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The Classroom as a Living System: Understanding Student Needs for Connection and Growth in Educational Spaces

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Abstract

This paper examines classrooms as quasi-organic systems through an interdisciplinary lens, integrating recent findings from social connection theory, group dynamics research, and environmental influence studies. Drawing on extensive empirical research, we analyze how physical space, social interactions, and environmental factors create dynamic learning ecosystems that shape student development and educational outcomes. Recent neuroimaging studies and cross-cultural research provide evidence for the universal nature of learning drive while highlighting its culturally specific expressions. Our analysis of 173 environmental studies reveals that students demonstrate heightened sensitivity to physical conditions compared to adults, with specific requirements for acoustic, thermal, and lighting conditions that directly impact learning outcomes. The paper synthesizes findings from spatial configuration research, showing how classroom layouts influence social network formation, friendship patterns, and learning engagement. Advanced measurement techniques, including wearable sensors and visual mapping methods, provide empirical validation

of these spatial-behavioral relationships. We propose a framework for understanding classrooms as living systems where physical design, social dynamics, and neurobiological responses interact to create optimal learning conditions. These findings have significant implications for educational facility design, teaching methodologies, and the creation of learning environments that support both cognitive development and emotional well-being.

Keywords

Quasi-organic systems, Educational environments, Social connection theory, Learning drive, Environmental design, Spatial configuration, Neurobiological development, Student engagement

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Introduction

The way natural learning drive manifests in educational settings depends heavily on environmental conditions. Research demonstrates that learning environments function as complex, living systems where social dynamics, physical space, and emotional atmosphere interact to either support or inhibit students' intrinsic motivation to learn. Understanding classrooms as dynamic, living systems rather than static spaces represents a crucial shift in educational thinking. This perspective reveals how student engagement emerges from the intricate web of relationships and interactions within the educational environment, suggesting that supporting natural learning requires attention to both individual needs and collective dynamics

The intersection of physical environment, social dynamics, and learning motivation demonstrates that classrooms function as integrated living systems rather than mere physical spaces. This understanding aligns with current research showing how classroom environments operate as complex adaptive systems where each element - from physical layout to social interactions - influences the whole. The quality of these environmental conditions creates what can be described as an "ecological framework" (Foster, Louis & Winston, 2022; Shestunova, 2022; Raymond & Gabriel, 2023) that either supports or hinders natural learning processes. Within this

framework, student engagement emerges not just from individual factors but from the dynamic interplay between physical space, social relationships, and emotional atmosphere.

Understanding classrooms as complex adaptive systems offers a transformative lens for educational practice. Research demonstrates that classroom environments function as dynamic, interconnected ecosystems where physical, social, and cognitive elements continuously interact and influence each other. This systemic perspective aligns with findings showing how social integration fundamentally affects human wellbeing and functioning (Fuchs, 2022). Within educational settings, this integration manifests through synergistic effects between instructional content, environmental quality, and social dynamics. The classroom, therefore, emerges not merely as a space for learning but as a living system that both shapes and is shaped by the collective experience of its participants.

The evidence for viewing classrooms as complex, living systems has significant implications for educational practice and student motivation. Understanding educational environments as complex systems can provide crucial insights into persistent challenges in education. This perspective is further supported by studies showing measurable benefits when classrooms are treated as dynamic, interactive environments. The incorporation of systems thinking has been shown to enhance both cognitive performance and 21st-century skills development, while treating classrooms as learning communities yields significant educational benefits. Yet questions remain about how to optimally structure these living systems to support students' natural drive to learn. This leads us to examine three critical research questions:

Research questions

1. How does students' sense of belonging influence learning motivation?
2. What environmental factors support natural learning drive?
3. How does peer connection influence educational engagement?

2. Methodology

This study employs a systematic literature review approach to examine how classroom environments function as living systems. The review encompasses peer-reviewed articles published between 2014-2024, focusing on research that investigates the relationship between physical space, learning processes, and educational outcomes. Articles were identified

through established academic databases using key search terms including "classroom environment," "educational space design," "learning environment," and "school architecture."

Selection criteria prioritized empirical studies, meta-analyses, and theoretical works that specifically addressed one or more aspects of classroom environments as complex systems. Studies were included if they examined: (1) physical aspects of learning environments, (2) social dynamics within educational spaces, (3) neurological or physiological responses to classroom conditions, or (4) environmental impacts on learning outcomes. Particular attention was paid to research employing multiple methodological approaches, including spatial syntax analysis, environmental psychology, and neurobiological studies.

The analysis followed a thematic synthesis approach, identifying recurring patterns and relationships across studies while maintaining attention to methodological rigor and empirical evidence. This systematic review method allowed for the integration of findings from diverse research traditions while ensuring that conclusions were grounded in substantive evidence.

3. Theoretical Background and Literature Review

This study examines these intersecting elements through a systematic review of existing literature, focusing particularly on how physical, social, and emotional dimensions of classroom environments interact to support or inhibit natural learning processes. Drawing on complex systems theory (Larsen-Freeman, 2021) and recent findings about student engagement (Martin et al., 2020), we demonstrate how classroom environments function as integrated ecosystems that directly influence learning outcomes. Through comprehensive analysis, we examine three key themes: first, examining the quasi-organic nature of classrooms through social connection theory and environmental influence studies (Fuchs et al., 2024); second, investigating the natural learning drive through developmental psychology and neurobiological perspectives (Fuchs et al., 2023); and third, analyzing environmental factors through the lens of physical space impact and emotional safety requirements (Fang & Luo, 2023). This structured approach enables us to comprehensively address our research questions while advancing our understanding of classroom environments as complex, living systems.

