Early Childhood Classroom Design: Integrating Montessori Principles with Neuroeducational Research

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Abstract: This critical literature review examines how classroom design influences attention, regulation, and learning in early childhood education (ECE). Combining Montessori pedagogy with Bronfenbrenner's theories as a conceptual framework, this review considers biopsychosocial impacts of physical classroom spaces. Experimental classroom research indicates the crucial first step of learning—encoding—may be disrupted in early classrooms cluttered with excessive visual stimuli that overwhelm children's attention. Drawing on neuroeducational concepts such as embodied cognition and allostatic load, this review highlights how intentionally prepared environments support attentional allocation, regulation, and encoding for content retention by emphasizing cognition's body-based and environmentally responsive nature. These findings challenge older models that view attention and regulation as fixed, child-based traits rather than capacities influenced through interaction with the environment. Additionally, decades of design research demonstrate exposure to nature in intentionally created spaces can reduce stress and improve cognitive functioning; yet this potential to enhance attention and learning in classrooms remains underexplored. By viewing classrooms dually as physical and cognitive spaces, this synthesis underscores the role of intentional design in promoting attentional allocation, regulation, and learning. These insights bridge the gap between Montessori practice and research, and offer a compelling rationale for optimizing ECE environments through a neurodevelopmental lens, with implications for educational policy, teacher preparation, and future empirical studies.

Although traditional measures of school readiness focus on literacy, numeracy, and physical development (Ghandour et al., 2024), educators often identify students' difficulties with self-regulation and attention as primary obstacles to children's readiness for school (Blair & Diamond, 2008; Eristi & Avci, 2021; Rimm-Kaufman et al., 2000). Attention-deficit/hyperactivity disorder (ADHD) has become one of the most common diagnosed conditions in young children (Danielson et al., 2024; Centers for Disease Control and Prevention, 2023; Mahone & Schneider, 2012). Research shows attention-related issues, such as distractibility and difficulty sustaining focus, are significant barriers to academic success in early childhood education (ECE), which encompasses birth through age 8 (Curby et al., 2018; Degol & Bachman, 2023).

Additionally, a growing body of cross-disciplinary research suggests physical classroom design plays a critical role in influencing children's attention and cognition. Studies show factors such as lighting, sound, color, visual displays, movement, and biophilic (nature-centered) elements can significantly impact attentional focus, well-being, and learning (Barrett et al., 2013; Brooks, 2010; Gaekwad et al., 2022; Godwin et al., 2022; Jeannin & Barthelemy, 2020; Kilbourne et al., 2017; Llorens-Gámez et al., 2021). Moreover, neurodivergent students experience additional sensitivity to overwhelming sensory input, demonstrating increasing externalized aggressive behavior (Baird et al., 2023), restricted participation (Cheryan et al., 2014), and greater distractibility and visual processing difficulties in autistic children and those with attentional differences (Hanley et al., 2017; Mallory & Keehn, 2021; Martin & Wilkins, 2021, Zazzi & Faragher, 2018).

Problem of Practice

Cumulatively, this body of research underscores the complexity of challenges early learning educators face, revealing a multidisciplinary and multifaceted problem of practice. Although the benefits of investing in ECE are well documented, empirical evidence indicates many early learning environments remain suboptimal for fostering effective learning. Specifically, visually dense settings, which are common in early childhood and elementary classrooms, deter children's attentional focus, reduce time spent on task, and negatively influence learning outcomes.

