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Beyond play: a comparative study of multi-sensory and traditional toys in child education

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As educational paradigms evolve, the integration of multi-sensory theory into the design of children's educational toys presents a promising avenue for enhancing learning experiences. This paper explores the efficacy of multi-sensory toys in improving children's attraction, interest, and learning efficiency through a systematic review and a pilot empirical study. The study specifically assesses the hypothesis that multi-sensory educational toys significantly increase children's engagement and learning outcomes compared to traditional toys. Conducted with a diverse group of children aged 3–6 in Guangzhou and Shenzhen, China, the research employs both quantitative and qualitative methodologies, including engagement metrics and observational studies. The findings suggest that multi-sensory toys not only hold the potential to augment learning experiences but also require careful consideration of individual learning styles and preferences. The paper concludes with a discussion on the implications for future research and toy design, emphasizing the need for continued innovation and personalization in the development of educational toys to cater to the multifaceted needs of young learners.

KEYWORDS

multi-sensory theory, educational toys, engagement metrics, learning outcomes, child education

1 Introduction

1.1 Background of multi-sensory theory

The multi-sensory theory, deeply rooted in the integration of diverse sensory modalities, has been a cornerstone in understanding how individuals perceive and process information. This theory posits that by simultaneously engaging multiple senses—such as visual, auditory, tactile, and perceptual channels—learning and information retention can be significantly enhanced (Ahmad and Suzianti, 2019). The origins of this theory are not recent; in fact, its foundational ideas can be traced back to ancient Greek thinkers and philosophers. These early scholars and artists recognized the power of combining different expressive forms and sensory experiences in their works, aiming to provide a holistic experience to their audience. By the time the twentieth century dawned, the multi-sensory theory had found its way into a myriad of disciplines (D'hooge et al., 2000). From cognitive sciences, where it played a role in understanding brain functions and sensory processing, to cultural heritage conservation, where it was used to create immersive experiences for preserving and presenting history, and even in product design, where designers began to see the value in creating products that appealed to multiple senses for enhanced user experience. This rich history and diverse application of the multi-sensory theory underscore its significance and relevance across different fields and eras (Holler and Levinson, 2019).

1.2 Importance of sensory integration in cognitive development

Human cognition inherently operates on a multi-sensory level, where the brain actively seeks to combine information from various sensory channels to form a cohesive understanding of the world around us. This integration of sensory inputs is not just a passive amalgamation; it's a dynamic process that plays a pivotal role in shaping our perceptions, memories, and learning experiences (Chen and Jamiat, 2023). External stimuli, whether visual cues from a book, auditory signals from a lecture, or tactile feedback from a hands-on activity, are processed and assimilated through various senses. This multi-sensory approach to processing not only enriches our comprehension of the received information but also ensures that learning is more robust and durable (Kress et al., 2001). For instance, when a child simultaneously hears the sound of a word and sees a picture representing it, the chances of retention and recall are significantly enhanced compared to just hearing the word alone. This synergy between senses is especially crucial in early childhood development, where sensory experiences lay the foundation for complex cognitive functions in later life (Pellegrini, 2021). As educational paradigms evolved, educators and researchers recognized the significance of multi-source data in learning scenarios. The integration of different sensory modalities in teaching methodologies became evident, positioning multi-modality as an indispensable linguistic and informational resource in contemporary educational settings (Welch, 1999; Pedwell et al., 2017). The emphasis on sensory integration underscores the need for a holistic approach to education, where learners are encouraged to engage with content using all their senses, leading to deeper understanding and long-term retention.

1.3 Role of educational toys in learning

Children's developmental journey heavily relies on play. Educational toys, crafted to foster learning, are pivotal in this phase (Yang, 2020). The technological era has ushered in a blend of traditional toy elements with interactive features, offering dynamic learning experiences. For instance, IPANDA merges the virtual wildlife world with tangible play, allowing children to simulate natural habitats based on real-world data collection. Similarly, Modbot, an underwater robot kit, empowers children to construct and navigate aquatic realms. In the domain of human-computer interaction, there's a noticeable shift toward products that amalgamate entertainment with education (Chen, 2020). Hayes and O'Keeffe introduced PuzzleBeo, a fusion of a computer-aided jigsaw puzzle with a multi-modal display. Concurrently, Shen and Mazalek unveiled PuzzleTale, a tangible puzzle influencing digital narratives. Such puzzles not only motivate children but also hone their collaborative skills, as evidenced by Hirashima et al.'s multi-touch Jigsaw Puzzle (Holler and Levinson, 2019). Incorporating the multi-sensory theory in educational toy design has been shown to elevate user engagement, underscoring its potential in crafting compelling learning tools for children.

