SpaceMates

A Spatial Reasoning Game for Children Using Desktop Robot

SpaceMates—a tangible programming game integrating tabletop robots and 3D-printed blocks, aimed at enhancing children's spatial reasoning abilities.

Background

Spatial reasoning is widely recognized as a crucial cognitive foundation for children's success in **STEM** fields. It refers to the ability to mentally represent, manipulate, and reason about spatial relationships.

SpaceMates engages children in constructing dynamic **3D structures** and **planning paths** with elevation variations; the introduction of **tabletop robots** validates the paths and provides feedback, thereby deepening children's understanding of 3D space.

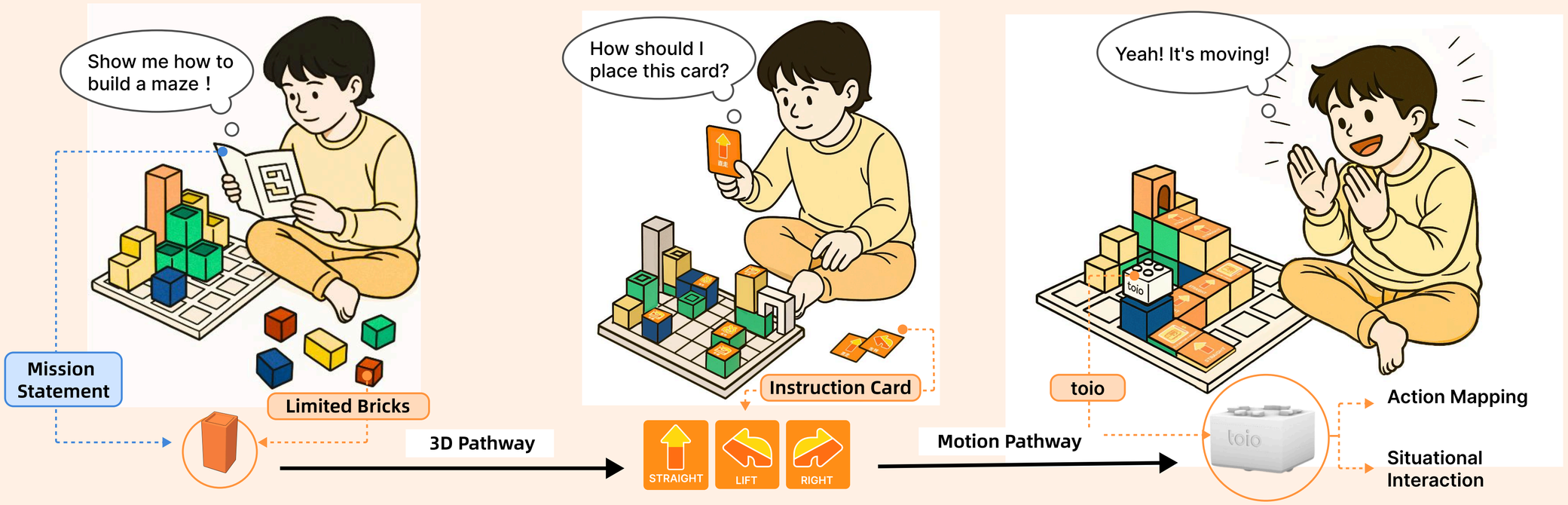
Drawing on the **developmental trajectory** of spatial skills in middle childhood and the **Spatial Reasoning Instrument (SRI)**, we categorized spatial reasoning games into three dimensions: Mental Rotation (MR), Spatial Visualization (SV), and Spatial Orientation (SO), designing **progressive games** tailored for children aged 7-8 and 9-10.