Figure 1

First-Grade Classroom at a Conventional Charter School

Note. Photo by Allison Shelley/Verbatim Agency for EDUimages (2017), licensed under CC BY-NC 2.0, https://www.flickr.com/photos/all4ed/36456780086

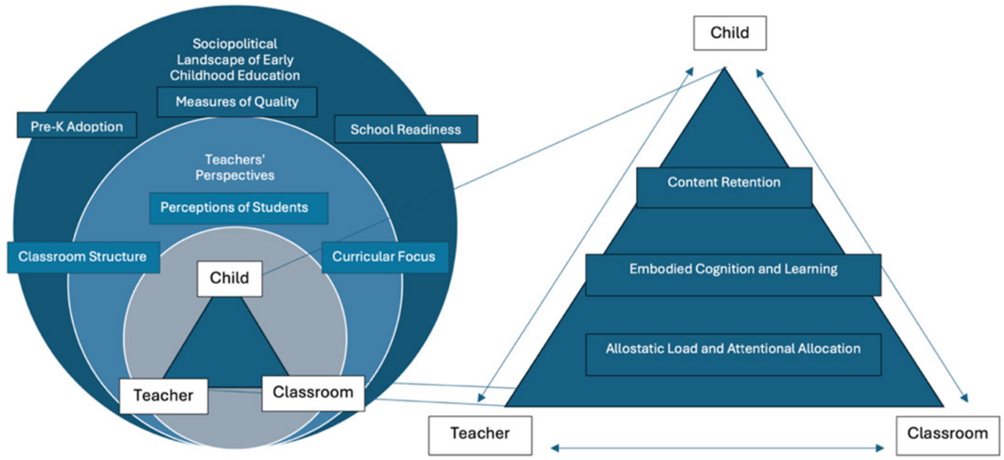
Rationale and Identified Gap in Literature

Despite robust findings in the science of learning that highlight the effectiveness of strategies such as interleaving, retrieval practice, and spaced learning for enhancing retention and understanding (Brown et al., 2014), these methods presuppose students have already successfully encoded the material. Cognitive scientists have long characterized the learning process as one of encoding, storage, and retrieval (Craik & Lockhart,1972; McDermott & Roediger, 2018); however, the foundational process of initial encoding is often undermined in early learning environments due to excessive visual clutter (Fisher et al., 2014; Godwin et al., 2022). Many classrooms, particularly those designed for young children, are saturated with prefabricated displays and dense visual stimuli (see Figure 1).

This proliferation of visual density may stem from a misapplication of Mayer's (2005) cognitive theory of multimedia learning, which supports dual-channel processing of visual and auditory information. Yet, there is limited empirical support for the effectiveness of these visually dense environments as inclusion of visual displays do not guarantee a learning effect (Guo et al., 2020). Instead, a growing body of evidence suggests they interfere with attentional allocation, stress regulation, and encoding, thereby undermining development and learning (Browning & Determan, 2024; Degol & Bachman, 2023; Dixon & Salley, 2007; Fisher et al., 2014).

Figure 2

Conceptual Framework of Early Learning Classroom Environments



The gap in current literature is twofold. First, although there is growing recognition of the importance of principles of the learning sciences, research has yet to fully explore how environmental design of early childhood classrooms impacts the initial encoding stage critical to content retention. Teachers are expected to design classrooms that promote learning, regulation, and sustained attention. However, interviews with teachers reveal they often lack empirical guidance on how to effectively design classroom environments and displays, and this leads them to depend on intuition, tradition, and social media rather than evidence-based strategies (Almeda et al., 2014; Lopez, 2020; Milo-Shussman, 2017).

Second, although adolescent students express preferences for calm, comfortable learning environments (Costa 2024; Students Speak, 2025), research rarely includes voices from children younger than 7 (de Leeuw et al., 2004). This lack of first-person accounts from young learners leaves a critical void in understanding how the physical classroom environment affects their cognitive and emotional engagement with learning.

To address this gap, this critical synthesis integrates insights from cognitive science, developmental psychology, architecture, and education to argue for a paradigm shift in early classroom design—one that is evidence-informed and child-centered. As Lillard (2023) suggests, reimagining the classroom through the lens of children's cognitive development, rather than institutional traditions, may be transformative.

Conceptual Framework

This review defines and examines how key factors—embodied cognition, allostatic load, and attentional allocation—affect encoding and content retention in visually dense early childhood settings. These factors are situated in the conceptual framework presented in Figure 2, which uses a novel approach to integrate two distinct theoretical perspectives .