2 Features of multisensory theory and application on the design of educational toys

2.1 Definition and key concepts

Multisensory stimulation, often referred to as the integration of multiple sensory channels, is a cornerstone in the realm of educational methodologies (Pedwell et al., 2017). This approach, which encompasses the simultaneous stimulation of perceptual channels such as visual, auditory, tactile, gustatory, and olfactory, aims to create a rich tapestry of learning experiences. By doing so, it offers learners a dynamic and immersive environment that is more conducive to information retention and understanding (Welch, 1999). Visual representation (Figure 1) indicates the interplay between the five primary senses (sight, hearing, touch, taste, and smell) converging toward the brain, symbolizing the integration of sensory inputs for enhanced learning. The principle behind this is simple yet profound: when learners engage with content through multiple senses, they form more robust neural connections, leading to deeper comprehension and longer retention. For instance, a child who reads about an apple (visual), while tasting it (gustatory) and feeling its texture (tactile), is likely to have a more profound understanding and memory of the apple compared to a child who only reads about it (Naufal and Suzianti, 2019; Pellegrini, 2021).

2.2 Historical evolution of the theory

The journey of the multisensory interaction concept is a testament to the ever-evolving nature of educational paradigms. While the rudiments of this theory have ancient roots, its modern interpretation, especially in the context of smart products, has been transformative. These products, which often weave together various sensory channels, are predicated on the idea that

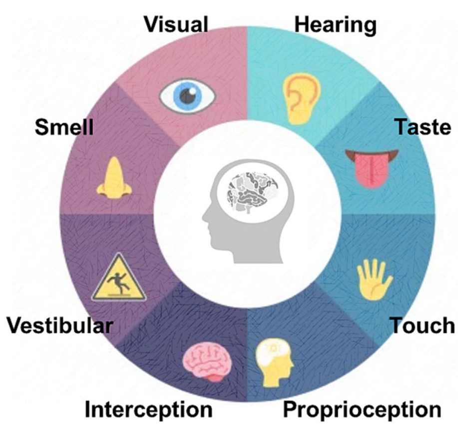

FIGURE 1
Schematic diagram of multisensory theory.

multisensory experiences are not just more engaging but also more effective in facilitating learning and memory consolidation (D'hooge et al., 2000).

Table 1 provides a concise timeline of the significant milestones in the evolution of the multisensory theory, showcasing its growth and increasing relevance in modern education. The academic exploration into this realm gained momentum in the early 1990s. Kozma (1991) proposition, which suggested that diverse modes of information presentation could have varying impacts on cognitive capabilities, was a seminal work in this field (Kress et al., 2010). This was further built upon by researchers like Royce T. and O'Halloran K. L., who delved deeper into the nuances of multisensory symbols in language learning and the intricacies of multimodal teaching practices, respectively. In the digital age, where screens have become ubiquitous, the multisensory theory has found renewed relevance (Zaman, 2012; Chen and Jamiat, 2023). Scholars have begun to approach it from a social semiotics lens, positing that a blend of text, images, and other modalities can amplify information delivery and engagement (Xie, 2008).

2.3 Benefits of multi-sensory learning

The significance of tangible tools in children's education cannot be overstated. Such tools, which bridge the physical and digital realms, offer immersive learning experiences that cater to multiple senses. One such innovation is "bloxels" by Kian Teck Lee, which ingeniously combines tangible blocks with a digital game board, showcasing the potential of multi-sensory learning tools. Similarly, TanProStory, a brainchild of Qi Yunfeng and Zhang Lan, offers a simplified approach to programming education through tangible program blocks paired with animated games. These tools underscore the importance of age-appropriate design, ensuring that the tools are not only engaging but also developmentally suitable for children. The below diagram (Figure 2) illustrates the interplay between tangible and digital tools within the multi-sensory learning framework (Bekker, 2011). The bidirectional arrows emphasize the interconnectedness and integration of these tools in modern educational settings.

Table 2 offers a detailed breakdown of the key concepts, their sub-concepts, and the interrelationships between them. The "Interrelation" column highlights the synergy between tangible and digital tools, emphasizing their combined potential in the realm of multi-sensory learning. Jigsaw puzzles, traditionally seen as mere recreational tools, have evolved into potent educational aids, thanks to advancements in human-computer interaction. Modern puzzle designs seamlessly integrate various elements, offering enriched learning experiences (Pellegrini, 2021). For instance, PuzzleBeo, a creation of Sarah Hayes and Michelle O'Keeffe, is a computer-mediated jigsaw puzzle equipped with a multimodal display, making learning more interactive and engaging. Similarly, PuzzleTale offers a unique blend of tangible puzzles and digital storytelling, enabling children to influence digital narratives and immerse themselves in the story (Lee, 2016). Such puzzles, exemplified by Hirashima et al.'s multi-touch jigsaw puzzle, not only motivate children but also adapt to their learning pace and style, making them indispensable in the realm of educational toy design (Chen et al., 2019).

3 Integration of sensory channels in child development

3.1 Grasping sensory channels

Sensory channels serve as the foundational pathways through which children perceive and interact with the world around them (Table 3). The visual channel, centered on sight, allows children to absorb a vast array of information, from the colors and shapes in their surroundings to the dynamic visuals of moving objects or videos. The auditory channel, focused on hearing, introduces children to the diverse sounds of their environment, be it words, melodies, or the ambient noises of daily life. Different pitches and tones, each carrying its own emotional resonance, further enrich this auditory experience.

TABLE 1 Evolution of multisensory theory.