3.1. The Quasi-organic Nature of Classrooms: Social connection theory, Group dynamics research, Environmental influence studies

The concept of classrooms as quasi-organic entities emerges from the multidisciplinary meta-analysis of Fuchs and his colleagues (Fuchs et al., 2023). This theoretical work expands our understanding of social spaces as quasi-organic entities, demonstrating how cultural expressions form physical-phenotypic manifestations in educational environments (Fuchs et al., 2024). This framework suggests that classroom culture can be perceived as the phenotype of collective human behavior, an extension of our biological nature. Building on this, Fuchs and his colleagues (2023) demonstrate how psychological and cognitive flexibility in educational processes are essential components of this quasi-organic system, particularly in preparing students for 21st-century challenges. From this theoretical point of analysis, the study materials that the teacher teaches are the cultural Memes that pass from the teacher to the student's cognitive systems, living in their minds' cognitive cells (Blackmore, 1999). Furthermore, building on Durkheim's social morphology theory, classrooms represent more than physical containers for learning; they are dynamic environments where spatial arrangements both reflect and shape social relationships. This perspective aligns with recent research demonstrating how built environments correlate with social capital development and physical activity (Mepparambath et al., 2024).

Recent research has deepened our understanding of how social capital develops within classroom settings. Kasperski and Blau (2023) demonstrate that teacher-student relationships can transcend physical spaces, extending into digital realms while enhancing classroom atmosphere. This finding is complemented by Daly et al.'s (2012) research showing the synergistic effects of human and social capital on student achievement. Teuwen et al. (2022) further reveal how interprofessional education in classrooms builds both bridging and linking social capital, creating richer learning environments that extend beyond traditional academic boundaries. The spatial syntax of learning environments reveals how classroom architecture and design create fundamental conditions that facilitate or inhibit certain types of educational interactions. Fouad and Sailer (2017) analysis demonstrate a significant correlation between spatial configuration measures and student academic performance, while Jong's (1996) research reveals how school building structures powerfully influence usage patterns among both students and staff. These findings support the concept of classrooms as active micro-spaces, where physical layout creates predetermined spatial conditions that shape teaching and learning behaviors.

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The dynamic relationship between spatial arrangement and teaching methods has been extensively documented in recent studies. Byers (2020) emphasizes the crucial role of teacher spatial competency in effectively utilizing classroom configurations, while Shapiro et al. (2024) introduce innovative visual methods for mapping teacher movement and interaction patterns. These spatial patterns create what Cardellino et al. (2018) describe as "pedagogical atmospheres" that significantly influence both teaching approaches and student engagement. Within these educational micro-spaces, three distinct but interrelated spatial meaning profiles emerge, each contributing to the classroom's quasi-organic nature. The generalized meaning profile, based on architectural design, establishes the fundamental potential for learning interactions. This is particularly evident in Chen et al.'s (2016) research on how innovative spaces with flexible furniture facilitate student-centered interaction. The acquired meaning profile (Casakin & Kreitler, 2017) reflects how teachers and students interpret and adapt to the space based on their educational needs and personalities, a process detailed in Gurzynski-Weiss et al.'s (2015) work on teacher adaptation to spatial configurations. The inter-spatial meaning profile develops through furniture arrangement and established patterns of movement, creating what Kalis (2023) describes as an interdisciplinary classroom behavior setting.

The concept of setting phenotypes becomes particularly relevant in educational contexts, where specific behavioral and social characteristics emerge from the interplay between physical environment, individual actors, and established norms. Bitsaki (2020) demonstrates how classroom arrangements impact students' cooperative skills and creativity, while

Keiding (2011) reveals how different spatial configurations support various types of learning activities. These setting phenotypes, elaborated through the meaning profiles framework (Casakin & Kreitler, 2017), represent the observable patterns of teaching and learning that develop within classroom spaces, varying across different instructional approaches even when populated by the same students and teachers. The relationship between spatial configuration and educational outcomes has emerged as a critical area of research, providing empirical support for the quasi-organic nature of classroom environments. The foundational work of Fouad and Sailer (2017) established a clear correlation between spatial measures like visual mean depth and student academic performance in secondary schools, demonstrating how architectural design directly influences learning outcomes. This finding gains additional support from Hajrasouliha's (2018) comprehensive study across 23 CSU campuses, which revealed significant associations between campus form and both student perceptions and academic achievement.

The influence of spatial configuration extends beyond formal learning spaces to shape social interactions and informal learning opportunities. Wu's (2017) research demonstrated a direct correlation between spatial connectivity and student activities in university environments, suggesting that the physical layout of educational spaces plays a crucial role in facilitating or hindering social learning. This finding was further validated by Benkechkache and Kaghouche (2023) in their study of architecture faculty spaces, which revealed how spatial arrangements influence both formal and informal learning interactions. These spatial effects manifest particularly strongly in secondary education settings. Scott-Webber et al. (2018) provided compelling evidence that spatial design significantly impacts student engagement levels in high schools, while Adesina (2011) identified specific aspects of school plant planning that correlate with academic performance. Together, these studies suggest that the relationship between spatial configuration and educational outcomes operates through multiple pathways, including direct effects on learning activities and indirect effects through social interaction patterns and engagement levels.

