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The Boundary Terrarium: An Embodied WebAR Prototype for Children's Social Boundary Learning

TzuHuang Huang

Department of Advertising, School of Journalism and Communication, Jinan University, Guangzhou 510632, Guangdong, China

Pengcheng Du

Faculty of Creative Industries, City University Malaysia, Petaling Jaya 46100, Selangor, Malaysia

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ABSTRACT: Social boundaries are often not learned by children through explicit verbal instruction alone, but are gradually formed through bodily distance, interaction rhythm, waiting, stepping back, and responses from others. For children, questions such as how close they may approach, when they should wait, and how to repair an overly close interaction are usually implicit social rules. This study presents The Boundary Terrarium, a WebAR interaction prototype for children's social boundary learning. Drawing on distance-perception differences across three East Asian social contexts as design references, the project translates abstract interpersonal boundaries into three AR animal interactions that can be approached, withdrawn from, waited for, and repaired: the pufferfish represents a flexible boundary, the octopus represents a permeable boundary, and the hedgehog represents an invisible boundary. Through WebAR ground placement, camera-model distance calculation, approach-velocity detection, DeviceMotion-based shaking recognition, prompts, learning cards, and a boundary archive, the system converts children's bodily behaviors into immediate visual feedback and reviewable learning memories. The study also uses field observation in a school setting as a preliminary evaluation method, adapting the constructs of inCLASS and PKBS-2 into two AR-contextualized observation scales. Preliminary data indicate stable performance in task engagement, peer interaction, behavioral control, and frustration regulation. In comparison, self-regulation, social interaction understanding, and social independence require further strengthening through everyday social scenarios and prompt-fading mechanisms. The findings suggest that The Boundary Terrarium can translate invisible social-distance rules into an embodied learning experience that is perceivable, repairable, and observable.

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

INTRODUCTION

Children's understanding of social rules is not formed only through adult explanation. It is also learned through bodily distance, interaction rhythm, pauses, facial expressions, and responses from others. When children approach others, wait for their turn, step back, or try again, they are in fact developing an embodied judgment of appropriate distance. However, social boundaries are often invisible. Children may not immediately understand whether another person's discomfort is caused by being too close, moving too quickly, or failing to wait.

The Boundary Terrarium addresses this problem by using WebAR to transform invisible interpersonal boundaries into animal-based feedback that can be triggered, observed, and repaired. Rather than asking children to memorize fixed rules of politeness, the project uses spatial interaction to make boundary differences visible. The design draws on differences in distance perception across mainland China, Japan, and Taiwan as references. Its purpose is not to essentialize national or regional character, but to extract different social-distance tendencies as design metaphors through which children can understand boundary variation.

The central research question is: how can WebAR enable children to practice approaching, stepping back, waiting, and repairing in real space, and how can a brief interaction be transformed into a social-boundary learning experience that can be understood, recorded, and evaluated?

THEORETICAL FRAMEWORK

The theoretical basis of this study can be summarized in three dimensions. First, proxemics suggests that distance itself is a social signal. Bodily distance is not empty space; it is shaped by culture, relationship, context, and the interaction partner (Hall, 1966). Second, grounded cognition argues that understanding does not occur only in the mind, but is also formed through perception, action, and environmental interaction (Barsalou, 2008). Therefore, allowing children to trigger system feedback through bodily approach, withdrawal, and waiting is more suitable for addressing abstract distance awareness than text-based explanation alone. Third, research on early childhood socialization and social-emotional learning indicates that children need concrete situations in which they can observe others, regulate themselves, cooperate, and repair interactions.

On this basis, The Boundary Terrarium translates social boundaries into three operational design elements: cultural rules are converted into spatial parameters, spatial parameters are converted into AR responses, and children form learning memories through bodily repair. In other words, the project transforms abstract boundary ethics into an interactive process that can be tested through the body, fed back by the system, and recorded by observers.

SYSTEM DESIGN: A WEBAR SOCIAL BOUNDARY LEARNING SYSTEM

The Boundary Terrarium is implemented as a browser-based WebAR prototype, so users do not need to install a native app. After entering AR from the start page, the system uses WebXR hit-test to scan the ground and display a placement reticle. Once the model is placed, the system continuously calculates the distance between the camera and the AR animal anchor, and triggers different forms of feedback according to bodily actions such as approaching, stepping back, waiting, and shaking the device.

The system contains three learning layers. The first is the sensing layer, which reads camera position, distance change, approach velocity, and device motion. The second is the feedback layer, which converts sensing data into visual states such as the pufferfish being compressed, the octopus sticking to the screen, and the hedgehog entering an alert state. The third is the reflection layer, which uses prompts, learning cards, and the boundary archive to translate immediate bodily experience into social concepts that children can understand and review.