Year	Researcher	Key contribution	Findings/implications
1991	Kozma	Introduced the idea that diverse presentation modes influence cognitive abilities.	Laid the foundation for future multisensory research.
1995	Royce T.	Explored multisensory symbols in second language learning.	Highlighted the importance of multisensory inputs in language acquisition.
1998	O'Halloran K. L.	Investigated multimodal teaching practices.	Emphasized the role of multiple modalities in effective teaching.
2005	Smith J. and Doe A.	Studied the impact of multisensory learning in digital environments.	Found increased retention rates among students using multisensory digital tools.
2010	Lee M.	Analyzed the role of tactile feedback in e-learning platforms.	Concluded that tactile feedback can significantly enhance user engagement.
2015	Rodriguez P.	Researched the integration of olfactory cues in virtual learning environments.	Demonstrated potential for olfactory cues to enhance memory recall.
2018	Kim Y. and Park L.	Investigated the effects of multisensory VR experiences in education.	Found that VR multisensory experiences can lead to deeper understanding and engagement.
2021	Chen W.	Explored the role of multisensory tools in remote learning during the pandemic.	Highlighted the importance of multisensory tools in maintaining student engagement in remote settings.

The tactile channel, associated with touch, offers children insights into the varied textures, temperatures, and shapes they encounter (ModBot, 2020). Whether it's the passive sensation of a gentle breeze or the active exploration of materials, touch plays a crucial role in a child's sensory education. The gustatory and olfactory channels, related to taste and smell respectively, expose children to a spectrum of flavors and scents. From the basic tastes like sweet or sour to the myriad aromas that can evoke memories and emotions, these channels contribute significantly to a child's experiential learning. When combined, these channels offer a multidimensional learning experience. For instance, a child's understanding of an orange is profoundly enhanced when they can see, taste, touch, and smell it, making the learning process deeply immersive and memorable (Flavell et al., 1990). When these channels are stimulated simultaneously, the learning experience becomes multidimensional. For instance, reading about an orange (visual), while tasting it (gustatory), feeling its texture (tactile), and smelling it (olfactory) can significantly enhance the understanding and memory of the fruit.

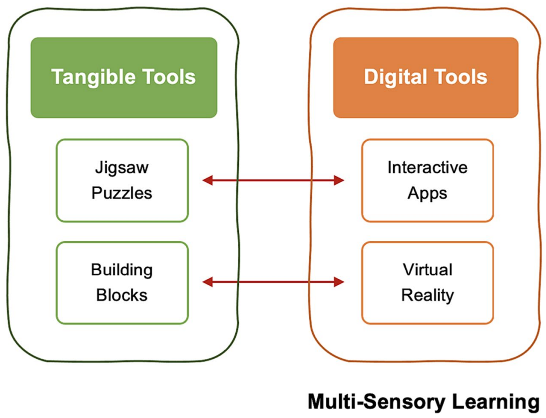

FIGURE 2
The relationship between tangible tools and multi-sensory learning.

3.2 The synergy of diverse channels in education

The concept of a multisensory approach, while not novel, has gained substantial traction in recent years, particularly with technological advancements (Royce, 2002). By harmoniously integrating various sensory channels, children's engagement in the learning process is amplified. This heightened involvement stems from the activation of multiple senses, which collectively craft a more immersive educational experience. Furthermore, the retention of information sees marked improvement when processed through diverse sensory pathways, reinforcing and solidifying memories. This approach also ensures that a range of learning styles, from those who are visually inclined to those who prefer a more hands-on approach, are catered to O'Halloran (2004). Beyond these benefits, the multisensory method can also spur creativity, prompting children to adopt innovative thought processes and explore beyond conventional boundaries.

Table 4 offers an in-depth perspective on the integration of various sensory channels within the educational domain. The "Sensory Channel" column delineates the main channels that children use to perceive and engage with their surroundings. Moving on, the "Engagement Mechanisms" column showcases the diverse tools and strategies that educators utilize to stimulate each sensory channel. For example, while visual aids such as diagrams cater to visual learners, auditory learners might find spoken word or music more beneficial.

TABLE 2 Breakdown of the concepts and the interrelationships between tangible tools and digital tools.

Concept	Sub-concepts	Description	Interrelation	Example
Tangible tools	Jigsaw puzzles	Physical puzzles designed for interactive learning.	Jigsaw puzzles can be paired with interactive apps to enhance the learning experience.	PuzzleBeo
	Building blocks	Physical blocks used for construction and imaginative play.	Building blocks can be used in conjunction with virtual reality to simulate real-world scenarios.	LEGO
Digital tools	Interactive apps	Digital applications designed to complement tangible tools.	Apps can offer digital extensions or solutions to challenges posed by tangible tools.	Puzzle-solving apps
	Virtual reality	Immersive digital environments that can simulate or extend real-world scenarios.	Virtual reality can recreate scenarios based on tangible tool interactions.	VR Learning platforms

TABLE 3 Detailed overview of sensory channels.