The first framework is Bronfenbrenner's bioecological theory of child development (Bronfenbrenner & Ceci, 1994), which places the child at the center of multiple, nested systems of biopsychosocial influence. These systems include the microsystem representing the child's immediate environments such as family, school, and peers; the mesosystem, which reflects the interconnections among these settings; the exosystem encompassing external and virtual (Navarro & Tudge, 2023) contexts that indirectly affect the child; the macrosystem, which consists of cultural values, beliefs, and societal norms; and the chronosystem, which captures the influence of time and change. Together, these interconnected systems illustrate the multilayered, ongoing biopsychosocial interaction between child and contexts.

The second framework is Montessori's model of education (Montessori, 1912), which emphasizes the dynamic, triangular relationship between the child, the teacher, and the prepared environment (Cossentino & Brown, 2017). Within this model, the child is viewed as an active learner who constructs knowledge through exploration and interaction with carefully tested prepared materials, which are designed to dually satisfy the child's natural inclination for play and academic curiosity (Lillard, 2021). In concert, the teacher as a guide, with the prepared environment, provides structure, order, and freedom within limits, allowing children to engage in purposeful activities that support autonomy, concentration, and intrinsic motivation (Tebano Ahlquist, 2023). When considered alongside Bronfenbrenner's bioecological theory, the Montessori framework offers a complementary perspective that highlights how environmental design, pedagogy, and developmental processes interact to shape children's learning experiences and outcomes in ECE settings.

Whereby many factors are acknowledged within this framework as part of a broader doctoral "scholarship of integration" (Boyer's [1990] academic model), the current literature synthesis focuses specifically on the elements within the triangle, which represent the neuroeducational experience of young children. Thus, this review underscores the critical connection between physical features of learning environments and learning outcomes. Advances in understanding the concepts of embodied cognition, allostatic load, and attentional allocation provide a robust framework for identifying the foundational factors that drive effective learning. By strategically optimizing educational environments to align with these principles, it becomes possible to create conditions that actively enhance students' content retention.

Embodied Cognition and Learning

Embodied cognition describes the inseparable connection between the environment, body, and brain (Kosmas et al., 2018). As Foglia and Wilson (2013) note, "there is no fracture between cognition, the agent's body, and real-life contexts … the body intrinsically constrains, regulates, and shapes the nature of mental activity" (p. 319). Gallagher's (2023) 4E model—embodied, embedded, extended, and enactive cognition—offers a powerful framework for understanding how young children learn through full-body engagement with their surroundings, particularly as they transition from home to school and begin forming identities as learners.

Central to this perspective is the concept of the "bodymind," a term with philosophical roots in the work of Husserl, Sartre, and Merleau-Ponty (Agostini & Francesconi, 2020), and extended into fields such as neuropharmacology (Pert, 1999), therapy (Rothschild, 2000), neuroscience (Damasio & Damasio, 2006), and dis/ability advocacy (Price, 2015; Nusbaum & Lester, 2021; Walker, 2021). This term also aligns with biopsychosocial theory (Engel, 1977) and bioecological systems theory (Bronfenbrenner, 1994), all of which reinforce the view that cognition is a dynamic process influenced by physical and social environmental factors. In classroom contexts, this means sensory inputs, such as color, density, and noise, directly influence children's regulation, attention, and learning capacity (Diamond, 2013; Fay-Stambach et al., 2014; Gaekwad et al., 2022). Thus, if attention is understood through a biopsychosocial lens, it encompasses neurobiological mechanisms as well as the social and environmental contexts in which children develop. This dynamic process illustrates how biological systems such as the autonomic nervous system and hypothalamic-pituitary-adrenal axis interact with interpersonal relationships, social expectations, and educational environments, thereby shaping not only the child's well-being but also their ability to attend, regulate, and engage in learning (Christensen et al., 2020; Lucente & Guidi, 2023).

