, continuing to reproduce standardised layouts that reflected a transmissive model of education. Only recently has this long-standing condition begun to shift. The design of educational spaces has garnered renewed attention in discussions on 21st-century education, emerging as a central concern for scholars, designers, educators, and school communities. Across Europe, this renewed focus has translated into extensive renovation initiatives, supported by new policies and design frameworks aimed at improving the quality and performance of school buildings. Concurrently, educational practices are being reshaped by the increasing adoption of eXtended Reality (XR) technologies. These technologies introduce immersive digital environments that allow learners to engage with content in ways that extend beyond the limits of the physical classroom, whether by navigating historical settings, interacting with abstract scientific phenomena, or collaborating within shared virtual spaces. In doing so, XR expands the spatial and experiential dimensions of learning and challenges traditional assumptions about where educational activities can take place.

Although both developments seek to redefine learning environments, they have largely evolved independently rather than in dialogue. On the one hand, the redesign of physical school spaces has mainly concentrated on the material qualities of space, such as spatial organisation, comfort, safety, and functional programming. On the other hand, the development of immersive learning environments has been driven by a focus on experience, prioritising immersion, interaction, and the feeling of presence within digital worlds. As a result, the physical and virtual dimensions of learning environments are often treated as separate domains, despite their overlapping educational goals. This separation, therefore, reveals a deeper issue: the absence of a shared conceptual framework capable of linking the principles that shape physical learning spaces with those that inform the design of immersive digital ones. Without a common language to connect these domains, both research and practice remain fragmented, making it difficult to develop integrated learning environments that fully respond to contemporary pedagogical needs across physical and virtual contexts.

This paper contributes to this integration by examining influential European policies and guidelines for school design alongside international recommendations for immersive learning environments. Through a thematic analysis, it identifies key pedagogical and spatial principles present in both domains and brings them into relation through a correlation matrix. By revealing alignments and tensions between design criteria for physical and virtual spaces, the matrix provides a tool for bridging these parallel discourses and for informing future approaches to learning environment design that span material and digital realms.

Methodology

To investigate how learning spaces, both physical and virtual, are currently being reimaged and to identify emerging design features across these domains, this study adopted a qualitative document-based methodology. The analysis drew on a targeted selection of policy documents, guidelines, and reports widely recognised as influential within the design of educational spaces and immersive learning environments.

Two complementary bodies of literature were examined: documents addressing the design of physical educational spaces and those focusing on the design of XR-based learning environments. For the design of physical learning spaces, seven key documents were

selected. Four reflect recent Italian design directions and policy frameworks: the latest *Legambiente Report* (2024), the *1+4 Learning Areas Manifesto* developed by INDIRE (2016), *Piano Scuola 4.0* (Futura PNRR, 2022a), and the *Futura* design guidelines (Futura PNRR, 2022b). To situate these national perspectives within a broader European context, three additional documents were included: the *OECD Handbook for Innovative Learning Environments* (OECD, 2017), *Spazi educativi e architetture scolastiche* (Borri, 2016), and *The Classroom Has Broken* (Borri, 2018). Although the latter two were produced by the Italian research institute INDIRE, they explicitly integrate international case studies and perspectives from several European countries, including Finland, Germany, and Sweden. With respect to XR learning environments, the selection revealed a more limited body of design-oriented literature. Three documents were identified that explicitly address the design of virtual learning spaces, rather than focusing solely on learning experiences or instructional strategies: *Designing Effective VR Learning Environments: Immersive Strategies and Methods* (Pradhan & Mantry, 2025), *The Immersive Classroom: Create Customized Learning Experiences with AR/VR* (Donally, 2022), and *Virtual Reality in Education: Designing Immersive and Innovative Learning Experiences* (Sulisworo et al., 2023).

All selected documents were reviewed and analysed using Thematic Analysis, a qualitative method that supports the identification, interpretation, and reporting of recurring patterns within textual data (Braun & Clarke, 2006). The analysis was applied consistently across both sets of documents to extrapolate the main pedagogical and spatial principles, and it involved a systematic coding process in which relevant excerpts were assigned to conceptual categories capturing key design principles and criteria (Vaismoradi & Snelgrove, 2019). These thematic categories were then synthesised into a unified framework intended to support the design and development of immersive learning environments informed by spatial design knowledge.

