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Design Research on an Educational Gamified Multisensory Interactive Experience Device for Children with Sensory Integration Dysfunction

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Abstract

This study focuses on the multisensory participation needs of preschool children aged 3–6 with sensory integration dysfunction in educational activities. It explores how multisensory training tasks can be organized through educational gamification and designs an interactive device that simultaneously supports children's participation, teachers' implementation, and family-based extension. On the basis of reviewing research on sensory integration difficulties, educational games, and multisensory learning, the study combines field observation, parent and teacher interviews, design translation, and prototype testing to address three key questions: how to enhance children's willingness to participate, how to strengthen activity feedback, and how to support application in educational settings. Based on the preliminary investigation, issues such as children's low initiative, teachers' difficulty in sustaining attention, and the large spatial footprint and poor quantifiability of home training were translated into a level-based game structure, multimodal real-time feedback, and compact composite training modules. This process ultimately led to a prototype of an educational gamified multisensory interactive device composed of precision matching, material blocks, and gesture interaction. The study argues that the device is particularly suitable as a short-duration, high-feedback, and easy-to-deploy experiential educational support tool for training and activity scenarios. It may also serve as a design case linking preschool education, family activities, and individualized support, thereby offering new ideas for the educational participation and multisensory learning of children with sensory integration difficulties.

Keywords: sensory integration dysfunction, preschool children, educational games, multisensory interaction, interactive device design

1. Introduction

Sensory integration dysfunction is not manifested merely as discomfort in a single sense; rather, it can affect children's daily life and learning through attention maintenance, motor coordination, emotional regulation, and social participation. Dunn, Little, Dean, Robertson and Evans (2016), in a scoping review, pointed out that sensory factors are associated with children's social participation, cognition, temperament, and daily participation; Critz, Blake and Nogueira (2015) likewise summarized the effects of sensory processing challenges on children's behavior, learning, and everyday adaptation. Chien, Rodger, Copley, Branjerdporn and Taggart (2016) found that children with potential sensory processing disorders are more likely to experience restrictions in both the extent and enjoyment of activity participation. These findings suggest that sensory integration problems are not only a medical or rehabilitation issue, but should also be incorporated into discussions of educational support and learning participation. In light of the interaction form and educational context examined in this study, the target users are defined as preschool children. This does not imply that sensory integration difficulties occur only at this stage; rather, such problems are easier to observe and identify once children enter collective activities and rule-based tasks, and this stage is also more suitable for interactive activities such as matching, touching, and action imitation.

It should be clarified that this paper does not describe sensory integration dysfunction simply as an organic disease in the traditional sense. Instead, it is understood as a developmental difficulty related to the reception, regulation, and organization of sensory information. Existing studies have shown that early identification of sensory vulnerabilities can help create better learning opportunities in natural contexts, while sensory integration support oriented toward participation, function, and individualized goals has also demonstrated certain potential for improvement. (Fernandes , Reis, Pereira, & Lucas, 2024; Acuña , Gallegos , Barfoot, Meredith, & Hill, 2025)

From the perspective of preschool education, whether the sensory environment is supportive and whether activities are organized in a participatory manner directly affect the likelihood that young children can enter activities, maintain attention, and complete tasks. Piller and Pfeiffer (2016) in a study of preschool contexts, pointed out that the sensory environment can become an important limiting factor for young children's participation in activities. Bartan and Alisinanoğlu (2024) further found that preschool teachers generally recognize the value of sensory education for children's development, yet still face clear shortages in material support, space conditions, and professional training. This means that if sensory integration support is to truly enter educational practice, conceptual advocacy alone is insufficient; concrete tools are also needed that can be understood by teachers and families, are easy to deploy, and can be used continuously.