Embedded cognition builds on this understanding by highlighting how the environment supports cognitive processing through affordances—objects like blocks, pencils, and digital tools—that enable children to externalize thinking through drawing, writing, and interactive media (Gallagher, 2023). *Enactive cognition* further emphasizes how physical expression, including gestures and body movements, supports meaning-making and communication (Schenck et al., 2022). In early childhood, intersubjectivity—children's tendency to perceive and respond through interaction with others—is a key enactive feature, exemplified in moments of physical attunement with caregivers (Gallagher, 2023). When classrooms become visually overstimulating, they may disrupt these foundational cognitive processes by overloading attention or suppressing natural sensory engagement.

This embodied perspective highlights how external stressors can lead to internal disruptions in both motor and emotional functioning (Gallagher, 2023; Immordino-Yang & Gotlieb, 2017). Conditions such as stress, sleep deprivation, or limited physical movement can impair executive functions. "Executive function" refers to the emergent ability to exert control in pursuit of specific goals (Doebel, 2020). As a result of disrupted executive functions, children may exhibit behaviors that could be misinterpreted as learning or attention disorders (Diamond, 2013). Internal states, influenced by learning environment, play a critical role in influencing children's well-being and cognitive engagement (Fugate & Wilson-Mendenhall, 2022; Immordino-Yang, 2015).

Embodied learning, which applies these cognitive principles to educational settings, emphasizes the importance of sensorimotor experiences in memory and concept formation (Agostini & Francesconi, 2020; Shapiro & Stolz, 2019). In a review of literature, Fugate et al. (2018) found embodied learning strategies to be meaningful in a wide variety of educational domains, including writing, physics, and math. Additionally, Lozada & Carro (2016) found children who actively manipulate materials in Piagetian conservation tasks demonstrate a better understanding of quantity invariance than those who only observe. However, Western education systems often restrict such experiences, favoring conventional models of instruction that marginalize sensory exploration (Macedonia, 2019). As Macedonia explains, "children cannot be prevented from touching, dropping, smelling the objects and putting them in their mouths. Therefore, in the brain's language, a word must be represented as a sensorimotor network that mirrors all experiences collected to the concept" (p. 3). When early learning environments are structured to suppress movement and sensory engagement, often under the pressure of "schoolification," they undermine the natural learning processes of young children (Schunk et al., 2022; Shepard, 1997).

Additional research confirms sensory processing influences participation and engagement in learning activities (Sleeman & Brown, 2021), and that difficulties in sensory regulation, particularly among preterm preschoolers, are linked to deficits in executive function (Adams et al., 2015). Taken together, these findings reinforce the need to critically evaluate and redesign classroom environments. Visually dense, overstimulating settings not only fail to support the body-based nature of cognition but directly interfere with children's ability to attend, engage, and learn effectively.

Allostatic Load and Attentional Allocation

The learning sciences have long explored conditions that best support learning (Sawyer, 2014). Yerkes and Dodson (1908) first described an inverted U-shaped relationship between arousal and performance, suggesting low and high levels of arousal both hinder learning. This principle has been repeatedly confirmed and applied to areas such as executive function (Blair & Ursache, 2011; Neuenschwander et al., 2014). A helpful framework for understanding children's tolerance to sensory input is allostatic load, the cumulative burden of everyday stressors and significant life events (Lucente & Guidi, 2023). Conkbayir (2021) describes this as it relates to young children as, "alteration of stress hormones in response to experience, with consequent effects on emotions, attention, and executive function" (p.129). Thus, when environmental demands exceed a child's capacity to adapt, allostatic overload can occur, resulting in elevated cortisol, emotional dysregulation, attention difficulties, and memory impairment (Christensen et al., 2020; D'Amico et al., 2020; Lucente & Guidi, 2023).

The stress response is further intensified by systemic inequities; chronic exposure to poverty and racism increases cortisol levels in mothers as well as young children, with measurable negative effects on cognitive development and executive functioning (Blair et al., 2011). These findings challenge older cognitive models that frame attention and self-regulation as purely top-down skills to be trained (Diamond & Ling, 2019). In contrast, Tang et al. (2022) propose that nature exposure, flow states, and effortless engagement support cognitive outcomes through autonomic pathways.