Subsequently, to examine relationships among the identified codes and themes, correlation matrices were generated using MAXQDA, a software for qualitative and mixed-methods data analysis. These matrices visualised code co-occurrences, enabling a deeper exploration of how different design concepts and features related to one another within and across the two domains. As a final step, an overarching correlation matrix was constructed to integrate all themes emerging from the analysis. This comprehensive matrix mapped points of contact between physical and virtual learning environments, highlighting areas where architectural and pedagogical design concerns intersected with the affordances and constraints of immersive technologies. In doing so, it made visible shared design features and provided a structured basis for bridging the design of physical and virtual learning spaces.

Results and Discussion

Thematic Analysis Results

The thematic analysis revealed distinct yet complementary sets of design principles for physical learning spaces and immersive XR learning environments. While the two domains were articulated through different vocabularies and priorities, the results highlighted meaningful points of convergence as well as structural gaps that help explain their parallel development.

Concerning physical learning environments, the analysis identified five core themes: “Building quality”, “Sustainability”, “Pedagogical Design of Spaces”, “Inclusion”, and “Community”, each capturing a critical dimension of contemporary school design.

The first theme, “*Building Quality*”, refers to the importance of ensuring high-quality built environments, which depend on several interrelated aspects. A first dimension is represented by *Spatial organization* (n = 17), highlighting the need to carefully consider the size, proportions, and distribution of spaces (*Size and distribution*) to support flexible management of learning activities, while also maintaining strong connections with other school areas, both indoor and outdoor (*Flexible and interconnected spaces*). Alongside spatial organisation, the analysis shows that attention should also be paid to *Aesthetic quality* (n = 3), which contributes to creating a relaxed and stimulating environment for students and simultaneously functions as a behavioural reference. In addition, *Comfort and safety* (n = 17) emerged as a key concern, encompassing aspects such as appropriate lighting, thermal comfort, air quality, acoustics, and the provision of adequate safety measures. The documents further underline the importance of integrating the school building into its urban or natural context (*Integrating the school into the context*, n = 3) and of providing outdoor spaces, which are considered essential for informal learning and students’ well-being (*Give importance to outdoor spaces*, n = 6). Finally, in response to the ongoing digital transition, school spaces are expected to accommodate technological infrastructure capable of supporting new teaching modalities (*Integrating spaces with technology*, n = 16). The second theme, “Sustainability”, relates to the construction of more environmentally responsible school buildings. This involves not only the use of sustainable materials and building techniques (*Sustainable materials and building techniques*, n = 3) and low-tech solutions (*Low-tech solutions*, n = 5), but also the enhancement of natural light (*Natural light*, n = 2) and a more conscious use of energy through energy-efficient systems (*Energy efficiency*, n = 5) and renewable energy sources (*Renewable energy sources*, n = 3). Another prominent theme identified in the documents is “Inclusion”. In this respect, school buildings are expected to support diverse abilities and learning styles in order to guarantee an inclusive and equitable learning environment for all students (*Supporting learning for all*, n = 13). In addition, all classrooms and school areas should be fully accessible, ensuring that no student is excluded from participation (*Accessibility for all*, n = 7).

These themes are closely connected to the broader concept of “Pedagogical Design of Spaces”, which emerges through a strong focus on the needs of both students and teachers. From the students’ perspective, the theme *Supporting students* (n = 40) highlights the importance of providing a variety of educational spaces capable of accommodating different needs, such as movement, rest, collaboration, or privacy, while also enabling personalised learning experiences and supporting the development of multiple skills. Achieving this requires a shift in perspective, placing students at the centre of educational design and, consequently, redefining the spaces in which innovative teaching methodologies take place. From the teachers’ perspective, the analysis emphasises the importance of *Valuing pedagogical leadership* (n = 18). This includes the provision of appropriate and welcoming spaces for teachers, recognition of the role of teaching design and classroom allocation, and the promotion of interdisciplinary collaboration between educators and designers. More broadly, educational architecture should support active and collaborative learning approaches while contributing to the learning and well-being of the entire school community (*Supporting learning and well-being of the school community*, n = 47). Finally, the theme “Community” emphasises the role of the school as more than a place for formal instruction. The school building is conceived as a social environment capable of transmitting shared values through

