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Potaland: Design and Research of a Multisensory AR Interactive Board Game for Children with Learning Disabilities

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ABSTRACT: PotaLand is an AR educational board game designed for children aged 3–6 with learning difficulties. It combines physical cards, clay models and augmented reality technology to integrate crop recognition into interactive learning. Children scan the cards to view three-dimensional AR crops, memorising the characteristics of the crop models through rotating and zooming. The system highlights the crops' colours and physical traits, making them easier for children with learning difficulties to observe and remember. The cards and clay models, made from eco-friendly rice husk material, not only aid memory but also add variety to gameplay. Children then complete tasks involving matching models to maps, enhancing their observation skills, memory and interest in learning through exploration and interaction. Based on theories of embodied cognition and multisensory learning, this study designed, developed and conducted preliminary testing of the system. The results indicate that multisensory interaction can effectively enhance children's attention, cognitive abilities and engagement in learning, providing a practical, immersive learning approach for special education.

KEYWORDS: social boundary; embodied cognition; child interaction design; cross-cultural communication; observation scale

INTRODUCTION

In recent years, the use of AR in education has become a growing trend, offering enormous potential for improving the education system. It enhances immersive experiential learning, bridges the gap between traditional classroom teaching and real-world experience, and brings tangible benefits to learners' professional development1). Children with learning difficulties exhibit significant differences in cognition, attention and social skills, and traditional educational models struggle to meet their learning needs3). In particular, for children with dyslexia, attention deficit hyperactivity disorder (ADHD) and autism spectrum disorder (ASD), standard teaching methods relying on text and numbers often fail to help them learn effectively. Research shows that interactive, multi-sensory activities and hands-on tasks can significantly improve these children's engagement with learning and their ability to retain information2). The PotaLand project aims to explore how to create a learning tool that enhances concentration whilst fostering observation, memory and spatial awareness through the design of a board game that combines AR with physical interaction. Through gamification and embodied cognition design, children learn naturally through hands-on activities rather than relying solely on text or verbal prompts, thereby reducing learning anxiety and stimulating a desire for active exploration.

THEORETICAL FRAMEWORK

This study is underpinned by three theoretical frameworks. Firstly, the theory of embodied cognition posits that cognition does not occur solely within the brain, but is a dynamic process that emerges through the interaction between the body, perception and the environment (Barsalou, 2008). Research indicates that bodily movements can serve as a key medium for the formation of cognition4).Traditional education often relies on verbal explanations and symbolic communication, but for children—particularly those with learning difficulties—comprehending abstract information can present a significant challenge. When children engage in learning through touching, moving, rotating, sorting and spatial manipulation, their understanding of knowledge becomes more concrete and stable. Furthermore, for children with learning difficulties, input consisting solely of text or speech often makes it difficult to sustain their attention. Research indicates that multisensory stimulation can enhance children's efficiency in processing information and promote the development of sensory integration skills5).This synergy between the senses is particularly important in early childhood development, as sensory experiences lay the foundation for complex cognitive functions later in life. In the field of special education in particular, elements such as colours, images, tangible materials and interactive feedback can effectively enhance children's learning outcomes6). Finally, in recent years, inclusive education models have been introduced into the classroom, emphasising the provision of equitable learning opportunities for children of varying ability levels through adjustments to the learning environment and teaching methods. By designing learning tools and environments tailored to children's cognitive characteristics, these models lower the barriers to learning and enhance engagement.

Educational toys offer an excellent starting point, as children's growth and development rely heavily on play. Furthermore, relevant case studies have demonstrated that incorporating multisensory theory into the design of educational toys can enhance user engagement, highlighting their potential in creating engaging learning tools for children6).

Drawing on these theories, PotaLand divides the learning content into three levels—recognition, interaction and memory—enabling children to receive continuous feedback and cognitive reinforcement as they engage with the activities.

