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NEURAL TIMING-DRIVEN AGE-SPECIFIC EDUCATIONAL SPACE DESIGN FOR PRIMARY SCHOOLS: A COGNITIVE-SPATIAL ADAPTATION STUDY

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This study presents a neurodevelopmentally informed framework for designing educational spaces appropriate for children aged 6-12 years. For younger students (6-9 years old), incomplete prefrontal myelination and immature hippocampal development require a mononuclear radial classroom layout and multisensory interaction design to reduce environmental load. Upper grades students (10-12 years old) with enhanced dopamine receptor function and higher abstract reasoning can benefit from modular, reconfigurable systems and delayed reward environments to stimulate higher-order cognition. The study provides new ideas for the optimization of educational spaces in elementary schools and promotes innovation in the field of educational space design.

Key words: *neurodevelopmental chronology, age-specific design, cognitive-spatial congruence, multisensory integration, modular spatial systems.*

INTRODUCTION

Elementary school (6-12 years old) is a critical period for children's rapid cognitive, emotional, and physical development. At this stage, children are very sensitive to their surroundings. Therefore, the design of the school space is very important. Studies have shown significant differences in neural structures and cognitive behaviors between younger (6-9 years old) and older (10-12 years old) students [1]. However, the traditional design of educational spaces is based on standardized functional zoning principles, which does not consider that children's neurodevelopment changes over time, resulting in a mismatch between the space and children's evolving cognitive needs. For example, the prefrontal cortical regions of younger students are not yet fully developed, making it difficult for them to process complex information, yet classroom layout tends to follow the standards of higher grades, which undoubtedly exacerbates the cognitive load. Whereas older children are better at abstract thinking and working with others, they lack the flexible space to support their higher-order development. Recent research in neuroarchitecture suggests that children's brains can show significant plasticity when exposed to different room layouts and sensory experiences. For example, multimodal sensory reinforcement improves the efficiency of parietal spatial coding [2], while collaborative spatial arrangement activates the mirror neuron system and promotes social cognition [3]. However, most of the existing research focuses on single discipline and lacks an integrated framework across neuroscience, education, and architecture. In view of this, the present study is driven by neurodevelopmental chronology, combined with empirical data from brain science, to systematically construct age-specific educational space design strategies, with the aim of realizing “cognitive-spatial” dynamic adaptation and optimizing children's learning effectiveness and behavioral development.

PURPOSE

This study aims to construct a framework for the design of educational spaces suitable for the cognitive-developmental characteristics of children aged 6-12 years old through the interdisciplinary integration of theories of neuroscience, pedagogy, and architecture. It provides a theoretical foundation and practical guidance for the scientific design and transformation of elementary school environments.

RESULTS AND DISCUSSION

Age-related neurodevelopmental characteristics directly influence the hierarchical adaptation of spatial requirements. Given the prefrontal immaturity and multisensory dependence characteristic of early-grade children, educational spaces must optimize learning outcomes through environmental load reduction and sensory adaptation. First, a simple and clear classroom layout can reduce cognitive load and facilitate navigation. For instance, a mono-core radial layout in which the teacher's podium is centrally located, and the learning area is arranged in a fan-shaped configuration naturally directs students’ visual attention toward the teacher, thereby reducing distractions. Furthermore, the circular kinetic design can also simplify path planning in the classroom and reduce the load on the students' prefrontal lobes during path planning. The simplicity of the decor of the classroom space should also be maintained to minimize the distraction of extraneous information from students' attention and enable them to focus more on the learning task.

Second, the design should prioritize the integration of multisensory guidance mechanisms, as the synergistic effects of visual, auditory, tactile, and other multimodal stimuli can facilitate the formation and strengthening of functional connections across brain regions [4]. For example, to accommodate the heightened color sensitivity and reliance on tactile and auditory cues among 6- to 9-year-olds, facilities should feature bright colors, equipped with brightly colored, high-contrast signs and guides to facilitate quick orientation. For example, large, vivid labels with icons instead of text at key points (e.g., corners of corridors and classroom entrances) can dramatically reduce target search time. Furthermore, tactile zoning (using contrasting flooring textures) combined with auditory feedback (e.g., proximity beeps) can enhance spatial memory encoding, while immediate audiovisual rewards (e.g., feedback for successful puzzle-solving) help mitigate distractions. In addition, magnetic geometric puzzles and ground-oriented arrows can reduce the load of multi-threaded information processing, forming a complete intervention chain from sensory adaptation to behavioral guidance.