an “implicit pedagogy” (*The school as a social place to promote an implicit pedagogy*, n = 5). As such, school design should foster meaningful social interactions both within the building (*The school as a place to foster social interaction*, n = 13) and beyond it, encouraging the involvement of students, teachers, families, and the wider non-school community (*Involvement of school and non-school community*, n = 6).

With regard to immersive learning environments, the thematic analysis identified two main themes: *XR Pedagogical Aspects* and *XR Technical Aspects*.

The first theme concerns the educational potential of VR and AR technologies, both in terms of learning activity design and alignment with virtual environments. According to the documents, XR technologies can increase the level of challenge for students, for example, through the use of gamification strategies (*Challenging students*, n = 3), while also enabling flexible lesson designs that can be adapted to different learners (*Lesson flexibility*, n = 4). The possibility of customising virtual environments, whether realistic, abstract, or imaginary, also emerged as a relevant factor in addressing students’ needs and learning goals (*Environment customisation*, n = 2). Moreover, immersive environments can enrich learning experiences by allowing students to explore complex or abstract concepts and to access environments that would otherwise be difficult or impossible to visit (*Immersive environments can enrich learning experiences*, n = 5). XR technologies are also associated with increased accessibility, particularly in relation to mobility and interaction, through the use of alternative input methods and personalisation options (*Immersive environments offer inclusivity and accessibility*, n = 4).

The second theme, *XR Technical Aspects*, encompasses the features that contribute to user experience design. *Immersion* (n = 7) refers to the extent to which users feel cognitively and emotionally involved in the virtual environment, while *Presence* (n = 2) relates to the sensation of being physically located within it. These experiences are supported by *Usability* (n = 2), which involves intuitive interfaces and smooth navigation, and by *Realism* (n = 4), referring to visual fidelity and environmental authenticity. The most frequently cited components within this theme are *Interaction* (n = 15) and *Engagement* (n = 14). Interaction enables users to meaningfully manipulate virtual objects and environments, whereas engagement supports sustained interest and active participation through strategies such as gamification, storytelling, and interactive challenges.

From Themes to Matrices to Guide the Design

Following the thematic analysis, five themes emerged that describe the key aspects to be considered in the design of physical learning spaces, alongside two themes addressing the main dimensions relevant to the design of immersive virtual learning environments. Each theme was articulated through a set of related codes. Building on these results, three main groups of correlations were identified and represented through three distinct matrices: (1) the relationship between building quality and sustainability; (2) the pedagogical design of spaces in relation to building quality, inclusion, and community; and (3) the pedagogical aspects of XR in relation to the technical aspects of XR.

Each matrix illustrates the co-occurrence of codes, enabling a more in-depth exploration of the connections and patterns linking different design concepts and features. In this sense, the matrices function as conceptual maps that make visible the intersections between pedagogy, architecture, and XR technologies, highlighting how these domains interact and overlap. The

intersections are represented by squares of varying sizes, indicating the frequency with which two codes appear together within the same text segment, with larger squares corresponding to stronger associations.

Matrix 1. Building Quality – Sustainability

The first matrix focuses on the interaction between the themes of “Building quality” and “Sustainability”, highlighting the extent to which architectural design considerations are aligned with environmental concerns (Figure 1).