For decades, architects and designers have studied how built environments influence human well-being. Foundational theories such as Ulrich's (1983) stress reduction theory and Kaplan's attention restoration theory (Kaplan & Kaplan, 1989; Kaplan, 1995) propose that exposure to nature can reduce stress and restore depleted attention. Building on these ideas, Albright (2015) suggests physical spaces meet bodily and psychological needs, highlighting a dynamic relationship between architecture and neuroscience. Empirical studies across various settings support these theories, confirming effects on cognitive, emotional, social, and behavioral well-being (Gaekwad et al., 2022; Gifford, 2013; Moll et al., 2022) Consequently, biophilic design elements such as natural light, open spaces, neutral color palettes, indoor plants, natural materials, and access to outdoor environments are intentionally incorporated into hospitality, medical, and commercial spaces to improve health and well-being.

Despite such applications, biophilic design in schools remains underexplored, particularly through the lens of allostatic load, thereby highlighting a key area for future research (Albright, 2015; Browning & Determan, 2024; Gaekwad et al., 2022). These insights reveal that classroom environments, if visually overwhelming or misaligned with children's stress regulation needs, can contribute to allostatic overload, ultimately impairing attention, executive function, and learning, particularly for children affected by systemic inequities.

To build on this, understanding how specific classroom sensory demands compete for children's limited cognitive resources requires examining how attention is allocated, a process researchers have explored through eye-tracking and behavioral observation both in laboratory and real-world settings (Mahone & Schneider, 2012; Posner & Rothbart, 2018; Caldani et al., 2020; Dixon & Salley, 2007; Henderson & Ferreira, 2004; Keller et al., 2020; Turoman et al., 2021). Turoman et al. (2021) found that attention is shaped by goals, sensory salience, meaning, and predictability, emphasizing the need for holistic models that consider multisensory and contextual factors. Given children's still-developing attentional systems, external influences are especially significant (Posner & Rothbart, 2018).

Researchers Godwin and Fisher (2011; Fisher et al., 2013, 2014; Godwin & Fisher, 2011; Godwin et al., 2018, 2021, 2022) have collaboratively investigated for a decade the impact of visual density on learning. To operationalize attentional allocation in classrooms, their studies have manipulated the density of visual environments and tracked resulting eye movements, on-task behavior, and content retention. Each of their studies has demonstrated improved attentional allocation, on-task behavior, and stronger content retention in settings that are less dense. In their latest work, Godwin et al. (2022) contrasted laboratory classrooms with authentic classrooms to study habituation to density over time. They found only partial habituation to classroom visuals in a lab setting and no habituation in real classrooms. Despite consistent off-task behavior, attentional allocation varied, and real classrooms grew more visually dense as weeks passed. This finding aligns with the larger, paradoxical question raised by Fisher et al. (2014): Why are our youngest learners, with the least developed attentional control, placed in learning environments rich with potential sources of distraction?

Figure 3
Early Childhood Classroom Utilizing Biophilic and Montessori Design

Note. Photograph from Montessori Māja, used with permission

Encoding for Content Retention

The persistent impact of visual density on attention and behavior also impacts initial encoding conditions, which directly affect content retention, a key metric increasingly prioritized in education policy and assessment (Willingham, 2015, 2021). In efforts to evaluate school effectiveness, economists and education researchers often focus on measurable outcomes, such as test performance (Brennan, 2023). Although there are various metrics to evaluate schooling, effectiveness is commonly operationalized in terms of content retention, typically measured through standardized tests (Hanushek, 2005; William, 2010). In 2024, the National Center for Education Statistics reported a decline of 7 points in reading and 14 points in mathematics on assessments administered to 13-year-olds during the past decade (Irwin et al., 2024). As a result, significant national pressure remains on schools to boost test scores and demonstrate academic improvement.

