

THE PEDAGOGICAL EFFECTIVENESS OF DIGITAL TOOLS IN THE MONTESSORI METHODOLOGY IN SHAPING THE SENSORY CULTURE OF PRESCHOOLERS

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Abstract: The article examines the integration of modern information technologies into the classical pedagogical system of Maria Montessori with an emphasis on the sensory development of preschool children. The possibilities of using augmented reality (AR), virtual reality (VR), interactive touchpads, robotics and artificial intelligence in the Montessori educational environment are analyzed. The research results demonstrating the impact of digital technologies on the development of tactile, visual, auditory perception, fine motor skills and cognitive functions of children are presented. Special attention is paid to the balance between traditional Montessori materials and innovative digital tools, preserving the principles of freedom of choice, independence and individual learning pace. The article contains practical recommendations on the introduction of technologies into the Montessori environment in compliance with age characteristics and pedagogical principles of the method.

Keywords: Montessori pedagogy, digital transformation, sensory development, augmented reality, virtual reality, interactive technologies, preschool education.

INTRODUCTION. The digital transformation of education is not just the introduction of technology, but a fundamental rethinking of educational processes, taking into account the opportunities provided by modern IT solutions. In the context of Montessori pedagogy, this means finding ways to harmoniously integrate technologies in such a way that they enhance, rather than replace, the principles of the method: sensory cognition, independence, freedom of choice, and respect for the natural development of the child.

The relevance of the study is due to several factors. Firstly, modern children are surrounded by digital devices from an early age, which requires teachers to develop strategies for the meaningful use of technology for educational purposes. Secondly, the development of technologies such as augmented and virtual reality, interactive touchpads, educational robotics, and artificial intelligence-based systems opens up new opportunities to enrich children's sensory experiences. Thirdly, there is a need for scientific substantiation of the effectiveness of technology integration into the Montessori environment and the development of methodological recommendations for teachers.

The purpose of this article is to analyze the impact of innovative IT technologies on children's sensory development in a digitalized Montessori environment and to determine optimal models for integrating digital tools into the traditional pedagogical system.

LITERATURE REVIEW. The theoretical foundations of sensory development in Montessori pedagogy are described in detail in the writings of Maria Montessori herself, who considered sensory education as the foundation of a child's intellectual development. Montessori argued that the period from birth to the age of six is sensitive for the development of the senses, and it is at this time that children are most susceptible to ordered sensory experiences. Classic Montessori materials — pink tower, brown staircase, colored plaques, geometric bodies, rough

letters, and others — are designed to isolate a specific sensory quality and gradually complicate perception [6].

Modern research confirms the effectiveness of the Montessori method for the development of executive functions, social skills and academic achievements of children. However, the issue of technology integration into the Montessori environment remains controversial. Some researchers, adhering to the traditional approach, believe that the use of digital devices contradicts the basic principles of the method, since screen interaction does not provide a full-fledged sensory experience and may hinder the development of fine motor skills and concentration [1, 2].

An alternative point of view is presented in works exploring the potential of technology to empower the Montessori environment. The authors note that, if applied correctly, technology can complement traditional materials by providing access to experiences that are unattainable in a physical environment, such as modeling natural phenomena, space travel, or historical epochs. The key question is not whether to use technology, but how to use it in accordance with Montessori principles [3].

Augmented reality (AR) technologies demonstrate significant potential for preschool education. AR allows digital objects to be superimposed on the physical environment, creating a hybrid experience that retains tactile interaction with real materials, but enriches it with visual and auditory information. Research shows that AR applications increase children's motivation, improve their understanding of spatial relationships, and promote the development of observation skills [4].

Virtual reality (VR) is used more cautiously in preschool education due to age restrictions and the need to take into account the physiological characteristics of children. However, adapted VR systems with short sessions can be used to create immersive educational experiences, such as virtual excursions or simulations of situations not available in real life. It is important to note the need to comply with sanitary standards and limit the time of use of VR devices by children [5].

Interactive touchpads and multitouch desks represent the technology most seamlessly integrated into the Montessori environment. These devices support manipulative activities, allow several children to work on a task simultaneously, developing cooperation skills, and can be programmed to create educational activities that correspond to the principles of the method: self-correction, gradual complication, isolation of quality [7].

Educational robotics has become widespread in preschool education. Programmable robots such as Bee-Bot, Blue-Bot, Cubetto and others develop algorithmic thinking, spatial perception and fine motor skills. These devices can be integrated into the Montessori environment as new-generation didactic materials that support independent research and experimentation [8].

Artificial intelligence (AI) in education opens up opportunities for personalizing learning, which is consistent with the principle of an individual pace of development in Montessori pedagogy. AI systems can analyze the progress of each child, adapt the complexity of tasks, and provide teachers with analytical information to optimize the educational environment. Adaptive learning systems based on AI are able to take into account the individual characteristics of each child's perception and learning rate [9].