Figure 1

Matrix 1 (Relationship Between “Building Quality” and “Sustainability”)



Note. Authors' elaboration

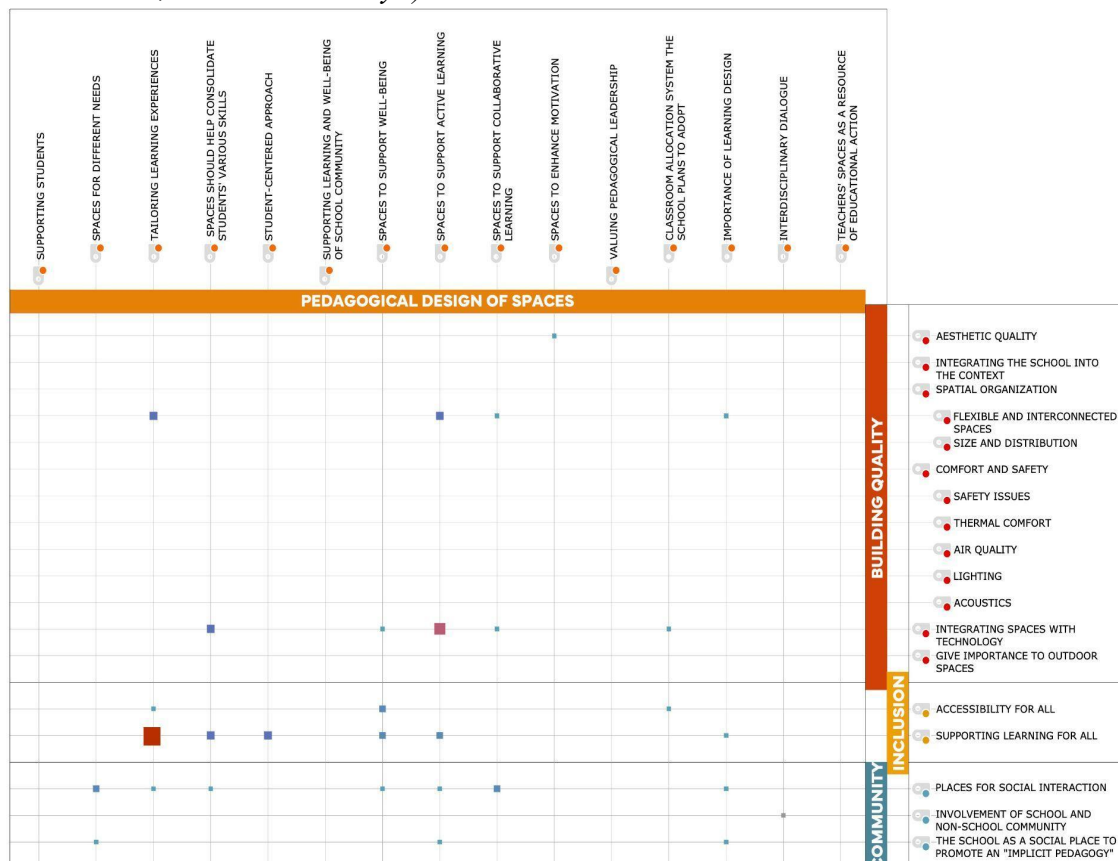
The most prominent relationship emerges between *Safety issues* and *Energy efficiency*. This strong association indicates that ensuring a safe school environment also entails minimising resource consumption and promoting responsible energy use, suggesting that safety and efficiency are understood as mutually reinforcing aspects of building quality. Indeed, *Safety issues* are also linked to both *Low-tech solutions* and *Renewable energy sources*, pointing to a conception of safety that, incorporating long-term robustness and resilience, is not limited to present conditions but is also oriented toward safeguarding future well-being. Another relevant association is observed between *Energy efficiency* and *Giving importance to outdoor spaces*. This relationship reflects a vision of sustainability in which energy performance is not restricted to building systems but is also influenced by spatial design choices. Outdoor spaces can support passive environmental strategies, reduce dependence on artificial lighting and ventilation, and encourage healthier daily practices.

Matrix 2. Pedagogical Design of Spaces - Building Quality, Inclusion, and Community

The second matrix examines how “Pedagogical design of spaces” intersects with the themes of “Building quality”, “Inclusion”, and “Community”, conveying more than the other

matrices an understanding of the school environment as an active component of the educational process, capable of shaping learning practices and social relations (**Figure 2**).