At the same time, educational games and technology-enhanced learning are opening new practical pathways for the education of children with special needs. Gallud et al. (2023) noted that research on technology-enhanced and gamified learning for children with special needs has grown rapidly in recent years, yet there is still little clear consensus regarding which tools, game forms, and learning contents are more effective. Tlili et al. (2022), in a systematic review, similarly pointed out that game-based learning has positive potential for learners with disabilities, although problems such as insufficient parental involvement and difficulty in standardizing performance measurement remain prominent. Kosmas, Ioannou, and Retalis (2018) further showed that motion-based games can have positive effects on short-term memory and emotional states in special education. Building on this background, the present study attempts to organize sensory integration training content into gamified interactive activities with clearer educational purposes and more explicit operational pathways, so that the functional value of multisensory stimulation can be retained while being transformed into learning experiences that preschool children can more readily understand.

Against this background, this paper focuses on two core questions. First, how can the key participation difficulties experienced by children with sensory integration dysfunction in educational activities be identified through field research? Second, how can these difficulties be translated into specific game mechanisms, interaction processes, and prototype modules, and ultimately developed into a multisensory interactive device that is both educational and operationally feasible?

2. Literature Review

2.1 Sensory Integration Difficulties and Educational Participation of Preschool Children

Existing studies generally indicate that differences in sensory processing affect the quality of children's participation in daily activities. Dunn et al. (2016) noted that sensory factors are related to children's social participation, temperament, cognition, and everyday participation; Chien et al. (2016) argued that potential sensory processing disorders can constrain both the extent of children's activity participation and the enjoyment derived from it. Nielsen, Brandt, and La. (2021), in a sample of Danish school-age children, also found that sensory processing difficulties affect participation in school activities and opportunities for learning. Although that study did not focus exclusively on preschool children, it suggests that participation problems in educational activities often have a structural relationship with sensory processing patterns.

At the preschool stage, direct evidence remains relatively limited. Therefore, many studies discuss early participation mechanisms by drawing on groups with marked sensory processing difficulties. From the perspectives of teachers and therapists, Piller and Pfeiffer (2016) pointed out that sound, spatial arrangement, and activity organization in preschool environments may all become barriers to children's participation. Lin (2020), in a study of preschool children with autism, found a significant association between social activity participation and sensory processing patterns. It should be noted that this paper does not equate autism with sensory integration dysfunction; rather, such studies are used as auxiliary evidence to illustrate how sensory processing differences manifest through activity participation and environmental interaction during the preschool years. For educational design, the implication of this literature lies in treating "how children enter activities, how they sustain participation, and how they receive comprehensible feedback" as the core design concern, rather than discussing symptoms in isolation.

2.2 Research Progress in Educational Games and Multisensory Learning

Gamified activities are well suited to sensory integration support contexts because they can transform tasks that are originally abstract, repetitive, and even stressful into action processes that are exploratory and feedback-rich. Tlili et al. (2022), in a systematic review, pointed out that game-based learning for learners with disabilities shows positive potential for improving skill performance, activity engagement, and learning experience, but the design process still needs to pay greater attention to differentiated needs, stakeholder collaboration, and consistency in evaluation. Gallud et al. (2023) similarly noted that technology-enhanced learning and gamified learning are widely applied in special education, but existing studies still find it difficult to answer which tools, game forms, and learning contents are better suited to specific categories of disability and instructional tasks.

More specifically, multisensory learning does not simply mean superimposing sound, images, and touch; rather, it requires establishing correspondences between perceptual input and behavioral feedback around learning objectives. Through research on motion-based games, Kosmas et al. (2018) demonstrated that the combination of bodily movement and digital feedback has positive effects on short-term memory and emotional states in special education. Di, Ponticorvo, Nadim, and Limone (2025) further found, in primary school contexts, that tangible user interfaces combining digital and multisensory materials can support information retention. Lucas, Pereira, Almeida, and Bellefeuille. (2024), in a systematic review, reminded us that the selection of early sensory integration-related tools should, as far as possible, take into account family-based, everyday, and child-centered usage scenarios. Taken together, these studies suggest that if sensory integration support is to become more closely aligned with educational contexts, designers need to understand "multisensory" as an organizable structure of teaching and feedback, rather than a mere accumulation of stimuli.