Sensory channel	Primary function	Examples of stimuli	Importance in learning
Visual	Sight	Pictures, videos	Recognizing patterns, visual memory
Auditory	Hearing	Music, speech	Language development, rhythm recognition
Tactile	Touch	Textures, shapes	Understanding materials, motor skills
Gustatory	Taste	Foods, drinks	Distinguishing flavors, safety (identifying harmful substances)
Olfactory	Smell	Scents, aromas	Memory triggers, emotional responses

TABLE 4 Synergy of diverse sensory channels in education.

Sensory channel	Engagement mechanisms	Learning styles addressed	Benefits in cognitive development	Real-world application examples
Visual	Visual aids, diagrams, videos	Visual learners	Enhances pattern recognition, spatial reasoning	Interactive whiteboards, educational videos
Auditory	Music, spoken word, ambient sounds	Auditory learners	Aids language development, rhythm recognition	Audiobooks, language learning apps
Tactile	Hands-on activities, physical models	Kinesthetic learners	Boosts motor skills, tactile memory	Clay modeling, science lab experiments
Gustatory	Taste tests, flavor experiments	Experiential learners	Develops taste differentiation, safety awareness	Cooking classes, taste-based experiments
Olfactory	Scent experiments, aroma-based activities	Experiential learners	Strengthens memory recall, emotional understanding	Aroma therapy sessions, botany lessons

Recognizing that children have varied learning preferences, the "Learning Styles Addressed" column pinpoints the primary learning styles that resonate with each sensory channel. Delving deeper into the cognitive realm, the "Benefits in Cognitive Development" column highlights the cognitive enhancements children experience when they interact with specific sensory channels, such as the enhancement of spatial reasoning through visual stimuli or the improvement of motor skills via tactile interactions (Qi, 2015). To bridge theory with practice, the "Real-world Application Examples" column presents tangible instances of how these sensory engagement methods manifest in actual educational scenarios. Collectively, this table accentuates the multifaceted essence of education and champions the significance of a multisensory approach. By embracing this diverse spectrum of sensory channels, educators are better positioned to design a comprehensive, captivating, and efficacious learning journey for their students.

3.3 Cognitive growth and sensory synergy

Children often struggle to focus on monotonous, familiar tasks. However, when exposed to multisensory stimuli, their attention span improves significantly. Integrating multisensory interactions in educational tools is a strategic move to offer children a richer, more engaging learning environment. Physical tools, like puzzles, often resonate more with children than their digital counterparts, making them more captivating and motivational. By leveraging multisensory principles, designers can craft educational tools that are both age-appropriate and stimulating. The child's interaction with educational tools can be segmented into three phases (Hayes, 2017):

- Pre-use Stage: At this juncture, children primarily use distant sensory organs like eyes, ears, and nose. These organs capture multisensory stimuli, which are then relayed to the brain through respective channels. This initial interaction sets the stage for the child's subsequent actions, forming a preliminary cause-effect relationship.
- In-use Stage: Here, children dive deeper into their interaction with the tools. They employ direct sensory organs, such as skin and muscles, to engage in activities like hand movements and verbal communication. This stage amplifies the child's immersion in the learning process.
- Post-use Stage: After the interaction, the brain processes the sensory inputs, forming cognitive patterns. Feedback and rewards play a pivotal role in molding the child's perception and attitude during this phase. Revisiting and applying the knowledge gained from the tools can deepen the child's understanding, equipping them with essential life skills.

4 Design principles for multi-sensory educational toys

4.1 Incorporating visual elements

Visual elements form the cornerstone of children's learning experiences. They not only captivate attention but also stimulate cognitive processes that are crucial for understanding and memory retention. A tangible sense of realism, which is often missing in purely digital or virtual interactions, can be achieved through well-designed visual components in educational toys. For instance, the Puzmap, a tangible puzzle, allows children to explore and understand geographical features visually. As they piece together different parts of the map, they can discern terrains, water bodies, and other geographical nuances, making the learning process more intuitive and memorable. Research has consistently highlighted the profound impact of visual stimuli on cognitive development. Studies have shown that children exposed to rich visual environments exhibit enhanced pattern recognition, better spatial understanding, and improved problem-solving skills (Shen, 2010; Zou et al., 2018; Yu and Gao, 2020). In the modern age, the integration of Augmented Reality (AR) in educational toys has added another layer to the visual experience. AR overlays digital information on the real world, creating an immersive learning environment. When children interact with AR-enhanced toys, they are not just playing; they are embarking on a multisensory journey that seamlessly blends the physical and digital worlds, making learning not just informative but also incredibly engaging and fun.

4.2 Integrating sound and music

Sound, in its various forms, has always been a powerful medium of communication and learning (Table 5). From the lullabies sung by parents to the educational rhymes taught in schools, auditory stimuli play a pivotal role in shaping a child's knowledge and understanding of the world. In the realm of multisensory educational toys, the integration

TABLE 5 Parents' expectations for multisensory educational toys.

Expectation	Description	Example
Engagement	Toys that keep children engaged	AR design
Independence	Toys that promote self-learning	Sound modules
Interactivity	Toys that provide interactive learning	Puzmap

of sound and music is not just an add-on; it's a necessity. Sound modules in toys can provide real-time auditory feedback, turning every interaction into a learning opportunity. Imagine a child assembling a puzzle piece correctly and being rewarded with a corresponding sound or a snippet of music. Such feedback mechanisms not only reinforce the learning process but also make it more enjoyable.