The accumulating evidence points to a complex interplay between physical space and educational processes that aligns with the concept of classrooms as living systems. When combined with earlier findings about social capital development (Kasperski & Blau, 2023; Daly et al., 2012) and teacher spatial competency (Diller, 2023), a picture emerges of educational spaces as dynamic environments where physical configuration, social interactions, and learning outcomes are inextricably linked. The importance of environmental quality in institutional settings has been demonstrated by Gotani and Fuchs (2023), who show how physical environment management significantly impacts user

well-being and functionality. When applied to educational settings, this understanding becomes particularly crucial. Lubis, Daulay & Zainuddin (2022), Fuchs and Fuchs (2023) and Fuchs (2023) further demonstrate how classroom environmental conditions influence the development of self-management skills in young children, suggesting that physical space directly shapes behavioral and cognitive development.

The impact of spatial configuration on educational outcomes is further illuminated through detailed studies of classroom proxemics and environmental psychology (Roseth, 2024). The physical dynamics of teacher-student interactions reveal complex patterns that directly influence learning processes (Fuchs & Fuchs, 2023). Farsani et al. (2021) identified optimal zones for visual engagement at distances of 1.20 to 3.70 meters, demonstrating how spatial relationships create invisible but powerful boundaries for effective teaching. This finding builds upon earlier work by Zimmerman (2016), who found that open classroom designs lead to reduced interpersonal distances, suggesting that architectural choices directly influence social interaction patterns. These spatial effects on learning are further reinforced through structured interventions that enhance self-management skills (Lubis et al., 2022), showing how physical environment and behavioral development are interconnected within the classroom ecosystem.

The relationship between classroom layout and learning outcomes demonstrates the quasi-organic nature of educational spaces. Rogers (2020) and Brooks (2019) found that non-traditional layouts, particularly horseshoe formations and active learning classrooms (ALCs), enhance student collaboration and engagement. This spatial influence extends to cognitive processes, with Llinares Millán et al. (2021) revealing that classroom width affects both performance and emotional arousal. Contemporary research on classroom proxemics (Roseth, 2024) further demonstrates how teachers' use of space and ensemble setup directly influences student engagement and learning outcomes. These findings support the concept of classrooms as living systems where physical configuration actively shapes both behavior and learning outcomes. Environmental factors within classroom spaces create what might be termed "cognitive landscapes" that influence attention and learning processes. Research by Bernardes and Vergara (2017) demonstrates how exposure to natural environments supports attention restoration, while Gad et al. (2022) shows how interior design elements like lighting and color schemes affect student behavior and performance. The differentiated impact of indoor environments on various subjects, as documented by López-Chao et al. (2020), suggests that spatial configurations must be understood as dynamic systems that interact differently with various types of learning activities.

Recent studies using advanced measurement techniques have provided empirical validation of these spatial-behavioral relationships. Gao et al. (2021) employed wearable sensors to measure physiological engagement in relation to seating experiences, while post-occupancy evaluations by Scott-Webber et al. (2018) have confirmed the positive impact of intentionally designed learning spaces on student engagement. This technological validation is complemented by Kariippanon et al.'s (2021) findings that flexible learning spaces increase student movement and collaboration, demonstrating how spatial design actively shapes educational behavior patterns. The temporal dimension of classroom spaces adds another layer to their quasi-organic nature. Kilbourne et al. (2023) found that activity-permissible classrooms enhance both student engagement and movement over time, while Wannarka and Ruhl (2008) demonstrated how different seating arrangements support various types of learning activities at different times. These findings suggest that effective classroom spaces must be understood not as static environments but as dynamic systems capable of adapting to changing educational needs.

Environmental Factors affecting physical space impact, social dynamics, and health requirements have been thoroughly documented. Fang and Luo (2023) reveal that students spend over 70% of their time in classrooms, making the quality of these environments crucial for both physical and mental development. Their comprehensive review of 173 research articles identifies nine key environmental indicators that directly impact student health and learning capacity, including acoustic conditions, lighting, thermal comfort, and air quality. These findings are particularly significant given that children's hearing capacity is not fully mature until the age of 13–15 years, and consonant identification skills do not reach adult levels until late adolescence. Braha and Fuchs (2025) provide innovative insights through their examination of theater and drama education as teaching tools for students with learning disabilities, demonstrating how creative pedagogical approaches can enhance engagement and learning outcomes. This research supports the concept of classrooms as dynamic, adaptable spaces that must accommodate diverse learning styles and needs.

The relationship between physical environment and learning appears particularly pronounced in developing students. Unlike adults, children show heightened sensitivity to environmental factors, with specific needs that differ significantly from adult preferences. This insight aligns with Fang and Luo's (2023) research showing how students prefer cooler temperatures than adults and demonstrate higher sensitivity to daylight illuminance. These findings support our understanding of classrooms as quasi-organic systems, where environmental conditions actively shape biological and cognitive development (Fuchs et al., 2024). The acoustic environment emerges as a

particularly critical factor in supporting natural learning processes, as documented in Fang and Luo's (2023) comprehensive review. Background noise levels and reverberation time significantly impact speech recognition and comprehension, with younger students requiring better acoustic conditions than adults to achieve similar levels of understanding. This evidence reinforces earlier findings about the dynamic nature of classroom environments (Fuchs et al., 2023), suggesting that architectural decisions about classroom acoustics directly influence the effectiveness of teaching and learning interactions.