Given that younger children in lower grades have not fully developed motor coordination or self-protective skills, and considering the heightened sensitivity of their brains to environmental stimuli, spatial design should prioritize safety and comfort. For instance, avoiding furniture with sharp edges and carefully planning furniture dimensions can ensure ample movement space, reduce potential hazards, and create a secure, learning-conducive environment.

Based on the neurological characteristics of upper-grade children (aged10–12) – including the synergistic development of the prefrontal-parietal network, optimized hippocampal function, and the gradual maturation of the default mode network (DMN) – educational spaces must employ design strategies that stimulate abstract reasoning, reinforce social interactions, and optimize self-regulation to accommodate their cognitive leap requirements. First, modular designs (e.g., magnetic patchwork walls) enable children to engage freely in graphic assembly and creative building, thereby stimulating topological reasoning in the dorsolateral prefrontal cortex [5]. Additionally, reconfigurable furniture units allow students to modify spatial layouts, enrich spatial expression, and enhance practical skills. Furthermore, offering blank “meta-spaces” equipped with fundamental components empowers children to customize environments to meet their diverse needs and stimulate abstract thinking.

Second, educational space design should emphasize functional interfaces with blurred boundaries to satisfy children's needs for imitative learning, collaborative interaction, and emotional exchange. For instance, interactive environments (e.g., open group discussion zones and role-playing areas) can be established to facilitate observational learning of social norms and behaviors. Additionally, creating multifunctional shared spaces (e.g., integrating a reading area with a play area, art studio with a science lab) can further stimulate children's creativity and social engagement. Such an approach not only fosters cooperative behavior but also cultivates a sense of collective responsibility.

Finally, educational space design should incorporate mechanisms driven by delayed gratification to optimize students' self-regulation. For instance, an intelligent sensor floor-linked reward system can allow students to unlock a reward storage compartment after maintaining focus on the learning area floor for a specified period, thereby reinforcing delayed gratification through a behavior-feedback cycle; a group communal area rotation maintenance mechanism can also be adopted, so as to allow students to exercise self-regulation in the process of fulfilling their responsibilities. In addition, dynamic environmental regulation (e.g., adjustable lighting) using smart devices can minimize distractions and optimize attention. A goal display area is set up to help students write down long-term learning goals and milestones plans and review their progress on a regular basis, thus enhancing goal awareness and self-management skills.

CONCLUSIONS

This study systematically constructed an age-specific educational space design framework for children aged 6–12 by integrating neurodevelopmental principles with spatial design theories, thereby revealing the dynamic interplay between neurodevelopmental features and spatial needs. The findings confirm that, due to insufficient prefrontal myelination and reliance on multisensory input for hippocampal memory encoding, lower-grade children benefit from simplified pathway configurations – such as a single-core radial layout – and enhanced spatial anchoring through high-contrast color markings and tactile guide bands. In contrast, the synergistic optimization of the prefrontal-parietal network in upper-grade children makes them better suited to modular and variable spaces (e.g., magnetic spliced wall surfaces and reconfigurable furniture) that stimulate abstract reasoning and foster social cognitive advances through collaborative partitioning (e.g., open discussion stations).

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ДИЗАЙН ОСВІТНЬОГО ПРОСТОРУ ДЛЯ ПОЧАТКОВОЇ ШКОЛИ НА ОСНОВІ НЕЙРОННОГО ТАЙМІНГУ, ОРІЄНТОВАНОГО НА ВІКОВІ ОСОБЛИВОСТІ: ДОСЛІДЖЕННЯ КОГНІТИВНО-ПРОСТОРОВОЇ АДАПТАЦІЇ

Це дослідження представляє нейророзвивальну основу для проектування освітніх просторів, придатних для дітей у віці 6-12років. Для молодших школярів (6-9 років) неповна префронтальна мієлінізація та незрілий розвиток гіпокампу вимагають одноядерного радіального планування класів та дизайну мультисенсорної взаємодії для зменшення навантаження від середовища. Учні старших класів (10-12років) з посиленою функцією дофамінових рецепторів і вищим рівнем абстрактного мислення можуть отримати користь від модульних реконфігурованих систем і середовищ з відкладеною винагородою для стимулювання пізнання вищого порядку. Дослідження надає нові ідеї для оптимізації освітніх просторів у початковій школі та сприяє інноваціям у сфері дизайну освітнього простору.

Ключові слова: *хронологія нейророзвитку, віковідповідний дизайн, когнітивно-просторова відповідність, мультисенсорна інтеграція, модульні просторові системи.*