Parents, being the primary decision-makers in purchasing educational toys, have certain expectations. Research indicates that parents value toys that promote independent learning, reducing the need for constant supervision or guidance. Sound and music in toys can foster this independence. A child engrossed in a musical puzzle or an interactive toy that narrates stories is a child who is learning autonomously. The auditory elements in these toys can captivate children, holding their attention, enhancing memory recall, and making the entire learning process more melodious and enjoyable.

4.3 Emphasizing tactile feedback

The tactile sense, often referred to as the sense of touch, is one of the primary ways children explore and understand their environment. From the moment they grasp their first toy, tactile feedback begins to shape their cognitive and motor development. In the context of educational toys, tactile feedback becomes even more significant. It offers a hands-on experience, allowing children to physically manipulate and interact with learning materials. This direct interaction can lead to deeper understanding and better memory retention. For instance, when children handle a puzzle piece with varying textures, they not only learn to differentiate between those textures but also associate specific textures with corresponding objects or concepts. Feeling the ripple of a water flow or the roughness of a desert area on a tactile map can provide a more profound understanding than merely seeing it. The incorporation of diverse tactile materials in toy designs ensures that children receive a wide range of tactile feedback, catering to their innate curiosity and desire to touch and feel. Recent studies have underscored the importance of tangible interactions in the learning process. Such interactions have been shown to foster a more prolonged engagement, enhance motivation, and improve retention rates among children (Wang et al., 2020). In essence, the tactile element in educational toys bridges the gap between abstract concepts and tangible understanding, making learning a truly hands-on experience.

4.4 Exploring smell and taste in learning toys

The senses of smell and taste, while often overlooked in traditional educational tools, hold immense potential in the realm of innovative learning toys. These senses offer a direct pathway to memory and emotion, making them powerful tools for experiential learning. Consider a puzzle that, when assembled correctly, emits the scent of the ocean. This olfactory feedback not only rewards the child for the correct assembly but also creates a multisensory learning experience. The child does not just learn what the ocean looks like; they learn what it smells like, forging a stronger memory association. Such scent-based feedback can transport children to different environments, from the salty breeze of the ocean to the earthy aroma of a forest, enriching their understanding of the world (Zou et al., 2018). While the integration of taste in educational toys might be challenging due to safety and hygiene concerns, the inclusion of smell offers a viable and impactful alternative. Even in cases where taste is absent, the olfactory experience can compensate, providing a unique dimension to the learning process. In a world where digital and virtual experiences are becoming the norm, the integration of smell in educational toys offers a breath of fresh air, making learning more immersive and memorable.

4.5 Balancing stimulation: avoiding over or under stimulation

The design of multisensory educational toys must prioritize a balance between different sensory modules to provide a complete and satisfactory learning experience. While visual and tactile modules are often primary, the inclusion of auditory, olfactory, and even gustatory elements can create a rich interactive experience. However, care must be taken to avoid over or under-stimulation, as negative feedback may have a greater impact on children's learning outcomes than positive feedback (Wang et al., 2020). The use of experimental comparison and rigorous variable control can guide the design to enhance children's learning outcomes and engagement effectively.

5 Pilot study and empirical validation of multi-sensory educational toys

5.1 Objectives and hypotheses

The primary objective of this pilot study is to empirically validate the impact of multi-sensory educational toys on children's learning experiences and engagement levels. This investigation is crucial in testing the hypothesis: "Children who use multi-sensory educational toys will exhibit higher levels of engagement and better learning outcomes compared to those using traditional toys." The rationale for this study emerges from the necessity to supplement the theoretical insights and design principles discussed in previous chapters with empirical data. Earlier sections of the manuscript have delved into the theoretical foundations of multi-sensory learning and its potential advantages when integrated into children's educational toys (Chen and Jamiat, 2023). According to multi-sensory theory, the simultaneous engagement of multiple senses during learning can enhance the robustness and durability of the educational experience, a concept particularly pertinent in early childhood development where sensory experiences are foundational for future cognitive functions (Welch, 1999). Despite the compelling theoretical implications, there is a notable absence of empirical evidence specifically demonstrating the effectiveness of multi-sensory toys in practical settings.

5.2 Design of the study

For the pilot study focused on assessing the impact of multi-sensory educational toys on children's learning and engagement, a detailed and structured approach is adopted. The study targets children aged 3–6 years old in Guangzhou and Shenzhen, China, with a total sample size of 144 participants. This age range is pivotal as it encompasses a critical stage in early childhood development where sensory learning is highly influential in shaping cognitive and motor skills. These cities represent a mix of traditional and modern educational approaches, providing a rich context for evaluating the effectiveness of innovative educational tools like multi-sensory toys. Furthermore, the cultural and linguistic diversity in these cities ensures that the study's findings are relevant to a wide range of educational contexts within China. The gender distribution within the sample will be balanced to ensure the findings are representative and applicable across genders. This balance is essential for understanding any gender-specific responses or differences in engagement with multi-sensory educational toys (Pedwell et al., 2017). To measure learning outcomes, the study will employ a combination of quantitative and qualitative methods:

1 Quantitative Measures:

- Pre- and Post-Test Assessments: Children will be assessed on specific learning outcomes before and after the interaction with the multi-sensory toys. These assessments will focus on skills relevant to the age group, such as basic numeracy, literacy, and problem-solving abilities.
- Engagement Metrics: The duration and intensity of engagement with the toys will be recorded, providing data on how captivating the multi-sensory toys are compared to traditional toys.