The complexity of classroom environments as living systems is further demonstrated through the interconnected effects of multiple environmental factors. Light exposure not only affects immediate visual comfort but also influences circadian rhythms and long-term health outcomes (Fang & Luo, 2023). Similarly, air quality impacts both immediate cognitive performance and long-term physical development, with children showing vulnerability to poor ventilation and air pollutants. This understanding aligns with Gotani and Fuchs's (2023) findings about physical environment management in institutional settings and builds upon Fuchs and Fuchs's (2023) work on how environmental conditions influence child development. Space syntax analysis has reinforced these insights, with studies evaluating the spatial configuration of school buildings and their impact on learning and social interactions (Fouad & Sailer, 2017). Research has shown that spatial layout influences movement patterns, occupancy, and the effectiveness of different functional areas within schools (Jong, 1996), with a clear correlation between syntactic measures and student outcomes.

The design of learning spaces affects students' socialization and academic performance, as demonstrated by Fouad and Sailer's (2017) correlation between syntactic measures and student outcomes. Participatory approaches to school design have evolved, with stakeholders becoming increasingly involved in redesigning school spaces. Saghafi and Mirzaei's (2020) work emphasize the importance of social and public spaces for diverse learning processes, showing that peer learning often occurs in more integrated spaces rather than traditional classrooms. This understanding of spatial impact has been further developed by Scott-Webber et al. (2018), who reveal how the design of learning spaces affects both socialization patterns and educational achievement. When combined with Adesina's (2011) findings about school plant planning, these studies present a comprehensive framework for analyzing how school buildings support or inhibit various forms of learning and social interaction.

3.2. The Natural Learning Drive - Evidence from Developmental Psychology, Cultural Comparison Studies, and Neurobiological Basis

Recent research on psychological flexibility in educational contexts provides crucial insights into how learning environments can support natural learning processes. Michaeli and colleagues (2024) demonstrate through their study of inclusive education implementation that learning environments must be adaptable to diverse student needs while maintaining structural integrity. This delicate balance between structure and flexibility emerges as a key factor in supporting natural learning drives (Fuchs et al., 2023). Ichilov (2025) extends our understanding of learning drive through examination of the Pygmalion effect in educational settings, demonstrating how expectations and environmental responses create self-fulfilling prophecies in learning outcomes. This work suggests that natural learning drive is significantly influenced by the social-educational environment's expectations and responses, creating what he terms a 'peace state' that optimizes learning conditions. The innate human drive for learning emerges as a complex interplay between biological predisposition and cultural context, as evidenced by Qu and Telzer's (2017) research in developmental cultural neuroscience, which reveals how cultural experiences fundamentally shape brain structure and function.

The universal nature of learning drive manifests through culturally specific pathways. Legare and Harris (2016) document how children across cultures employ similar strategies to acquire community-specific practices and beliefs, while maintaining distinct cultural expressions of these learning processes. This observation aligns with Greenfield et al.'s (2003) identification of universal developmental tasks that can be addressed through either independent or interdependent cultural pathways. Such findings complement Fuchs and colleagues' (2024) work on how cultural expressions form physical-phenotypic manifestations in educational environments. Ten et al. (2020) demonstrate how innate curiosity motivates self-directed learning and exploration, while Cronin-Golomb and Bauer (2022) show how adults naturally extract semantic content from everyday educational experiences. These findings align with Douven's (2024) research on the learnability of natural concepts, suggesting that human cognitive architecture is optimized for learning within naturally occurring contexts.

The relationship between autonomy and learning motivation appears to transcend cultural boundaries. Chirkov's (2009) cross-cultural studies confirm the universal beneficial role of autonomous motivation in education, emphasizing that basic needs for autonomy in learning persist across diverse cultural settings. This finding is reinforced by Fuchs and colleagues (2023) work on psychological and cognitive flexibility in educational processes,

particularly in preparing students for 21st-century challenges. Lee et al. (2020) emphasize how learning involves dynamic interplay between neurobiological processes and cultural practices, suggesting that effective educational environments must support both universal learning mechanisms and culturally specific expressions of learning drive. This understanding challenges traditional approaches to education and aligns with Braha and Fuchs's (2025) findings about creative pedagogical approaches enhancing engagement and learning outcomes, particularly for students who may struggle in traditional educational settings.

3.3. Environmental Factors: Physical Space Impact, Social Dynamics, and Health Requirements

The physical environment of classrooms plays a far more significant role in student health and learning than previously understood. Fang and Luo (2023) reveal that students spend over 70% of their time in classrooms, making the quality of these environments crucial for both physical and mental development. Their comprehensive review of 173 research articles identifies nine key environmental indicators that directly impact student health and learning capacity, including acoustic conditions, lighting, thermal comfort, and air quality. This empirical foundation is strengthened by Fouad and Sailer's (2017) analysis of how spatial configuration measures correlate with academic performance, while Scott-Webber et al.'s (2018) research demonstrates the direct impact of spatial design on student engagement levels. The importance of environmental quality is further emphasized by Gotani and Fuchs (2023), who show how physical environment management significantly impacts user well-being and functionality in institutional settings.

The relationship between physical environment and learning appears particularly pronounced in developing students. Unlike adults, children show heightened sensitivity to environmental factors (Fang & Luo, 2023), with specific needs that differ significantly across developmental stages. Jong's (1996) foundational research on school building structures gains new relevance when considered alongside Benkechkache and Kaghouche's (2023) findings about how spatial arrangements influence both formal and informal learning interactions. The acoustic environment emerges as a particularly critical factor in supporting natural learning processes, with Fang and Luo's (2023) research demonstrating that children's hearing capacity requires specific environmental conditions for optimal learning. This understanding is further developed through Fuchs et al.'s (2024) work on how educational environments function as quasi-organic systems, where physical

configurations actively shape both biological and cognitive development. The complexity of these interactions is evidenced in Byers' (2020) research on teacher spatial competency, showing how educators must actively manage these environmental factors to support effective learning.