In addition, Bartan and Alisinanoğlu (2024), in their study of preschool teachers, also emphasized that sensory education should be integrated into daily activity flows and family collaboration, and that teachers require richer material support and clearer implementation frameworks. This is highly consistent with the design direction of the present study: we aim to deconstruct the core tasks in sensory integration training into a number of small games that children can understand, while integrating immediate feedback, family extension, and teacher observation into a compact interactive system.

2.3 Gaps in Existing Research and the Positioning of This Study

Overall, at least three deficiencies remain in the existing research. First, many studies discuss sensory processing from rehabilitation or therapeutic perspectives, but rarely situate it within the framework of educational participation and gamified learning. Second, although research on educational games covers populations in special education, it often lacks detailed discussion of sensory differences, tactile experience, and proprioceptive participation. Third, in preschool contexts, there are still relatively few compact multisensory device cases that simultaneously address teachers' implementability, families' ability to extend use at home, and children's comprehensibility. Accordingly, this paper takes the educational participation of children with sensory integration dysfunction as its point of departure. Its focus is not on diagnosis or proof of clinical efficacy, but on proposing a design pathway that begins with real needs, proceeds through the translation of game mechanisms, and is ultimately implemented in an educational prototype.

3. Research Methods

3.1 Field Research and Interviews

This study adopted a design-based research approach and focused on preschool children with sensory integration dysfunction. Problems were first identified through field observation, teacher interviews, and parent interviews, and were then gradually translated into game mechanisms and prototype structures. The research team entered an offline sensory integration training institution to conduct observation and carried out interviews with three stakeholder groups: children, parents, and training teachers. The investigation focused on the pain points of existing training methods, children's behavioral performance during training, the practical constraints of home-based training, and the feasible scenarios for technological intervention.

The findings showed that, on the children's side, the core problems lay in insufficient course interest, weak willingness to initiate training, and anxiety easily triggered by classroom settings, course arrangements, and teacher scheduling. On the teachers' side, the major problems were the lack of real-time data feedback, heavy reliance on experiential judgment, and difficulty in maintaining children's sustained attention for more than 15 minutes. On the parents' side, the main difficulties were the large footprint of home training equipment, the difficulty of quantifying training progress, and the lack of support tools that could be conveniently extended to home settings. Compared with simple questionnaire statistics, such issues are more appropriately captured through observation and interviews; therefore, this paper retains a research path centered on qualitative investigation.

3.2 Translating Research Findings into Game Mechanisms

This study did not directly equate research findings with functional requirements; rather, it proceeded through a three-step translation of "problem–mechanism–educational goal." First, in response to children's low initiative, a level-based structure and visual rewards were introduced, transforming originally repetitive training tasks into small games that are achievable and anticipatory. Second, in response to teachers' lack of real-time feedback, triggered animations, sound effects, and staged result presentation were introduced so that a clearer correspondence could be established between children's behavior and system feedback. Third, in response to limited family training space and the difficulty of quantifying progress, priority was given to developing composite training modules that integrate proprioception, fine motor skills, and tactile desensitization, while controlling device size and reserving possibilities for difficulty adjustment and subsequent record keeping.

At the level of educational objectives, the design tasks were specified into three observable learning activities: first, shape recognition and visual–spatial correspondence; second, material discrimination and tactile exploration; and third, action memory, hand–eye coordination, and proprioceptive participation. The purpose of this approach was to ensure that the device does not merely "stimulate" children, but enables them to obtain sensory participation, motor practice, and cognitive feedback while completing a concrete task.

3.3 Prototype Development and Preliminary Testing

At the prototype stage, the study was carried out through a combination of a physical device and screen-based feedback. For materials and animation, software such as C4D, Blender, AE, and Procreate was used to produce visual assets and dynamic content, while the hardware interaction component was linked through sensors together with tools such as Arduino and TouchDesigner. Prototype testing mainly adopted process observation and feedback from parents and teachers, focusing on whether children were willing to enter the activity, whether they could understand the rules, whether they were able to complete the operations, and the preliminary performance of different modules in sustaining attention and stimulating interest.