SYSTEM DESIGN: A WEBAR LEARNING SYSTEM

PotaLand has been designed as a multisensory learning system that integrates hands-on activities, augmented reality interactions and memory training tasks, with the aim of providing children with learning difficulties a more intuitive and engaging learning experience. Unlike traditional methods that rely on text and language to convey knowledge, this system transforms crop-related content into a embodied learning process that can be completed through observation, touch, movement and recall. During the learning process, children first establish links between physical objects and digital information through AR recognition; they then explore the morphological characteristics, colour information and growth stages of these crops by observing and manipulating three-dimensional crop models; finally, they recall and apply the acquired information through spatial matching tasks, thereby consolidating their understanding. The entire system forms a continuous learning cycle spanning perception, exploration and memory formation, the core of which can be summarised as three interrelated learning stages: the Recognition Layer, the Interaction Layer and the Memory Layer.

Table 1. Three learning stages and interaction rules

Learning layer	Study phase	User actions	System feedback	Learning objectives
Recognition layer	Open and recognise	Open the packaging, take out the model and cards, and scan the cards	Trigger the corresponding AR crop model	Establishing a cognitive link between physical and digital content
	A basic understanding	Read the task instructions and note the model names and categories	Display basic information and visual cues	Helping children develop basic cognitive skills
Interaction layer	AR Insights	Rotate the AR model to view its shape, colour and details	The model can be rotated 360° for viewing	Improving observational and visual recognition skills
	Feature Exploration	Comparison of the characteristics of different crops	Provide visual feedback	Gaining a deeper understanding of crop characteristics
	Card Matching	Match the clay models with their corresponding cards	Determine whether the match was successful	Enhance feature recognition and classification capabilities
Memory layer	Memory Challenge	Hide the cards, leaving only the models	Remove visual cues	Stimulate the process of active recall
	Spatial Mapping	Place the model in the corresponding area on the farm map	Display the correct or incorrect result	Training spatial awareness and working memory
	Complete the task	Complete pairing for all areas	Display completion feedback	Consolidate long-term memory and gain a sense of achievement

FIELD EVALUATION

This field trial was conducted in a classroom environment familiar to the children, in order to replicate interactive behaviour in a real-life learning context as closely as possible. Compared to a laboratory setting, the classroom space allows for a more natural observation of children's exploratory behaviour, shifts in attention, and interactions with learning materials during the learning process. Consequently, this study chose to conduct the trial within a routine teaching environment to observe the genuine responses of children with learning difficulties whilst using the PotaLand system. A total of three children aged between 4 and 5 participated in this test. To explore learning performance across different cognitive profiles, the participants represented three distinct learning characteristic types: attention-related difficulties, reading-related difficulties, and information processing difficulties. The focus of this study was not on academic achievement, but rather on how multisensory interaction, physical manipulation and augmented reality technology influence children's engagement, observational behaviour, memory performance and task completion.

Two observation scales were designed for the study. Scale One, the 'Learning Interaction Observation Form', primarily recorded children's performance in terms of task engagement, independent operational ability, sustained attention, and interactive behaviour; Scale Two, the 'Learning Outcome Observation Form', primarily recorded children's memory performance, object recognition ability, spatial matching accuracy, emotional responses, and overall level of engagement. Both scales employ a combination of behavioural observation records and rating scales to obtain more comprehensive test data. Data sources include on-site behavioural observation records, researchers' field notes, task completion records, and posttest feedback interviews. Observations focused on how children explored AR content, manipulated physical crop models, understood system feedback, and recalled and applied previously acquired information during the map-matching phase.

As this study is currently in the prototype validation phase, the findings should be regarded as preliminary observational data rather than formal educational effectiveness evaluations. The primary objective of this testing is to validate the feasibility of the design concept and to provide a basis for subsequent system optimisation and larger-scale user research.

(a) Photo 1 Children use iPad/phones to scan cards to observe the characteristics of crops. **(b) Photo 2 Children attempt to match cards and memorize the characteristics of plants.** **(c) Photo 3 In the final stage, the children will place the clay models on the map accordingly.**

Figure 1. Field testing photographs of children. (a) AR placement and approach testing; (b) Interaction Smoothness Test; (c) Memory Difficulty Test.