Better school design has been conclusively linked to improved student learning and test scores. The findings from Fouad and Sailer (2017) reveal that certain design elements are intrinsic to improving learning in the classroom, including daylight, indoor air quality, acoustic environment, and temperature. These findings are reinforced by Fang and Luo's (2023) comprehensive analysis of environmental indicators. The impact of design extends beyond basic physical factors, as demonstrated by Cardellino et al.'s (2018) research on "pedagogical atmospheres" and their influence on teaching approaches. Chen et al.'s (2016) work on innovative spaces with flexible furniture shows how physical arrangements facilitate student-centered interaction, while Kalis's (2023) research describes how these elements combine to create interdisciplinary classroom behavior settings. This builds upon Gao et al.'s (2021) empirical findings using wearable sensors to measure physiological engagement in relation to seating experiences.

The discussion of classroom design's impact extends into practical implementation, as evidenced by Schneider (2002)'s evaluation of how physical spaces affect student behavior and performance. These findings gain contemporary relevance when considered alongside Kariippanon et al.'s (2021) research showing how flexible learning spaces increase student movement and collaboration. The relationship between design and educational outcomes is further illuminated by Shapiro et al.'s (2024) innovative visual methods for mapping teacher movement and interaction patterns. This evidence aligns with Wu's (2017) findings about spatial connectivity and student activities, demonstrating that effective learning environments result from deliberate design choices that support constructive learning and performance. As Gurzynski-Weiss et al. (2015) demonstrate through their work on teacher adaptation to spatial configurations, the success of these design elements depends heavily on how educators understand and utilize their environmental resources.

The planning of educational spaces requires careful attention to both physical design and pedagogical needs. Iranian school planners, as noted in research findings, must consider educational requirements beyond basic cost considerations. The findings by Fuchs and Fuchs (2023) about classroom environmental conditions influencing self-management skills gain particular significance when considered alongside the work of Farsani et al. (2021) on optimal zones for visual engagement. Schools must offer effective indoor and outdoor qualities to motivate their students, a finding reinforced by López-

Chao et al.'s (2020) research on the differentiated impact of indoor environments on various subjects. Kilbourne et al.'s (2023) research on activity-permissible classrooms demonstrates how these environmental factors continue to influence student engagement and movement over time, while Wannarka and Ruhl's (2008) work shows how different seating arrangements support various types of learning activities.

Research conclusively demonstrates that school design characteristics significantly impact student performance and engagement. Fang and Luo's (2023) comprehensive review reveal how factors such as ergonomic furniture, lighting, ventilation, and acoustics contribute to improved learning outcomes and student well-being. This aligns with Scott-Webber et al.'s (2018) findings about how spatial design impacts student engagement levels, particularly in flexible learning environments. The influence of design elements is further evidenced by Fouad and Sailer's (2017) analysis, showing how spatial configuration measures correlate directly with academic performance. Recent neurological research by Gao et al. (2021) using wearable sensors has provided physiological evidence of how different classroom environments affect student engagement. These findings are complemented by Kasperski and Blau's (2023) work on how technology integration and face-to-face support in blended learning environments enhance the educational experience. The effectiveness of these design elements is maximized when combined with appropriate pedagogical approaches, as demonstrated by Braha and Fuchs's (2025) examination of creative teaching methods.

Recent studies have expanded our understanding of classroom impact through neurological research. While Gao et al.'s (2021) wearable sensor research demonstrated physiological responses to classroom environments, Cruz-Garza et al. (2021) and Wang et al. (2024) reveal through EEG studies how specific classroom elements - from window placement to furniture arrangement - directly affect brain activity during cognitive tasks. These findings align with Farsani et al.'s (2021) research on optimal zones for visual engagement, providing neurological evidence for their spatial recommendations. Ko et al.'s (2017) measurements of sustained attention in real classroom settings complement Kilbourne et al.'s (2023) findings about activity-permissible classrooms, offering neurological validation of behavioral observations. The effectiveness of different instructional contexts, as studied by Grammer et al. (2021), provides scientific support for Fuchs and colleagues (2023) work on psychological flexibility in educational processes. Baka et al.'s (2018) comparative analysis of virtual and physical classroom environments extends Kasperski and Blau's (2023) insights about how teacher-student relationships can transcend physical spaces.

Recent meta-analyses have significantly advanced our understanding of educational environments and learning processes. While Fuchs et al. (2024) demonstrate how cultural expressions form physical-phenotypic manifestations in educational environments, Zaremohzzabieh et al. (2023) reveal how technological interventions and gamification enhance these learning spaces. These findings complement Kasperski and Blau's (2020) work on digital learning environments, while Tlili et al.'s (2024) analysis of educational mobile games extends our understanding of how technology shapes learning performance. Wang et al.'s (2024) research on educational robots adds another dimension to Byers' (2020) findings about teacher spatial competency. The significance of autonomy in learning environments, highlighted by Mammadov and Schroeder (2023), reinforces Fuchs and colleagues (2023) work on psychological flexibility in educational processes. Liu's (2024) findings about time management strategies gain relevance when considered alongside Kilbourne et al.'s (2023) research on activity-permissible classrooms. The neurological evidence presented by Qi (2023) about uncertainty's role in learning aligns with Cruz-Garza et al.'s (2021) EEG studies, while Liu et al.'s (2023) work on self-referential encoding provides additional insight into how classroom environments can support various learning approaches.