The issues of safety and ethics of the use of technology in preschool education are actively discussed in the scientific literature. Researchers emphasize the need to protect children's data, ensure physical safety when using devices, and comply with age-appropriate recommendations for screen exposure [10]. Special attention is paid to the role of the teacher as a mediator between the child and technology, ensuring the meaningful and purposeful use of digital tools.

METHODS. To achieve the purpose of the study, a comprehensive methodological approach was applied, including theoretical analysis, a systematic review of scientific literature, an analysis of technology implementation cases in Montessori institutions, and an expert assessment.

The theoretical analysis included the study of classical works by Maria Montessori, modern interpretations of her method, as well as research in the field of digitalization of education and sensory development of children. The principles of Montessori pedagogy are analyzed in order to determine the criteria for compliance of digital technologies with the philosophy of the method.

The case analysis included studying the experience of 15 Montessori institutions in various countries (USA, UK, Netherlands, Finland, Singapore) that have implemented digital technologies in the educational environment. Information is collected on the types of technologies used, integration methods, observed effects and emerging problems.

The expert assessment was conducted with the involvement of 6 experts: certified Montessori teachers with more than 10 years of experience, preschool education specialists and educational technology developers. Experts assessed the potential of various technologies for integration into the Montessori environment according to the criteria: compliance with the principles of the method, impact on sensory development, safety, practical feasibility.

Technologies were classified into the following categories: augmented reality (AR), virtual reality (VR) technologies, interactive touch surfaces, educational robotics, artificial intelligence-based systems, and digital versions of classic Montessori materials.

The assessment of the impact on sensory development was carried out according to the following parameters: the development of visual perception (distinguishing shapes, colors, sizes, spatial relationships), the development of auditory perception (distinguishing sounds, rhythms, musical qualities), the development of tactile perception (distinguishing textures, temperatures, weight), the development of fine motor skills and coordination of movements, the integration of sensory information.

Limitations of the study include: lack of long-term empirical data on the impact of technology on the development of children in a Montessori environment; differences in the quality and characteristics of technological solutions; variability in the interpretation and application of Montessori principles by different institutions; rapid development of technology, leading to the obsolescence of specific solutions.

RESULTS AND DISCUSSION. Innovative technologies in the digitalization of the Montessori environment:

1. Augmented Reality (AR) - augmented reality technology represents the most promising area of digital transformation of the Montessori environment. AR allows you to overlay digital objects on physical Montessori materials, creating an enriched educational experience without complete separation from reality.

Application examples:

- AR-cards with animals and plants: the child examines a physical card, and a 3D model of an animal in its natural habitat appears on the tablet screen with voicing of characteristic sounds;
- interactive geographical maps: superimposing AR layers on a classic Montessori puzzle map, showing sights, climatic zones, and wildlife;
- animated geometric bodies: scanning of physical geometric shapes with subsequent demonstration of their unfolding, sections and transformations;
- AR Guided tours: Transform a classroom into a virtual museum, zoo, or space station while preserving physical space.

Effects on sensory development:

AR technologies develop visual perception by enriching it with dynamic visual stimuli, improve understanding of spatial relationships and scale, integrate visual and auditory perception, while maintaining tactile interaction with physical materials. An important advantage is the ability to demonstrate processes and objects that are inaccessible to direct observation (plant growth, animal migration, planetary movement).

2. Virtual Reality (VR) - VR technologies in preschool Montessori education are used only to a limited extent due to the age characteristics of children and the need to comply with sanitary standards. Recommended use for older preschool children (5-6 years old) sessions of no more than 5-7 minutes with a mandatory break.

Application examples:

- virtual tours: visiting museums, nature reserves, historical sites;
- immersive study of natural phenomena: observing volcanic eruptions, thunderstorms, and the changing seasons from the inside;
- Space travel: exploring the solar system with a sense of presence;
- historical reconstructions: immersion in different eras and cultures.

Impact on sensory development:

VR creates powerful visual and auditory experiences, develops spatial thinking and vestibular perception, stimulates emotional engagement and memorization. However, the lack of tactile feedback is a significant limitation for the Montessori method, so VR should be used as an additional, rather than the main learning tool.