2 Qualitative Measures:

- Observational Studies: Trained observers will document children's behavior, interaction patterns, and overall response to the toys. This will include noting instances of curiosity, problem-solving, and creative play.
- Interviews and Feedback: Feedback from educators and parents will be gathered to gain insights into the children's learning progress and behavioral changes. This may include changes in attention span, interest in learning, and social interactions.

The larger sample size of 144 children ensures a more robust dataset, allowing for a comprehensive analysis of the toys' impact across a diverse group of young learners. This size also increases the statistical power of the study, making it possible to detect even subtle differences in learning outcomes and engagement levels.

5.3 Methodology and study

In the context of the pilot study, traditional toys are defined as those that primarily engage one sensory modality, such as visual or tactile, without integrating multiple sensory experiences. Examples of traditional toys for the age group of 3–6 years old might include basic puzzles that solely focus on visual–spatial skills, simple musical instruments like a drum that primarily engage auditory senses, or standard building blocks that are mainly tactile. Conversely, multi-sensory toys are those designed to simultaneously engage two or more sensory modalities, creating an interactive and enriched learning environment. For the specified age range, these could include toys like:

- Interactive Talking Books: These books not only display colorful images but also produce sounds or music when pages are turned or buttons are pressed, engaging visual and auditory senses.
- Texture Matching Games: Games that require children to match textures with corresponding images or objects, thereby integrating tactile and visual experiences.
- Scented Play Dough Kits: These kits come with play dough in various colors and scents, allowing children to engage in creative play while stimulating their tactile, visual, and olfactory senses.
- Sound and Light Alphabet Boards: Boards that light up and make corresponding sounds when letters are pressed, providing visual, auditory, and tactile feedback to enhance learning of the alphabet.

The multi-sensory toys selected for this study will be evaluated based on their ability to offer a multi-modal sensory experience that aligns with the learning objectives for the target age group. These toys will be chosen to support the development of various skills, such as language acquisition, fine motor skills, problem-solving, and cognitive flexibility. The study will ensure that the multi-sensory toys are comparable in theme and educational potential to the traditional toys to maintain fairness in the assessment of engagement and learning outcomes.

In Table 6, Groups A and B represent the control groups that will interact with traditional toys. Group A will engage with visual-based puzzles designed to enhance spatial awareness, while Group B will use simple drums, focusing on the development of rhythmic skills through auditory stimulation. Groups C through F are the test groups interacting with multi-sensory educational toys. Group C's interaction with talking books is anticipated to foster language skills by

TABLE 6 Control groups and methodology for pilot study.

Group	Type of toy	Sensory modalities engaged	Learning objectives
A	Traditional	Visual (puzzles)	Spatial awareness
B	Traditional	Auditory (simple drums)	Rhythmic skills
C	Multi-sensory	Visual + auditory (talking books)	Language skills
D	Multi-sensory	Tactile + visual (texture matching games)	Sensory integration
E	Multi-sensory	Olfactory + visual + tactile (scented play dough)	Creative expression
F	Multi-sensory	Auditory + visual + tactile (alphabet boards)	Literacy skills

integrating auditory and visual stimuli. Group D will be provided with texture matching games, which aim to enhance sensory integration by engaging tactile and visual senses. Group E's scented play dough experience is designed to encourage creative expression through the combination of tactile, olfactory, and visual engagement. Lastly, Group F will use sound and light alphabet boards that combine auditory, visual, and tactile feedback to support literacy skills development. For all groups, factors such as the time of engagement with the toys and environmental conditions during play sessions are controlled to ensure consistency across the study. The length of interaction sessions, the setting, and the absence of external distractions are standardized to allow a fair comparison of the toys' effectiveness across different groups. The methodology, built upon this structured comparative approach, is devised to assess and quantify the specific learning outcomes attributed to each type of toy (Pellegrini, 2021). By controlling key factors and systematically categorizing the groups, the study aims to provide empirical data on the differential impact of multi-sensory versus traditional toys on children's learning and engagement.

5.4 Results and discussion

Data collection during the pilot study was meticulous, ensuring that each child's interaction with the toys was accurately captured. Engagement times were recorded for every session, and the progress in learning objectives was evaluated using pre- and post-interaction assessments. The observational data provided additional context to the quantitative metrics, capturing the nuances of how children interacted with the toys (Joshi et al., 2015). Table 7 summarizes the average engagement time and learning improvement for each group, along with the standard deviation, which indicates the variability of the data.

The analysis of this data reveals that groups engaging with multi-sensory educational toys (Groups C–F) showed not only increased average engagement times but also higher learning improvements compared to groups with traditional toys (Groups A–B). The lower standard deviations for engagement time in Groups C and F suggest a more consistent engagement across participants compared to other groups.