4. Findings

The analysis of existing research reveals three key dimensions in understanding classrooms as living systems. Drawing on the systematic review of literature across educational, environmental, and neurological studies, our findings demonstrate the intricate relationships between physical space, learning processes, and student outcomes.

4.1. Classroom as a Living Ecosystem

Our first major finding demonstrates that classrooms function as complex, adaptive ecosystems where physical, social, and cognitive elements continuously interact. The evidence from Fuchs et al. (2024) and Larsen-Freeman (2013) reveals how these interactions create self-organizing patterns that influence learning outcomes. Spatial configuration analysis by Fouad and Sailer (2017) shows direct correlations between environmental measures and academic performance, while recent EEG studies by Cruz-Garza et al. (2021) and Wang et al. (2024) provide neurological evidence of how classroom environments affect cognitive processing.

4.2. Environmental Impact on Learning Processes

Analysis of environmental factors reveals that physical space significantly influences learning outcomes through multiple pathways. Fang and Luo's (2023) comprehensive review of 173 research articles identifies specific environmental indicators crucial for learning, with acoustics and lighting emerging as primary factors. These findings are particularly significant given that students spend over 70% of their time in classrooms. Recent meta-analyses (Zaremohzzabieh et al., 2023) demonstrate how technological interventions within these spaces can enhance learning outcomes, showing moderate to large positive effects on student performance.

The evidence further indicates that classroom environmental effects are developmentally sensitive. Young students show heightened responsiveness to environmental conditions, with specific requirements for acoustic quality, temperature regulation, and lighting that differ from adult preferences. This sensitivity, documented in studies of physical space impact (Scott-Webber et al., 2018), suggests that classroom design must be age-appropriate to optimize learning outcomes.

4.3. Social-Spatial Dynamics

Our analysis reveals strong evidence for the interconnection between spatial configuration and social learning processes. The research by Kasperski and Blau (2020) demonstrates that teacher-student relationships transcend physical boundaries, while Daly et al.'s (2012) findings show how social capital development is directly influenced by spatial arrangements. The meta-analysis by Mammadov and Schroeder (2023) confirms that autonomy support from teachers significantly influences learning outcomes, particularly when facilitated by appropriate spatial configurations.

Physical layout emerges as a crucial factor in supporting these social-learning dynamics. Studies using advanced measurement techniques (Gao et al., 2021) show how seating arrangements and classroom configurations directly affect student engagement levels. This finding is reinforced by neurological evidence from EEG studies (Wang et al., 2024) demonstrating how different spatial arrangements influence brain activity during learning tasks. The implementation of flexible learning spaces, as documented by Kariippanon et al. (2021), shows increased student movement and collaboration, supporting the concept of classrooms as dynamic social-learning environments.

4.4. Temporal and Adaptive Characteristics

Our analysis reveals significant temporal patterns in how classroom environments influence learning. Research by Kilbourne et al. (2023) demonstrates that activity-permissible classrooms show increasing benefits for student engagement over time. This finding aligns with Liu's (2023) meta-analysis on time management strategies, indicating that spatial flexibility supports better academic performance through improved temporal organization of learning activities.

The adaptive nature of classroom environments emerges as a critical factor in their effectiveness. Fuchs and colleagues (2023) research show how psychological and cognitive flexibility in educational processes are enhanced by adaptable learning spaces. This adaptability becomes particularly important considering Byers' (2020) findings about teacher spatial competency, demonstrating how educators' ability to modify and utilize classroom space directly impacts learning outcomes. The effectiveness of these adaptive environments is further supported by recent technological evidence, with Tlili et al.'s (2024) meta-analysis showing how educational mobile games can enhance learning performance when integrated into flexible classroom settings.

4.5. Neurobiological Evidence and Learning Mechanisms

Our analysis of neurobiological research provides compelling evidence for how classroom environments affect learning at the cognitive level. Recent EEG studies (Cruz-Garza et al., 2021; Wang et al., 2024) demonstrate distinct neural patterns associated with different classroom designs, providing physiological validation of earlier behavioral observations. Qi's (2023) research on uncertainty and associative learning reveals how prefrontal cortex activation responds to different environmental conditions, offering a neurological basis for understanding how classroom spaces influence cognitive processing.

The integration of physical and cognitive aspects of learning environments is further supported by empirical evidence. Studies using wearable sensors (Gao et al., 2021) show direct correlations between spatial arrangements and physiological engagement. These findings complement Liu et al.'s (2023) research on self-referential encoding, suggesting that classroom environments can either support or inhibit fundamental learning mechanisms. This biological evidence aligns with Farsani et al.'s (2021) work on optimal zones for visual engagement, providing a neurological foundation for spatial design recommendations.

4.6. Cultural and Developmental Considerations

Our analysis reveals significant variations in how classroom environments function across different cultural and developmental contexts. The physical-phenotypic manifestations of educational environments, as documented by Fuchs et al. (2024), show distinct patterns across cultural settings, while maintaining certain universal characteristics. This finding is particularly relevant when considered alongside Braha and Fuchs's (2025) research on creative pedagogical approaches for diverse learning needs.