The testing showed that, for some children, the "action–graphic" mapping in the gesture game imposed a relatively heavy memory burden. Accordingly, subsequent improvements added voice prompts and associative cues, and proposed an optimization direction involving the introduction of difficulty adjustment. This indicates that, for preschool children, game mechanisms should not pursue novelty alone, but also need to balance rule comprehensibility and gradual support.

4. Design of the Educational Gamified Multisensory Interactive Device

4.1 Design Principles and Overall Approach

The prototype developed in this study consists of three interconnected modules: “Precision Matching,” “Material Blocks,” and “Gesture Interaction.” The overall approach is to establish the first step into the activity through fine motor training, expand the multisensory experience through tactile exploration, and then strengthen action memory and visual association through gesture interaction. Functionally, the three modules correspond to shape cognition, material discrimination, and action–feedback mapping, respectively; experientially, however, they remain continuous, enabling children to complete a learning cycle of “observation–operation–feedback–re-operation” within one integrated context.

Unlike traditional large-scale sensory integration equipment, this study deliberately chose a smaller-scale and more easily deployable interactive form. On the one hand, this responds to the practical problem that home-based training occupies considerable space; on the other hand, it seeks to minimize the impression of “equipment” in educational settings while enhancing the sense of “activity” and “play.” The advantage of such a small-scale design lies in its ease of arrangement, transferability, and low threshold for entry, making it suitable for rapid setup in family corners, sensory corners, or individualized activity areas. Its limitation, however, is that the scope of training is relatively concentrated, focusing more on hand operation, localized tactile experience, and action response, and it cannot replace large-scale training activities involving extensive bodily movement, vestibular stimulation, and whole-body coordination. Therefore, the prototype is positioned not as a replacement for all training courses, but as a multisensory educational support tool that teachers, parents, and trainers can readily embed into everyday activities.

4.2 Module I: Precision Matching

The “Precision Matching” module provides geometric shapes of different forms and their corresponding grooves. Children are required to complete one-to-one matching through actions such as grasping, rotating, aligning, and inserting. Once a match is successful, the screen immediately presents a 2D geometric animation, and after all matches are completed, a visual transformation from 2D to 3D is presented. This module has three main educational objectives: first, to help children establish visual–spatial correspondences between geometric shapes and contours; second, to train small hand muscle groups and hand–eye coordination through operations such as alignment and insertion; and third, to enhance the sense of achievement after task completion through progressively appearing dynamic rewards.

Unlike ordinary puzzles, this module does not treat "completing the puzzle" as its only goal; rather, it regards the matching action as an operational process with a learning purpose. During grasping and rotation, children need to continuously adjust posture and force, so proprioceptive and fine motor training are naturally embedded into shape cognition activities. This design precisely reflects the educational gamification approach of this paper: training tasks are embedded in game goals that children can understand.

4.3 Module II: Material Blocks

The "Material Blocks" module consists of six basic textures, including materials such as glass, sponge, spikes, jelly, soft fluff, and metal. A sensor is embedded at the bottom of each cube. When children press or touch different materials, the system triggers corresponding screen animations and sound effects. As shown in Figure 1, different materials reinforce the multisensory experience through visual–tactile linkage. For example, glass may correspond to a transparent, cool-toned shattering animation; metal may correspond to a visually magnetized effect; and soft fluff may present gentle and soft visual changes.

This module has at least three educational values. First, it transforms "touching" from a behavior that may provoke anxiety or avoidance into an activity that is exploratory, predictable, and enjoyable. Second, through visual and auditory feedback, it helps children observe and remember subtle differences among materials, thereby supporting the formation of perceptual vocabulary and comparative awareness. Third, it situates tactile stimulation within children's active pressing and exploration rather than passive reception, thus aligning more closely with a child-centered logic of activity. In other words, this module not only carries out tactile training, but also serves functions of perceptual education and material cognition.