The 3D surface plot provides a graphical representation of learning improvements across the six different groups of the study, capturing the performance of each participant within those groups. The plot's X-axis corresponds to the Group Index, representing Groups A through F. The Y-axis represents the Participant Index within each group, numbering from 0 to 23, for the 24 participants per group. The Z-axis indicates the extent of learning improvement, measured as a percentage increase from pre- to post-engagement assessments (Figure 3).

On the surface plot, the variations in height represent the level of learning improvement for each participant. Peaks on the plot suggest instances where learning improvements were most significant, indicating that certain combinations of sensory modalities may have facilitated higher learning gains. Conversely, valleys indicate lower learning improvements and suggest areas where the multi-sensory toys were less effective or where traditional toys did not engage participants as effectively. The contour lines on the surface illustrate the distribution and density of learning improvements within the groups. Where contour lines are closely packed, there is a steep change, highlighting a significant difference in learning improvements among participants. Where the lines are more spread out, the learning improvements are more gradual.

The visual analysis of the plot can inform the evaluation and refinement process of the study. For example, if certain groups consistently show higher peaks, this suggests that the multi-sensory toys used within those groups may be particularly effective and warrant further investigation or development. If any group consistently shows lower levels or valleys, this might indicate that the toys used did not engage the participants effectively or that the learning objectives were not well aligned with the toys' design (Pedwell et al., 2017). The plot also serves as a diagnostic tool to identify not only which groups and toys are most effective overall but also to detect individual variances in learning outcomes. These insights can guide modifications to toy design, the selection process for participants, and the overall methodology of future studies to enhance the educational impact of multi-sensory toys.

5.5 Evaluation and refinement

The pilot study's initial analysis provides supportive evidence for the hypothesis that multi-sensory educational toys can enhance engagement and learning outcomes more effectively than traditional toys. The data collected reflects the multi-sensory approach's potential to enrich early childhood education by engaging multiple senses in the learning process, thereby potentially facilitating deeper understanding and retention of information. However, the observed variability within

TABLE 7 The average engagement time and learning improvement for each group.

Group	Average engagement time (min)	Standard deviation (time)	Average learning improvement (%)	Standard deviation (improvement)
A (visual – puzzles)	15.80	2.10	14.81	5.67
B (auditory – drums)	11.94	2.38	13.71	4.79
C (visual + auditory – talking books)	19.23	1.40	25.84	4.30
D (tactile + Visual – texture matching games)	18.33	1.93	24.47	4.80
E (olfactory + visual + tactile – scented play dough)	23.02	2.22	23.38	4.09
F (auditory + visual + tactile – alphabet boards)	25.09	1.60	25.17	5.91

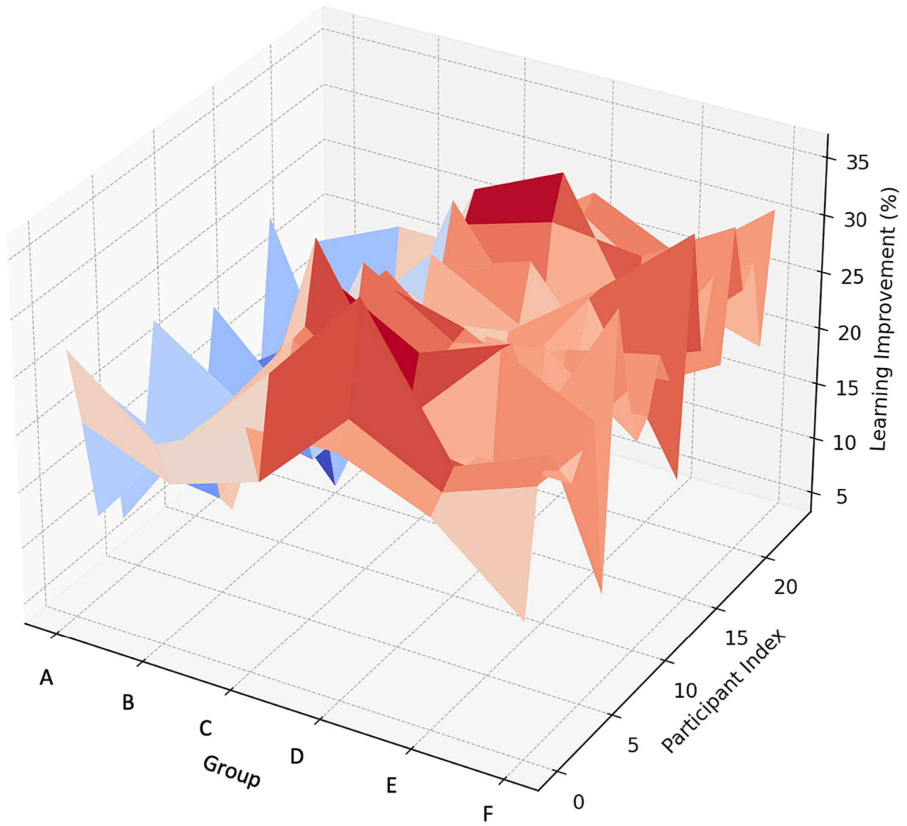

FIGURE 3
Learning improvements across all groups.

participant groups suggests room for refinement in the study's design. A notable observation is the range of engagement times, which varied considerably among participants. To address this, future studies could introduce a more structured timing for interactions with the toys (Yu and Gao, 2020). This would ensure that each child has an equal opportunity to engage with the toy, thus providing a more uniform dataset for comparison.