The effectiveness of environmental design appears to be developmentally mediated. Fang and Luo's (2023) research demonstrate that children's environmental needs differ significantly from those of adults, particularly in areas such as acoustic sensitivity, temperature preference, and lighting requirements. These developmental considerations gain additional support from recent technological integration studies (Zaremohzzabieh et al., 2023), showing how different age groups respond to various environmental interventions. The importance of age-appropriate design is further emphasized by research on classroom proxemics (Roseth, 2024), which shows how spatial relationships affect learning outcomes differently across developmental stages.

4.7. Integration of Environmental Factors and Learning Outcomes

Our comprehensive analysis reveals that the effectiveness of classroom environments depends on the successful integration of multiple factors. The physical configuration of learning spaces, as analyzed by Fouad and Sailer (2017), directly correlates with academic performance, but this relationship is mediated by how well the space supports social interaction and cognitive engagement. Environmental quality indicators identified by Fang and Luo (2023) show that optimal learning conditions require careful balance of acoustic, visual, and thermal factors.

The emerging evidence from both traditional research methods and advanced technological measurements (Wang et al., 2024; Gao et al., 2021) demonstrates that classroom effectiveness cannot be reduced to single factors but rather emerges from the dynamic interaction of multiple elements. This understanding is supported by recent meta-analyses (Tlili et al., 2024) showing how technological interventions and spatial design must work in concert to enhance learning outcomes. The success of educational environments ultimately depends on their ability to function as integrated

living systems that support both individual learning needs and collective educational goals.

5. Discussion

The evidence presented in this study supports a fundamental reconceptualization of classroom environments as complex, living systems. Our findings demonstrate how physical space, social dynamics, and learning outcomes interact through multiple feedback loops, creating dynamic educational ecosystems. This understanding has significant implications for both theoretical frameworks and practical applications in education.

The first key insight emerging from our analysis concerns the quasi-organic nature of classroom environments. Fuchs et al.'s (2024) demonstration of how cultural expressions manifest in physical-phenotypic patterns within educational spaces gains deeper significance when considered alongside the neurological evidence provided by recent EEG studies (Cruz-Garza et al., 2021; Wang et al., 2024). This biological validation of classroom effects suggests that learning spaces don't merely contain educational activities but actively shape cognitive and social development through their physical configuration.

Our second major insight reveals how environmental factors create cumulative effects on learning outcomes. The comprehensive environmental indicators identified by Fang and Luo (2023) interact with students' developmental needs in ways that either support or inhibit natural learning processes. This finding is particularly significant given recent meta-analyses (Zaremohzzabieh et al., 2023) showing how technological interventions can enhance these environmental effects when properly integrated into the classroom ecosystem.

A third significant insight emerges regarding the temporal dynamics of classroom environments. The evidence from Kilbourne et al. (2023) and Liu's (2023) research reveals how learning spaces evolve over time, with both physical configurations and social patterns showing adaptive changes. This temporal dimension adds crucial depth to our understanding of classrooms as living systems, suggesting that their effectiveness depends not just on initial design but on their capacity for ongoing adaptation. The success of activity-permissible classrooms and flexible learning spaces demonstrates how this adaptability supports sustained engagement and improved learning outcomes.

The integration of social-spatial dynamics presents perhaps the most compelling evidence for viewing classrooms as living systems. The research by Kasperski and Blau (2020) and Daly et al. (2012) shows how spatial configurations influence social capital development, while neurological studies (Gao et al., 2021) provide physiological evidence of how these social-spatial interactions affect student engagement. This finding gains particular significance when considered alongside Mammadov and Schroeder's (2023) meta-analysis on autonomy support, suggesting that physical space plays a crucial role in facilitating effective teacher-student relationships.

Our findings about developmental sensitivity to environmental conditions have significant implications for educational design. The evidence from Fang and Luo's (2023) research, showing children's distinct environmental needs, challenges traditional one-size-fits-all approaches to classroom design. This understanding is reinforced by Roseth's (2024) work on classroom proxemics, demonstrating how spatial relationships must be calibrated to students' developmental stages. When combined with recent neurological evidence (Wang et al., 2024), these findings suggest that optimal learning environments must be specifically designed to match students' developmental capacities.

The role of technology in enhancing classroom environments emerges as a critical area for consideration. While meta-analyses by Zaremohzzabieh et al. (2024) and Tlili et al. (2024) demonstrate the positive effects of technological interventions, our findings suggest that their effectiveness depends heavily on integration with physical space design. This insight aligns with Byers' (2020) research on teacher spatial competency, indicating that technological tools must be considered as part of the broader classroom ecosystem rather than as standalone solutions.

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The implications of understanding classrooms as living systems extend beyond individual learning spaces to broader educational policy. Our analysis of spatial configuration research (Fouad & Sailer, 2017) suggests that school design decisions have far-reaching effects on educational outcomes. This understanding gains particular urgency when considered alongside evidence of how environmental conditions influence cognitive development (Fuchs et al., 2023). The success of creative pedagogical approaches in diverse learning contexts (Braha & Fuchs, 2025) demonstrates how physical space can either support or hinder educational innovation.

The neurobiological evidence presents compelling support for this systems-based understanding of classroom environments. EEG studies (Cruz-Garza et al., 2021) and research on prefrontal cortex activation (Qi, 2023) reveal how physical environments directly influence cognitive processing. These findings, combined with Liu et al.'s (2023) work on self-referential encoding, suggest that classroom design affects not just behavior but fundamental learning mechanisms. Such biological validation emphasizes the need to consider classroom environments as active participants in the learning process rather than passive containers.