Figure 1 *Visual Design*

Note. created by the author

4.4 Module III: Gesture Interaction

The "Gesture Interaction" module requires children to perform corresponding gestures according to prompted actions and then interact with material models on the screen. For example, interaction related to jelly may be designed as a "stretching" action, whereas interaction related to sponge may be designed as a "pressing" or "squeezing" action. After children complete the action, the system provides feedback through model deformation, changes in sound effects, or visual rewards.

This module primarily trains action memory, visual perception, and proprioceptive participation. Compared with simple button triggering, gesture interaction requires children to establish a continuous relationship among understanding prompts, recalling actions, completing imitation, and observing feedback. In this way, the body is no longer merely an operational tool, but becomes part of the learning process. For preschool children, this type of embodied interaction is closer to their natural mode of learning. Preliminary testing also indicated that overly abstract gesture prompts increase cognitive burden; therefore, optimization requires the inclusion of voice prompts, action associations, and layered difficulty to ensure that children can smoothly enter the activity.

4.5 Usage Process and Educational Scenarios

As shown in Figure 2, in the overall process, children first establish task order and expectations of achievement through “Precision Matching,” then enter “Material Blocks” for tactile exploration, and finally consolidate action–image correspondences through “Gesture Interaction.” This arrangement takes into account the progressive increase in activity difficulty and also helps gradually improve children’s understanding of system rules. For kindergartens or training institutions, the device can be placed in sensory corners, individualized activity areas, or small-group rotation activities. For families, it can also serve as a supplementary practice tool alongside large-scale equipment, helping parents organize more engaging extension activities within a smaller space.

In terms of usage, the device is more suitable as a short-duration, high-feedback experiential activity module rather than a curriculum system driven by complex rules and long-duration tasks. Its advantages lie in lightweight deployment and relatively low guidance cost, enabling children to enter activities more quickly. However, if used repeatedly over a long period, the current richness of rules and variation of tasks may still limit its reusability. Therefore, future improvements are better pursued through thematic updates, graded difficulty, teachers’ verbal guidance, or module reorganization, so as to enhance flexibility in sustained use.