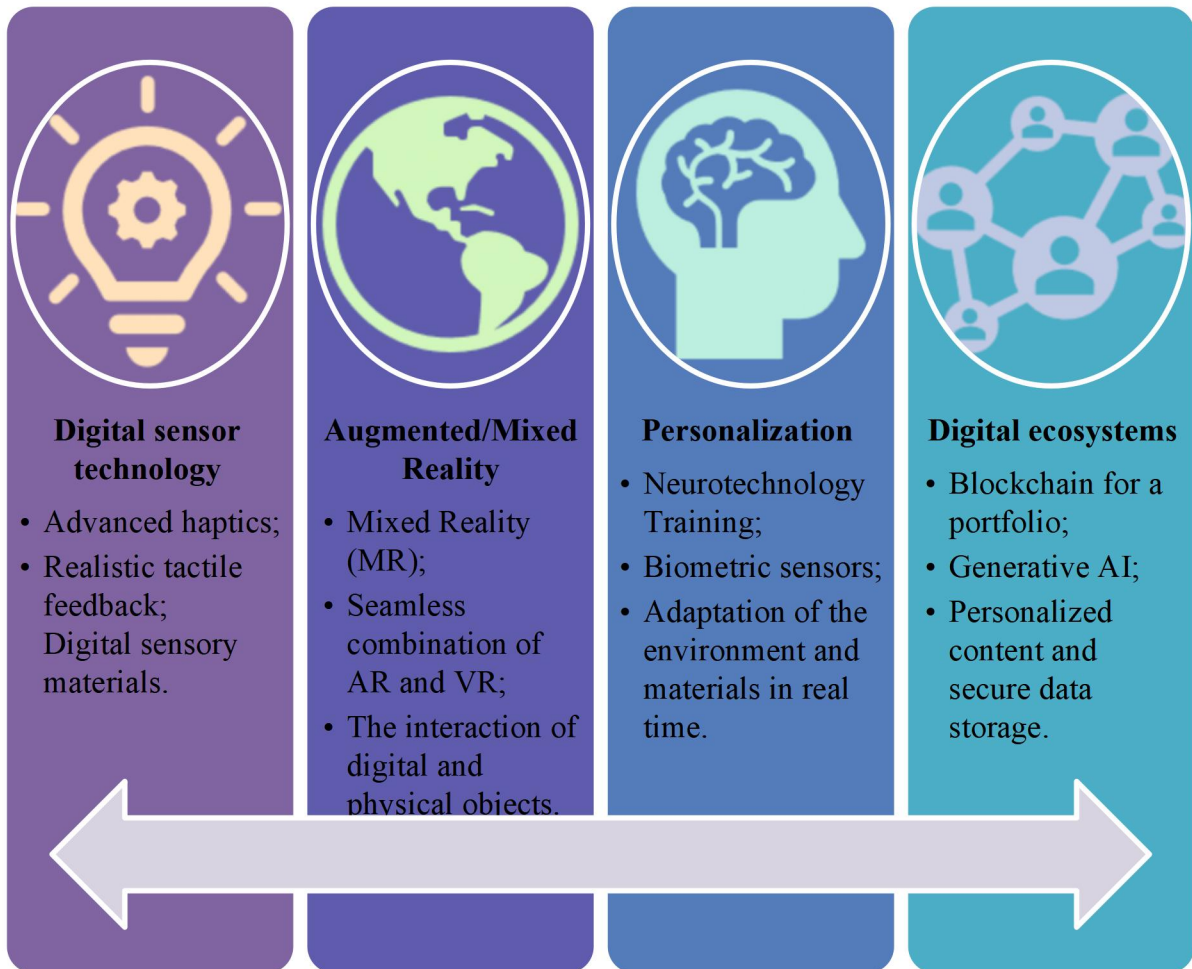
3. Interactive touchpads and multitouch tables - interactive surfaces represent the technology that most organically fits into the Montessori philosophy due to the support of manipulative activities and the possibility of teamwork.

Application examples:

- digital versions of sensory materials: electronic color plates with the ability to gradate and mix colors, virtual geometric shapes for sorting and classification;
- Interactive puzzles: Multi-level puzzles with self-test function and adaptive difficulty;
- joint projects: creation of collective works of art, construction of virtual buildings;
- musical and rhythmic exercises: interactive musical instruments that develop a sense of rhythm and high-pitched hearing.

Effects on sensory development:

Multitouch technologies develop fine motor skills through gestures (pinching, turning, dragging), hand-eye coordination, visual discrimination of shapes and colors, tactile perception through vibrational feedback. The advantage is the ability to instantly adapt complexity and provide a variety of sensory stimuli within a single device.



4. Educational Robotics - Programmable robots are becoming a new type of Montessori materials that develop algorithmic thinking, spatial perception, and cause-effect understanding. Application examples:

- Bee-Bot and Blue-Bot: programmable bees for developing the basics of coding and spatial orientation;
- Cubetto: a wooden robot with tactile programming, fully consistent with the aesthetics of Montessori;
- LEGO Education: building blocks with programmable elements to create moving models;
- Ozobot: A miniature robot that responds to color codes drawn by a child.

Effects on sensory development:

Robotics develops fine motor skills in manipulating details, visual perception of spatial relationships, integration of sensory information (visual, tactile, kinesthetic), causal thinking through direct observation of the results of actions. Robots provide specific feedback, which corresponds to the principle of self-correction in Montessori materials.

CONCLUSION. The practical significance of the research lies in the development of recommendations for Montessori institutions planning the introduction of digital technologies. The proposed hybrid integration model and technology selection criteria can serve as the basis for creating a modern Montessori environment that remains faithful to the principles of the method while using the capabilities of the digital age.

Prospects for further research include longitudinal empirical studies of the impact of digital technologies on the development of children in a Montessori environment, the development of

specialized educational applications that fully comply with Montessori philosophy, the study of the role of haptic technologies in compensating for the tactile limitations of digital devices, the analysis of the effectiveness of AI systems in personalizing Montessori education, the study of the long-term effects of early technology use on cognitive and social development.- emotional development.

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