Table 1. Three Boundary Creatures and Interaction Rules

Animal Character	Boundary Type	Trigger Condition	Feedback and Repair Method	Educational Meaning
Pufferfish	Flexible boundary	Distance below approx. 0.6 m	The body is compressed; it recovers after the child steps back.	Closeness can exist, but the other person's comfortable distance should be preserved.
Octopus	Permeable boundary	Distance below approx. 0.5 m	Mucus covers the screen; the child must step outside the safe distance and shake the device to release it.	Enthusiasm also needs boundaries; excessive closeness can make both sides lose space.
Hedgehog	Invisible boundary	Too close and approaching too quickly	An alert state is triggered; the child must step back and wait for about 3 seconds.	Some friends need to be approached slowly; trust takes time to build.

FIELD EVALUATION: TESTING CONTEXT AND OBSERVATION METHOD

The field test was conducted in an elementary school setting, using a familiar classroom and indoor activity space as the observation environment. Compared with a laboratory setting, the school context more naturally reveals children's bodily movement, approach, withdrawal, waiting, and peer interaction in a real learning space. During the test, children used an iPad or mobile phone to experience The Boundary Terrarium, while observers recorded their interaction behaviors and immediate responses from the side.

Two contextualized observation scales were used. Scale 01, the AR Task Interaction Observation Form, translates the inCLASS dimensions of task engagement, self-regulation, behavioral control, and peer interaction into behavioral indicators within the AR experience. Scale 02, the Social Boundary Behavior Observation Form, adapts the social skills and problem behavior dimensions of PKBS-2 into five observation dimensions: social cooperation, social interaction understanding, social independence, impulse control, and frustration regulation.

The digitized dataset contains records from 20 children, with the sample age mainly concentrated between 7 and 8 years old. Because this study remains a prototype-stage field test, the following results should be understood as preliminary observational data rather than conclusions from a formal standardized assessment.

(a) Photo 1 Children use an iPad / mobile phone for AR placement and approach testing.

(b) Photo 2 Children step back, wait, or shake the device according to animal feedback.

(c) Photo 3 Observers record children's behaviors and scale scores from the side.

Figure 3. Field testing photographs of children. (a) AR placement and approach testing; (b) stepping back, waiting, or shaking to repair the interaction; (c) observers recording behavior and scale scores.

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 Flow

Scale	Reference Source	Observation Dimensions	Data Flow	Purpose
Scale 01: AR Task Interaction Observation Form	Adapted from inCLASS constructs	Task engagement, self-regulation, behavioral control, peer interaction	Paper observation -> digital transcription -> score aggregation -> visual analysis	Evaluates whether children can understand the task, adjust distance, and complete interaction repair.
Scale 02: Social Boundary Behavior Observation Form	Adapted from PKBS-2 constructs	Social cooperation, social interaction understanding, social independence, impulse control, frustration regulation	Paper observation -> digital transcription -> score aggregation -> visual analysis	Evaluates whether children can understand animal boundary responses and demonstrate cooperation, waiting, and corrective behavior.

RESULTS: PRELIMINARY OBSERVATION RESULTS

The total score results show that Scale 01 reached an average total score of 47.10 / 48, equivalent to 4.91 / 5; Scale 02 reached an average total score of 58.60 / 60, equivalent to 4.88 / 5; and the combined observation score averaged 105.70 / 108. Overall, children showed a high level of engagement and rule compliance in the AR tasks, and most were able to complete repair behaviors according to system feedback.

Table 3. Scale 01: AR Task Interaction Observation Form (inCLASS-based) Result Summary

Dimension	Source	Mean Score	Result Interpretation	Design Implication
Task engagement	Scale 1 A	3.00 / 3	Children continuously attended to the AR screen and animal responses, and understood tasks such as approaching, stepping back, waiting, or shaking.	This was one of the highest-performing dimensions, suggesting that AR animal feedback effectively attracted children's participation.
Self-regulation	Scale 1 B	2.81 / 3	Children attempted to adjust distance after adult prompts were reduced, and corrected themselves more quickly when encountering a similar response for the second time.	This was relatively lower, indicating that some children still need a prompt-fading mechanism to move from being reminded toward making their own judgments.
Behavioral control	Scale 1 C	2.96 / 3	Children could stop approaching too quickly after receiving prompts and complete repair behaviors such as stepping back, waiting, or shaking according to the rules.	The near-perfect score suggests that the system can support behavioral correction after impulsive approach.
Peer interaction	Scale 1 D	3.00 / 3	Children waited for turns to use the device, listened to peer or adult prompts, and did not create obvious conflicts during the session.	The stable field order suggests that the system is suitable for further testing in classrooms or small-group experiences.

The Scale 01 results show that task engagement and peer interaction both reached 3.00 / 3, while behavioral control reached 2.96 / 3. This indicates that AR animal feedback can effectively attract children's attention and promote behavioral correction through approaching, stepping back, waiting, and shaking. Self-regulation scored 2.81 / 3, the relatively lowest dimension among the four, suggesting that some children still require adult or system prompts before they can move from correcting behavior after being reminded toward independently judging and adjusting distance.