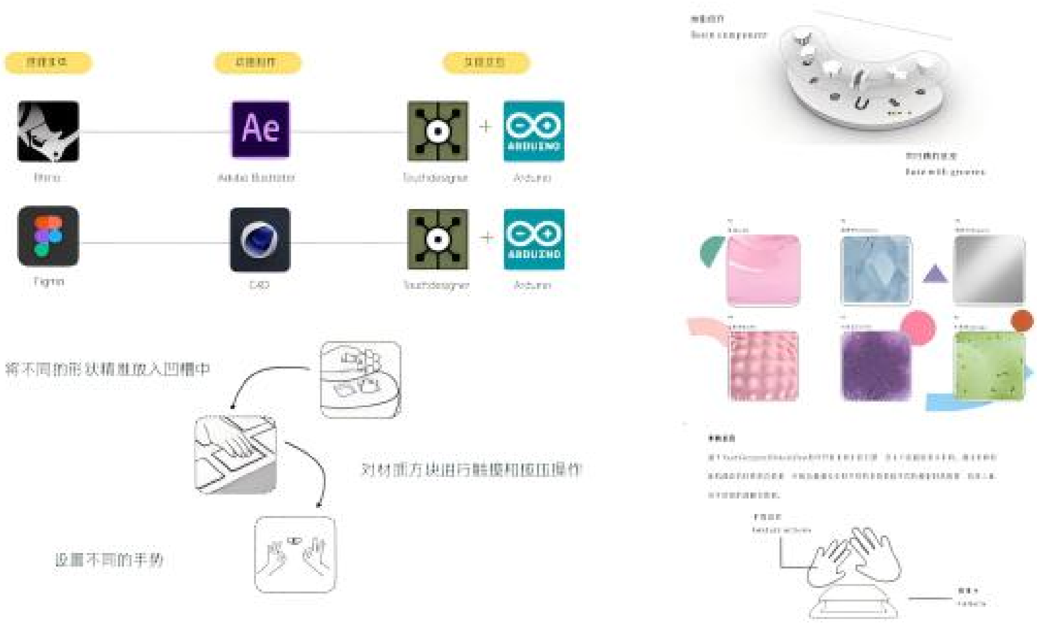

Figure 2 *Illustration of the Interactive Prototype*

Note. created by the author

5. Discussion

5.1 Educational Significance: From Training Equipment to Learning Activity

The most important shift in this paper lies in understanding the multisensory device within a framework of educational participation. The three modules of the device do not correspond to abstract "therapeutic goals," but to observable learning activities for children: Precision Matching focuses on shape cognition and hand–eye coordination, Material Blocks on tactile discrimination and the formation of perceptual vocabulary, and Gesture Interaction on action memory and embodied participation. In this way, the value of the system is no longer manifested only in "whether symptoms are improved," but also in whether it can help children become more willing to enter activities, whether it can support teachers in organizing activities, and whether it can make it easier for families to continue practice.

This line of thinking also echoes recent studies on preschool sensory education. Bartan and Alisinanoğlu (2024) emphasized that sensory education should be embedded in daily routines and supported through family cooperation, while Tlili et al. (2022) and Gallud et al. (2023) reminded us that educational games for children with special needs require clearer design principles and stronger stakeholder collaboration. Although the practical scale of this study is limited, it provides an operational prototype case showing that sensory integration-related design can indeed intersect with educational games, preschool activities, and family-based extension.

5.2 Design Innovation and Practical Value

The innovations of this paper are mainly reflected at three levels. First, at the level of research pathway, it organizes "field research–mechanism translation–prototype design–feedback optimization" into a relatively clear design chain. Second, at the level of device structure, it does not adopt large-scale training equipment, but instead uses a small-scale, multi-module, and serially connectable interactive form to respond to real spatial constraints. Third, at the level of value positioning, it defines the multisensory device as an "educational support tool," emphasizing its application potential in preschool education, family companionship, and individualized support.

From a practical perspective, this prototype is particularly suitable for use as a "bridging tool": it can retain the functional objectives of training institutions while reducing children's resistance through a form closer to everyday activities; it can provide teachers with game activities that are easy to organize, and can also help parents understand what specific abilities each exercise is intended to support. At the same time, its current strengths lie more in facilitating entry into experiences, providing immediate feedback, and enabling deployment in small scenarios, whereas its support for large-scale bodily training and highly complex rule learning remains limited.

Figure 3 *Exhibition Site*

Note. photographed by the author

5.3 Research Limitations and Future Directions

This paper still has clear limitations. First, the study is mainly based on qualitative investigation and prototype testing, and the sample size is limited, which is not yet sufficient to form quantitative conclusions regarding educational effectiveness. Second, the testing scenarios were still mainly focused on display and experience, and continuous tracking has not yet been carried out in kindergarten classes or long-term family training. Third, the device is currently more suitable for short-duration, experiential activities, and its variation in rules and expansion of tasks still need to be enriched. This also means that its long-term reusability and transferability require further verification in subsequent research.

Future research may proceed in three directions: first, conducting longer-term contextualized trials in kindergartens or training institutions to observe its stability in daily activities; second, establishing clearer process evaluation indicators by combining teacher records and parent feedback; and third, continuing to optimize difficulty adjustment, prompting methods, and data-recording functions, so that the device can move from being merely “experiential” toward being “implementable, trackable, and reusable.”

6. Conclusion

Taking the participation issues of preschool children with sensory integration dysfunction in preschool educational activities as its point of departure, this study identified the key pain points faced by children, parents, and teachers in training through field investigation, and translated these issues into gamified level progression, multimodal feedback, and composite training modules. It ultimately developed a prototype of an educational gamified multisensory interactive device composed of Precision Matching, Material Blocks, and Gesture Interaction. The study shows that design for children with sensory integration dysfunction need not be confined to the logic of rehabilitation equipment; it can also function as an educational support tool for promoting activity participation, perceptual learning, and family–institution collaboration. The core contribution of this paper does not lie in claiming clinical efficacy, but in providing a multisensory design case connected to educational settings, together with a relatively clear pathway of design translation.

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