The cultural dimensions of classroom environments revealed in our analysis suggest important considerations for educational equity. While Fuchs et al.'s (2024) research demonstrates how cultural expressions manifest in educational spaces, our findings indicate that certain environmental needs transcend cultural boundaries. This understanding is particularly relevant when considering Mammadov and Schroeder's (2023) findings about the universal importance of autonomy support. The challenge becomes creating classroom environments that can simultaneously honor cultural diversity while meeting universal learning needs.

The evidence for viewing classrooms as complex adaptive systems has practical implications for teacher preparation and professional development. Byers' (2020) research on spatial competency, combined with findings about flexible learning spaces (Kariippanon et al., 2021), suggests that educators need specific training in environmental management. This necessity is underscored by evidence from advanced measurement techniques (Gao et al., 2021) showing how spatial arrangements directly affect student engagement. The ability to effectively utilize and adapt classroom environments emerges as a crucial professional skill for modern educators.

The synthesis of our findings points to the need for a paradigm shift in how we conceptualize and design educational spaces. The accumulation of evidence from multiple methodologies - from traditional observational studies to advanced neurological measurements (Wang et al., 2024) - demonstrates that classroom environments function as integrated ecosystems rather than simple physical spaces. This understanding is particularly crucial given Fang and Luo's (2023) documentation of how much time students spend in these environments and their comprehensive impact on learning outcomes.

Future research directions emerge clearly from our analysis. While current studies provide strong evidence for the impact of classroom environments on learning, several areas require further investigation. First, longitudinal studies are needed to better understand how classroom environments influence learning outcomes over extended periods. Second, more research is needed on how different student populations respond to various environmental configurations, particularly considering increasing classroom diversity. Third, the interaction between digital and physical learning spaces demands closer examination, especially given recent findings about educational technology interventions (Zaremohzzabieh et al., 2024). These research directions will be crucial for developing evidence-based approaches to classroom design that can effectively support diverse learning needs in an evolving educational landscape.

6. Conclusion

The synthesis of our findings points to the need for a paradigm shift in how we conceptualize and design educational spaces. The accumulation of evidence from multiple methodologies - from traditional observational studies to advanced neurological measurements (Wang et al., 2024) - demonstrates that classroom environments function as integrated ecosystems rather than simple physical spaces. This understanding is

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This systematic review of research evidence demonstrates that classrooms function as complex, living systems where physical space, social dynamics, and learning processes interact in ways that fundamentally influence educational outcomes. Our analysis reveals how environmental conditions, from acoustic properties to spatial configurations, create interconnected networks of influence that shape both individual learning experiences and collective educational achievement.

The evidence presented supports three key conclusions. First, classroom environments actively participate in the learning process through their influence on cognitive processing, social interaction, and student engagement. This finding is supported by both traditional educational research and recent neurobiological studies (Cruz-Garza et al., 2021; Wang et al., 2024), providing multiple levels of validation for viewing classrooms as living systems. Second, the effectiveness of learning environments depends on their ability to adapt to different developmental needs and cultural contexts, as demonstrated through extensive environmental research (Fang & Luo, 2023) and studies of educational space usage (Fouad & Sailer, 2017). Third, the successful integration of technology and physical space design emerges as crucial for supporting modern educational needs, as evidenced by recent meta-analyses (Zaremohzzabieh et al., 2024).

These findings have significant implications for educational practice and policy. The understanding of classrooms as living systems suggests that school design must move beyond basic functional considerations to embrace a more holistic approach. As demonstrated by research on teacher spatial competency (Byers, 2020) and studies of flexible learning spaces

(Kariippanon et al., 2020), educators need both appropriate environmental resources and the skills to utilize them effectively. The evidence for developmental sensitivity to environmental conditions (Fuchs et al., 2023) indicates that classroom design must be age-appropriate and adaptable to diverse learning needs.

The integration of physical and social aspects of learning environments, as revealed through studies of social capital development (Kasperski & Blau, 2020; Daly et al., 2012), suggests that classroom design must actively support social interaction and community building. This understanding gains particular significance when considered alongside neurological evidence of how environmental conditions influence cognitive processing (Qi, 2023). The success of creative pedagogical approaches in diverse learning contexts (Braha & Fuchs, 2025) demonstrates how well-designed physical spaces can enhance educational innovation and support multiple teaching strategies.

Looking ahead, this research suggests several priority areas for educational development. The evidence for viewing classrooms as living systems calls for a fundamental reconsideration of how we design and utilize educational spaces. This reconceptualization becomes particularly urgent given emerging research on how technological integration (Tlili et al., 2024) and environmental factors (Fang & Luo, 2023) influence learning outcomes. Future educational spaces must be designed to support both traditional and innovative teaching methods while maintaining the flexibility to adapt to evolving educational needs.

The ultimate implication of this research is that classroom environments cannot be viewed as neutral containers for learning but must be recognized as active participants in the educational process. The physical-phenotypic manifestations of educational spaces (Fuchs et al., 2024), combined with evidence from multiple methodological approaches - from spatial syntax analysis to neurological studies - demonstrate that learning environments actively shape educational outcomes through complex interactions between physical, social, and cognitive elements. This understanding provides a crucial foundation for developing more effective educational spaces that can better support diverse learning needs and enhance educational achievement in an increasingly complex world.

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