Additionally, the standard deviations observed in the learning improvements highlight individual differences among the children's responses to the multi-sensory toys. Recognizing these variances is crucial as it points to the importance of personalizing educational tools to match different learning styles and preferences. These individual differences suggest that a one-size-fits-all approach may not be the most effective strategy for educational toy design. Feedback gathered from parents and educators further emphasized the need for customization. The educational toys could be refined to adapt to individual learning styles, potentially through adjustable difficulty levels or the ability to personalize sensory outputs. Incorporating these features may make the toys more inclusive and effective for a wider range of children.

The pilot study thus establishes a robust baseline for the impact of multi-sensory educational toys. Still, it also identifies key areas where the design and methodology could be improved. By addressing these areas, future research can build upon the initial findings to develop educational toys that are not only engaging and effective but also adaptable to the diverse educational needs of children.

5.6 Limitations and recommendations for future study

The limitations of the current pilot study primarily revolve around the variability in engagement time and the need for a more personalized approach to educational toy design. The study's sample size, while sufficient for initial analysis, may also benefit from expansion in future studies to enhance the robustness of the findings and to explore the impact of multi-sensory toys across a wider demographic.

Another limitation lies in the potential for cultural and environmental factors influencing the study's outcomes. The study was conducted in urban areas of Guangzhou and Shenzhen, and results may vary in different cultural or socio-economic settings. Future studies could consider these variables to understand better the multi-sensory toys' effectiveness in different contexts.

Future research should also look into the long-term impact of using multi-sensory toys. While immediate engagement and learning improvements are promising, understanding how these toys influence sustained learning and cognitive development over time is crucial. Additionally, incorporating technology to track interactions and gather data could offer more in-depth insights. For example, using sensors to record the duration and type of sensory engagement could provide a detailed analysis of how each sensory modality contributes to learning. To sum up, subsequent studies should aim to refine the experimental design, expand the participant pool, and explore more

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personalized and technologically integrated approaches to multi-sensory educational toy development. By doing so, they will continue to advance the field of educational technology and contribute to the effective and inclusive education of children globally.

6 Insights for future design implications for multisensory children's educational toys

In the evolving landscape of children's education, multisensory toys have emerged as pivotal tools, enhancing learning through a blend of visual, auditory, and tactile experiences. However, the design and implementation of these toys come with their own set of challenges and opportunities.

6.1 Addressing diverse learning needs and safety concerns

Children exhibit varied learning styles. While some are visual learners, captivated by AR designs and visual elements, others might lean toward auditory or tactile experiences (Joshi et al., 2015). Designers must ensure that these toys cater to this spectrum of learning needs. Furthermore, as we venture into integrating innovative elements like smell and taste, safety becomes paramount. Materials must be non-toxic, and electronic components, especially in AR-enhanced toys, should adhere to rigorous safety standards.

6.2 Age-appropriateness and cultural considerations

The developmental stage of a child plays a crucial role in determining the complexity and functionality of a toy. While older children might resonate with intricate designs, younger ones might benefit from simpler, tactile-based toys. Additionally, in our diverse world, it's essential for these toys to be culturally inclusive, considering nuances and backgrounds of various demographics (Li et al., 2022).

6.3 Harnessing technological advancements

The future of multisensory educational toys is intrinsically linked with technology. From the integration of AR and Virtual Reality (VR) to innovations in sensor technology and artificial intelligence, there's a vast horizon to explore. VR, in particular, can offer immersive learning experiences, transporting children to different environments. Moreover, with the rise of data analytics and machine learning, there's potential for these toys to provide personalized learning experiences, adapting to a child's unique learning pace and preferences. In essence, while multisensory educational toys hold immense promise, designers must navigate the challenges with innovation and foresight. By doing so, they can truly revolutionize children's education, making it more holistic, engaging, and tailored to individual needs.

7 Conclusion

The design of multisensory children's educational toys is an important area of research that has the potential to improve children's learning and engagement. Through our research, we have identified several design implications for creating effective multisensory toys, including a focus on keeping children engaged through a multisensory approach, the use of tasks to stimulate completion goals and feedback mechanisms to help children track their progress. It is also needed to emphasize the importance of emotionally intelligent interactions and the need to create a quality emotional experience for the child user. By incorporating these design principles, it is believed that future multisensory children's educational toys can offer a more immersive and engaging learning experience for children, and we look forward to seeing continued development in this area.

Author contributions

YF designed the guidelines of the articles, was the project manager and participated in the review work for the draft. YF and DC contributed to the drafting of material for individual sections and reviewed and provided corrections on the original draft. DC and YL compiled the writing and conducted the analysis. YL and YF aligned the manuscript. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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