Note: For the final version, three photographs with similar horizontal proportions and consistent lighting are recommended. If children can be identified, consent should be obtained in advance or faces should be masked

Table 2. Observation Scale Design and Data Collection Framework

Scale	Reference Source	Observation Dimensions	Data Collection Flow	Purpose
Scale 01: Learning Interaction Observation Form	Adapted from Fredricks et al. (2004) Student Engagement Framework and Castro-Alonso et al. (2024) Embodied Learning Framework	Task engagement, operational independence, attention maintenance, interaction frequency, exploration behavior	Behavioral observation → Observation sheet → Score coding → Visual analysis	Evaluate children's participation, attention, and interaction process during learning activities
Scale 02: Learning Outcome Observation Form	Adapted from Castro-Alonso et al. (2024) and Liu et al. (2025) Learning Performance Frameworks	Object recognition, memory recall, matching accuracy, spatial cognition, emotional response	Task performance recording → Observation sheet → Score coding → Comparative analysis	Evaluate children's cognitive performance and learning outcomes after interaction

RESULTS: PRELIMINARY OBSERVATION RESULTS

Table 3. Scale 01: Learning Interaction Observation Form Result Summary

Dimension	Participant Scores (n=3)	Average Score	Result Interpretation	Design Implication
Task Engagement	3 / 3 / 2	2.67	All three children were able to independently carry out key tasks such as scanning, operating the device and pairing, and their overall level of engagement was high.	A gamified task structure effectively encourages children to participate voluntarily
Operational Independence	2 / 2 / 3	2.33	Most children can complete the task independently, though they may occasionally need adult assistance when unpacking the product.	The packaging opening design could be further optimised for young children
Attention Maintenance	2 / 3 / 2	2.33	The AR segment attracted the highest level of attention, whilst some children became briefly distracted during the memory challenge segment	You can add audio cues or sound effects during the memorisation phase to help maintain concentration
Interaction Frequency	3 / 2 / 3	2.67	Children interacted actively with the AR models and physical materials on a high number of occasions, repeatedly scanning them of their own accord	AR's dynamic feedback is highly engaging for children and should be retained as a key strength of the interactive design.

Exploration Behavior	2 / 3 / 3	2.67	Most children took the initiative to rotate and zoom in on the AR models or compare different crop cards, going beyond the basic requirements of the task	The open-world exploration design strategy is effective; more hidden content to explore could be added in future updates.

The Scale 01 results indicate high levels of engagement and participation across all participants. All three children remained actively involved throughout the learning activity and frequently interacted with both physical and digital elements. Minor differences were observed in operational independence and attention maintenance, suggesting that additional instructional cues may further support children with greater learning difficulties.

Table 4. Scale 02: Learning Outcome Observation Form Result Summary

Dimension	**Participant Scores (n=3)**	**Average Score**	**Result Interpretation**	**Design Implication**
Object Recognition	3 / 2 / 3	2.67	Children are able to correctly identify most crops	AR models help build crop awareness
Memory Recall	3 / 2 / 2	2.33	Children are able to recall the main features, but tend to forget some of the details	Mechanisms for revision and repeated observation can be incorporated
Matching Accuracy	3 / 3 / 2	2.67	Most children are able to complete the map-matching task correctly	The matching mechanism is appropriate for children's cognitive development
Spatial Cognition	2 / 3 / 2	2.33	Children are able to understand basic spatial relationships, but still make a few mistakes	The map guidance could be further optimised
Emotional Response	3 / 3 / 3	3.00	All the children displayed positive emotions and a willingness to participate	Gamified experiences can reduce the pressure of learning

The Scale 02 results suggest that the system effectively supported object recognition, memory recall, and matching performance. While some variation was observed in memory and spatial cognition tasks, all participants demonstrated positive emotional responses and successfully completed the learning activities. These findings indicate that the combination of AR interaction and physical manipulation may contribute to both cognitive engagement and positive learning experiences.