Figure 2
 Matrix 2 (Connection of “Pedagogical Design of Spaces” With “Building Quality”, “Inclusion”, and “Community”)



Note. Authors' elaboration

Within the area of “Building quality”, the strongest relationships involve *Spaces to support active learning* and *Integrating spaces with technologies*. This pattern suggests that architectural quality is closely linked to the ability of spaces to accommodate contemporary pedagogical approaches. Technology integration, in this sense, is not treated as an add-on but as an integral feature that enables active and participatory learning. A similar interpretation is supported by the association between *Integrating spaces with technologies* and *Spaces should help consolidate students' various skills*, indicating that school buildings are conceived as infrastructures that facilitate the development of transversal competencies. Furthermore, the connections between *Flexible and interconnected spaces* and both *Tailoring learning experiences* and *Spaces to support active learning* emphasise the importance of spatial adaptability in supporting student-centred pedagogies. Strong relationships also emerge in relation to “Inclusion”. The most pronounced association links *Tailoring learning experiences* with *Supporting learning for all*, underscoring the idea that personalisation is a key mechanism for achieving inclusive education. *Supporting learning for all* is also connected to *Spaces should help consolidate students' various skills* and to a *Student-centred approach*, suggesting that inclusion is understood not only in physical terms but also as the capacity of spaces to support diverse learning pathways. Additionally, though less prominent, links with *Spaces to support well-being* and *Spaces to support active learning* reinforce the view of inclusion as a multidimensional principle embedded in both spatial and pedagogical

design. The intersection with the theme of “Community” reveals another set of meaningful relationships. In particular, the code *Places for social interaction* is strongly associated with *Spaces for different needs* and *Spaces to support collaborative learning*. These links reflect an understanding of the school as a socially rich environment, where spaces must simultaneously address individual requirements and foster collective engagement. The emphasis on collaboration and interaction points to a conception of the school as a civic space, in which architectural design and pedagogical intentions converge to support participation and a sense of belonging.

Matrix 3. XR Pedagogical Aspects - XR Technical Aspects

The third matrix explores the relationship between *XR pedagogical aspects* and *XR technical aspects*, showing how pedagogical objectives (e.g., enhancing learning experiences, increasing challenge, or adapting environments to learners) are directly connected to technological characteristics (e.g., immersion, presence, interaction, usability, realism, and engagement) (Figure 3).

Figure 3

Matrix 3 (Relationship Between “XR pedagogical Aspects” and “XR Technical Aspects”).



Note. Authors’ elaboration

The most prominent association is observed between *Engagement* and *Immersive environments can enrich learning experiences*. Rather than being a secondary outcome, engagement appears as the mechanism through which immersive environments support meaningful and memorable learning experiences. The code *Immersive environments can enrich learning experiences* is also strongly linked to *Interaction*, *Presence*, and *Immersion*, suggesting that learning enrichment is conceived as the result of multiple, interrelated processes. Interaction enables learners to actively influence virtual environments; presence contributes to a heightened sense of involvement and authenticity; and immersion provides the sensory depth necessary to sustain attention and emotional engagement. Further associations add nuance to this interpretation. The link between *Challenging students* and *Engagement* indicates that the capacity of XR to stimulate deeper cognitive processes and push learners beyond routine activities depends on sustained motivation and involvement. Likewise, the connection between *Environment customization* and *Interaction* suggests that the pedagogical aim of adapting learning contexts to specific needs relies on the degree of agency and control afforded to users within the virtual environment.

Intersecting Learning Space Design and XR Technologies

The final correlation matrix (Figure 4) offers an integrated view of how the design principles associated with physical learning spaces relate to those emerging from immersive virtual learning environments. By bringing together all the themes identified in the analysis, the matrix allows us to observe where the two domains intersect and where they remain distinct, thereby highlighting shared design features as well as structural gaps between physical and virtual learning spaces.