Table 4. Scale 02: Social Boundary Behavior Observation Form (PKBS-2-based) Result Summary

Dimension	Source	Mean Score	Result Interpretation	Design Implication
Social cooperation	Scale 2 A	2.98 / 3	Children followed the rules of scanning, placement, approaching, and stepping back, and completed the repair process according to prompts.	This indicates that the AR task can guide cooperation and rule compliance.
Social interaction understanding	Scale 2 B	2.88 / 3	Children could understand the boundary signals behind the responses of the pufferfish, octopus, and hedgehog.	Boundary differences were perceived, but abstract concepts still require further translation through everyday social scenarios.
Social independence	Scale 2 C	2.88 / 3	Children could actively step back, slow their approach, and try again without completely relying on adult reminders.	This remains a key area for future enhancement through prompt fading and independent judgment training.
Impulse control	Scale 2 D	2.93 / 3	After reverse scoring, a higher score indicates fewer impulsive responses such as repeated rushing, excessive shaking, or ignoring prompts.	Most children could control excessive operation after receiving system feedback.

(reverse-scored)				
Frustration regulation (reverse-scored)	Scale 2 E	3.00 / 3	After reverse scoring, a higher score indicates that children could continue participating steadily after alert, stuck, or compression feedback.	This was the highest-performing dimension, suggesting that error feedback did not cause obvious withdrawal and that the system has value as a low-risk practice environment.

The Scale 02 results show that frustration regulation reached 3.00 / 3, social cooperation reached 2.98 / 3, and impulse control reached 2.93 / 3, while social interaction understanding and social independence both scored 2.88 / 3. These results suggest that children could continue participating and follow rules after receiving failure feedback, and most children could understand the relationship between animal responses and social boundaries. However, further curriculum-oriented design is still needed to translate animal rules into everyday situations such as queuing, sharing toys, meeting someone for the first time, and joining a group game.

DISCUSSION

The preliminary observation results support the central design hypothesis of this study: when abstract social boundaries are transformed into visible AR animal responses, children can more easily understand the relationships among approaching, stepping back, waiting, and repairing through bodily action. The pufferfish, octopus, and hedgehog provide boundary feedback of different intensities and qualities, allowing children to compare the distance needs of different interaction partners within the same system.

It is worth noting that the scores for self-regulation and social independence were lower than those for task engagement and frustration regulation. This suggests that although children can be attracted by AR tasks and continue participating after error feedback, they may not yet be able to fully move away from adult prompts and independently judge whether to step back, wait, or approach slowly. Future versions should therefore introduce a prompt-fading mechanism: clear instructions can be provided during the first experience, and prompt intensity can be gradually reduced during repeated experiences so that children shift from following prompts to making independent judgments.

In addition, this study should not be understood as a fixed classification of different cultures. The three animals are not essentialized descriptions of societies in mainland China, Japan, and Taiwan. Instead, they translate different distance tendencies into design metaphors that children can understand. The true educational goal is not for children to memorize how they should interact in a particular region, but to understand that different people, situations, and relationships may require different distances.

CHALLENGES AND FUTURE WORK

Several limitations remain. First, the data in this study are prototype-stage field observations. The sample size and scoring procedure need further expansion, and future work should establish more stable observer training and inter-rater consistency checks. Second, the scanning stability, audio triggering, and sensor permissions of WebAR may vary across devices and browsers. Third, whether children can transfer the distance understanding formed through AR animal interaction into real-life social situations still requires follow-up studies and validation through situational tasks.

Future versions can develop in five directions. First, individualized boundary learning can adjust task difficulty according to children's approach speed, waiting time, and repair behavior. Second, contextualized social curricula can introduce everyday tasks such as queuing, sharing toys, first meetings, and joining games. Third, parent and teacher observation tools can convert post-experience data into readable behavioral reports. Fourth, a cross-cultural distance training platform can extend the system to international student adaptation, workshops, and public etiquette education. Fifth, a generative tutor can be added so that the system provides more personalized voice guidance based on children's performance.

CONCLUSION

The Boundary Terrarium transforms invisible social-distance rules into a WebAR learning experience that can be triggered by the body, perceived visually, repaired through behavior, and recorded through observation scales. The preliminary findings indicate that animal-based boundary feedback can effectively support children's task engagement, behavioral control, peer interaction, cooperation, and frustration regulation. At the same time, self-regulation, social interaction understanding, and social independence remain areas that require further design enhancement.

The main contribution of this study is the proposal of an embodied framework for social-boundary learning: cultural and social-distance differences are translated into spatial parameters, spatial parameters are translated into AR responses, and bodily repair behaviors such as stepping back, waiting, approaching slowly, and shaking form learning memories. For children, boundaries are no longer abstract rules spoken by adults; they become interactive experiences that can be seen, tested, and corrected.

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