DISCUSSION

Preliminary results from this study indicate that the multisensory AR learning system developed by PotaLand can effectively support cognitive engagement and task completion among children with learning difficulties in a real classroom setting. A synthesis of observational data from Scale 01 and Scale 02 revealed that all three participants achieved high scores across three dimensions: task engagement, interaction frequency and emotional response. This suggests that the integration of gamified design and AR technology plays a positive role in stimulating children's intrinsic motivation for learning. This aligns closely with the core tenet of embodied cognition theory that 'physical manipulation facilitates cognitive formation': whilst rotating AR models, touching clay models and completing map-matching tasks, the children constructed concrete cognitive representations of crop characteristics through multisensory, collaborative engagement, rather than relying on abstract verbal or textual descriptions. In terms of memory performance, Scale 02 showed that the average scores for object recognition and matching accuracy both reached 2.67, outperforming the memory recall and spatial cognition dimensions (both 2.33). This discrepancy suggests that children demonstrate relatively stable recognition of crops with visually salient features (such as colour and shape), but their ability to translate these features into spatial position memory remains challenging, potentially due to limitations in working memory capacity and the duration of the task. Data from Scale 01 similarly indicates relatively low scores for sustained attention and independent operational ability, with some children exhibiting brief lapses in attention during the memory challenge phase. This aligns with the typical cognitive characteristics of children with learning difficulties and validates this group's specific need for immediate feedback and step-by-step guidance. Notably, scores for the exploratory behaviour dimension were high (average 2.67), reflecting the children's strong inclination to spontaneously explore the AR content; this provides a basis for designing more discoverable hidden content and reward mechanisms within the system in future. Overall, the integration of physical manipulation and AR technology demonstrated good complementarity in this test: the tactile information from the physical models reinforced the children's memory anchoring of crop morphology, whilst the dynamic three-dimensional presentation of AR effectively reduced cognitive load; together, they constituted a multisensory cognitive scaffold that is accessible to children with learning disabilities.

CHALLENGES AND FUTURE WOR

Although the results of this test were generally positive, the study also revealed several design issues that warrant further refinement. Firstly, in terms of system usability, some younger children (aged 4) required adult assistance when opening the packaging, suggesting that the design of the packaging opening mechanism and operational guidance needs to be further optimised for younger users. Secondly, regarding cognitive load management, the memory challenge phase proved too difficult for some children, particularly the requirement to independently recall crop characteristics and complete spatial matching tasks without visual cues, which places high demands on both attention and working memory. In future, an adaptive difficulty mechanism could be introduced to dynamically adjust the complexity of memory tasks based on children's real-time performance, thereby accommodating children with learning difficulties across different cognitive ability levels. Furthermore, the current version features a relatively limited variety of crops (12 in total), which may not sustain the appeal of the content for long-term, repeated use. Future developments could expand this to over 30 crop varieties and incorporate seasonal and growth cycle-based narrative task lines, providing children with a richer space for cognitive exploration. Regarding home-school collaboration, this test did not yet address the user experience for parents. Future work will involve the development of a dedicated parental monitoring interface, displaying children's learning progress and task performance data in real time, to assist parents in extending classroom learning into the home environment and establishing a closed-loop learning support system through home-school collaboration. Finally, the sample size of this study was small (n=3), limiting the generalisability of the findings. Future research should expand the scale of testing to include participants with a wider range of learning difficulties (such as ASD and dyscalculia), and conduct longitudinal studies tracking learning outcomes over a longer timeframe to obtain more representative, evidence-based data.

CONCLUSION

This study proposes and validates PotaLand—a multi-sensory AR educational board game system designed for children with learning difficulties. By integrating augmented reality technology, physical clay models and farm map matching tasks, PotaLand constructs a continuous learning cycle encompassing three levels: recognition, interaction and memory, enabling children to naturally establish and consolidate their understanding of crops through embodied manipulation. Preliminary user testing results indicate that three children with varying characteristics of learning disabilities were able to maintain consistent engagement and positive emotional responses throughout the entire task sequence. They demonstrated strong performance in object recognition and matching accuracy, whilst also exhibiting reasonable levels of performance in memory recall and spatial cognition, collectively validating the feasibility of the design concept. Framed by embodied cognition theory and multisensory learning theory, this study explored effective pathways for the synergistic use of AR and physical materials in special education settings through a combination of design practice and prototype testing, providing a methodological basis for the design of inclusive learning tools for children with learning difficulties. Future work will expand the sample size and introduce an adaptive difficulty system and a home-school collaboration platform to further deepen evidence-based research into the educational effectiveness of multisensory learning systems.

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