Disparities in test scores are already evident at the point of school entry (Burchinal et al., 2020; Ghandour et al., 2024) and can have lasting effects on students' educational trajectories and accumulated opportunities (Dearing et al., 2024). As a result, content retention has become a central focus in efforts to improve educational outcomes. The learning sciences have established that encoding and retaining content are possible only when children are fully able to attend to and process information (Craik et al., 1996; Posner & Rothbart, 2007). Brown et al. (2014) define encoding as "the process of converting sensory perceptions into meaningful representations in the brain" (p. 72). However, when the sensory environment is flooded with nonessential stimuli, encoding is impaired (Craik et al., 1996). Maximalist classroom designs, which often create visually dense, sensory-overloading environments, hinder effective encoding (Dixon & Salley, 2007; Keller et al., 2020; Rodrigues & Pandeirada, 2018).

This underscores the critical need for classroom environments that not only reduce visual and sensory overload but also promote the encoding process by centering children's attentional focus. Maria Montessori's purposefully constructed classroom environment—the prepared environment—exemplifies how intentional design can positively influence student outcomes. Montessori spaces are grounded in principles that prioritize concentration, support sustained engagement, and promote sensory clarity (Haines, 2017). Carefully prepared to reduce distraction, Montessori environments feature natural light, open space, neutral color palettes, natural materials, and minimal visual clutter. A growing body of research confirms that students in Montessori environments experience positive outcomes, including improved academic performance, emotional regulation, and focused attention (Denervaud et al., 2019; Randolph et al., 2023; Phillips-Silver & Daza, 2018). Additionally, biophilic elements commonly used in Montessori and similar pedagogies have been associated with lower stress levels and enhanced cognitive functioning (Browning & Determan, 2024; Cha, 2023; Dadvand et al., 2015; O'Connor & O'Connor, 2024; Vella-Brodrick & Gilowska, 2022; Yang et al., 2019).

Discussion

The impact of classroom environments on attention, regulation, and learning is well documented but often overlooked in conventional preservice teacher training (Almeda et al., 2014; Godwin et al., 2018; Godwin & Fisher, 2011; Milo-Shussman, 2017). Teacher preparation programs frequently neglect the sensory and environmental aspects of classroom design, leaving educators ill-equipped to optimize learning spaces (Lopez, 2020). Consequently, teachers often default to familiar or trend-driven designs lacking a foundation in research-based practices (Almeda et al., 2014; Lopez, 2020). Lopez emphasizes this issue, noting that "the majority of teachers relied on the current culture that promotes the same types of displays that have continued to pervade classrooms for generations" (p. 85). As a result, many classrooms become visually cluttered and overstimulating, which disrupts students' abilities to focus, impairs regulation, and decreases learning by hindering encoding and content retention.

Montessori's approach offers a compelling alternative by centering attention and regulation through intentional classroom design. Based on her scientific observations, Montessori (1946) emphasized the "awakening of mental concentration" as essential to learning, achievable through prepared environments and materials (p. 78). She found that children's natural sense of order fosters responsibility and discipline when classrooms support independent engagement (Montessori, 1966, 1979). As the Montessori approach includes many layered aspects, such as specialized teacher training, a full complement of materials, uninterrupted work cycles, and other elements beyond the scope of this review, the research presented here supports this fundamental principle of physical classroom design. Importantly, this principle can be readily incorporated into more conventional classrooms through small-scale, practical adaptations (Debs et al., 2024), demonstrating that intentional environmental features can enhance attention, regulation, and learning outcomes even outside full-fledged Montessori settings.

Ultimately, classroom design is not simply aesthetic; the learning environment is a critical pedagogical tool that influences children's cognitive development. This approach moves beyond viewing attention and regulation as fixed traits or solely child-based challenges, instead framing these capacities as emergent through dynamic interaction with the learning environment. By grounding classroom environments in research and theory, educators and policymakers can transform everyday learning spaces into settings that foster attentional focus, regulation, and academic growth, making evidence-based improvements accessible even in traditional educational contexts.

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