Figure 4
Final Correlation Matrix



Note. Authors' elaboration

What emerges from this overall view is that the themes related to immersive environments, “XR pedagogical aspects” and “XR technical aspects”, do not show substantial connections with “Sustainability” or “Community”, and display only marginal associations with “Building quality”. These dimensions, which play a central role in the design of physical learning spaces, appear to remain largely confined to the material, environmental, and social characteristics of school buildings. In contrast, the points of contact between physical and virtual environments are concentrated primarily around the themes of “Inclusion” and “Pedagogical design of spaces”.

With respect to “Inclusion”, the strongest relationships in the final matrix link *Supporting learning for all* with *Environment customization* and with *Immersive environments can offer inclusivity and accessibility*. These correlations indicate that immersive technologies are perceived as extending inclusive educational practices by enabling adaptable environments and new forms of access that are not limited by physical constraints. Additionally, though less prominent, connections with *Lesson flexibility* reinforce this interpretation. Similarly, *Accessibility for all* is associated with both *Environment customization* and *Immersive environments can offer inclusivity and accessibility*, suggesting that XR environments support inclusion through the alignment of technical affordances with pedagogical goals.

An even denser set of relationships emerges around the theme of “Pedagogical design of spaces”. Within the final matrix, the most prominent association links *Spaces to support active learning* with *Engagement*, indicating a strong convergence between pedagogical intentions rooted in physical space design and XR features that sustain learner involvement. This pedagogical code is also closely connected with *Interaction* and *Immersive environments can enrich learning experiences*, while slightly weaker but still relevant associations appear with *Challenging students*. In addition, *Engagement* shows strong links with a *Student-centred approach* and with *Spaces to enhance motivation*, highlighting how XR’s technical characteristics align with pedagogical strategies that prioritise learner agency and motivation. Another important group of connections links *Tailoring learning experiences* with both *Lesson flexibility* and *Environment customization*, reinforcing the role of XR in supporting differentiated and adaptable learning pathways.

Beyond these central clusters, the matrix also reveals a range of weaker but meaningful associations between the pedagogical design of spaces and both XR pedagogical and XR technical aspects. While less pronounced, these connections contribute to the overall pattern emerging from the matrix, suggesting a shared conceptual ground between physical and immersive learning environments.

Overall, the final correlation matrix shows that the most substantial bridges between physical and virtual learning spaces are built around inclusion and pedagogical design. In contrast, sustainability, community, and building quality remain largely disconnected from XR-related themes. These findings suggest that immersive technologies currently extend and amplify educational principles that are already central to the design of physical learning environments, particularly those related to learner-centred pedagogy and inclusion, rather than redefining the broader spectrum of design considerations.

Conclusion

This contribution examines the relationship between two domains that are increasingly central to educational innovation but have often developed in isolation from one another: the

design of physical learning spaces and the creation of immersive digital environments for learning. By considering policy documents, guidelines, and recommendations at both European and international levels, the analysis has made it possible to identify the main principles guiding each domain and to explore how these principles intersect.

The comparison reveals a differentiated pattern of alignment. Elements such as building quality, sustainability, and the role of the school as a community space continue to be primarily associated with the physical learning environment and find little correspondence in current approaches to immersive environments. By contrast, the pedagogical and technical dimensions of XR show strong affinities with inclusive educational aims and with pedagogical strategies that inform the design of learning spaces. Most notably, the recurring links between support for active learning and XR features such as engagement and interaction point to the capacity of immersive technologies to enhance educational practices through adaptable, personalised, and learner-centred experiences.

On the basis of these findings, a preliminary conceptual framework can be outlined, positioning inclusion and pedagogical design as the primary bridges between physical and virtual learning spaces. This framework offers an initial interpretive lens for an emerging and multidisciplinary field, while also serving as a guiding reference for architects, educators, technologists, and school communities engaged in the design of immersive learning environments.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The authors declare that Grammarly, an AI-assisted writing software, was used in proofreading and refining the language used in the manuscript. The usage was limited to correcting grammatical and spelling errors and rephrasing statements for accuracy and clarity. The authors further declare that, apart from Grammarly, no other AI or AI-assisted technologies have been used to generate content in writing the manuscript. The ideas, design, procedures, findings, analyses, and discussion are originally written and derived from careful and systematic conduct of the research.

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