Game Mechanics

MENTAL ROTATION + SPATIAL VISUALIZATION

SPATIAL ORIENTATION

SPACE VERIFICATION



Step1 : Build（5-8min）

Build the pathway according to the instructions

Step2 : Plan（3-5min）

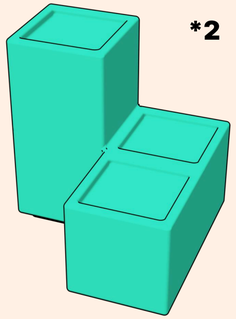
Place ID card

Step3 : Verify（1-2min）

Place toio, read ID, and complete path verification

construction or planning errors，return to the previous process

Game Element Design



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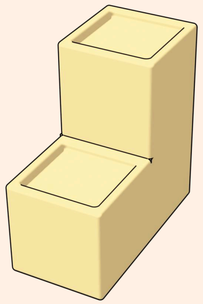

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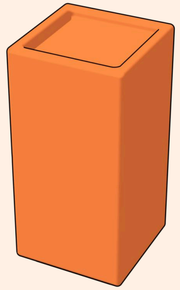

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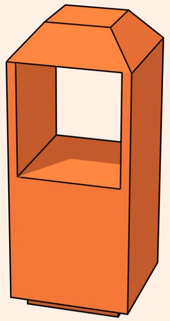

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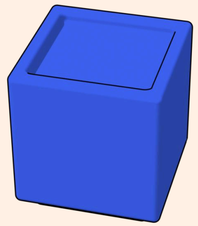

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1-Cell-High
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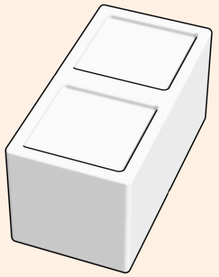

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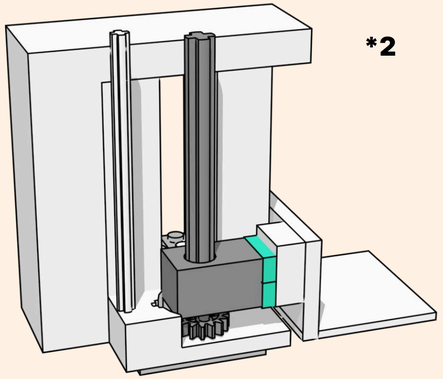
1-Cell-High
2-Cell-Wide



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2-Cell-High
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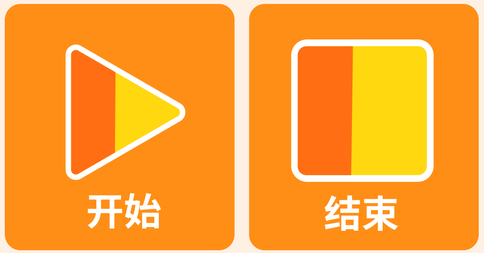
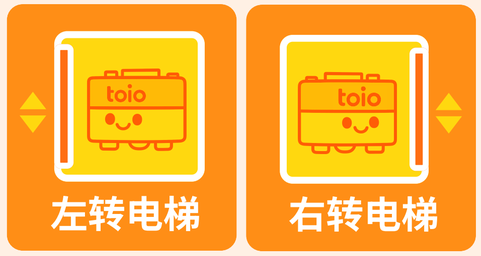


Indicate the start and end of a task. Upon recognizing the start card, the robot emits a“beep-beep”; upon recognizing the goal card, it produces a sound and spins in place.

The “Treasure” card is a required path card and can be overlaid with action cards; the “Monster“ card is to be avoided - when recognized, the robot emits a “beep” and vibrates sideways to indicate an incorrect path.



Introduced in older-age tasks, these represent composite actions where the robot enters the elevator structure, performs ascent/descent, then turns left/right, and finally moves forward one cell.

Forward Card: The robotmoves forward one cell.Left Turn / Right Turn Cards:The robot turns left or rightby 90° and then movesforward one cell.

Game Level Design

We themed the background of SpaceMates as "Robot Adventure Island," where the robot acts as a companion for the children. Children of different age groups are required to complete three challenge tasks, with the difficulty of these tasks progressively increasing based on Scaffolding Theory. Each task comprises three gameplay processes: construction, planning, and verification.

Prior to the game, children receive their missions through a physical illustrated task manual.

Game 1

Escape the Maze (aged 7-8)

Verifiy: Place the programming cards as instructed by the manual, then position the robot at the starting point to validate the path.

Build: Children restore the correct orientation by mentally rotating the images.

The children's objective is to interpret the maps in the task manual—which have been intentionally rotated by 90 degrees—and subsequently construct the correct maze paths on the game board.

Game 2

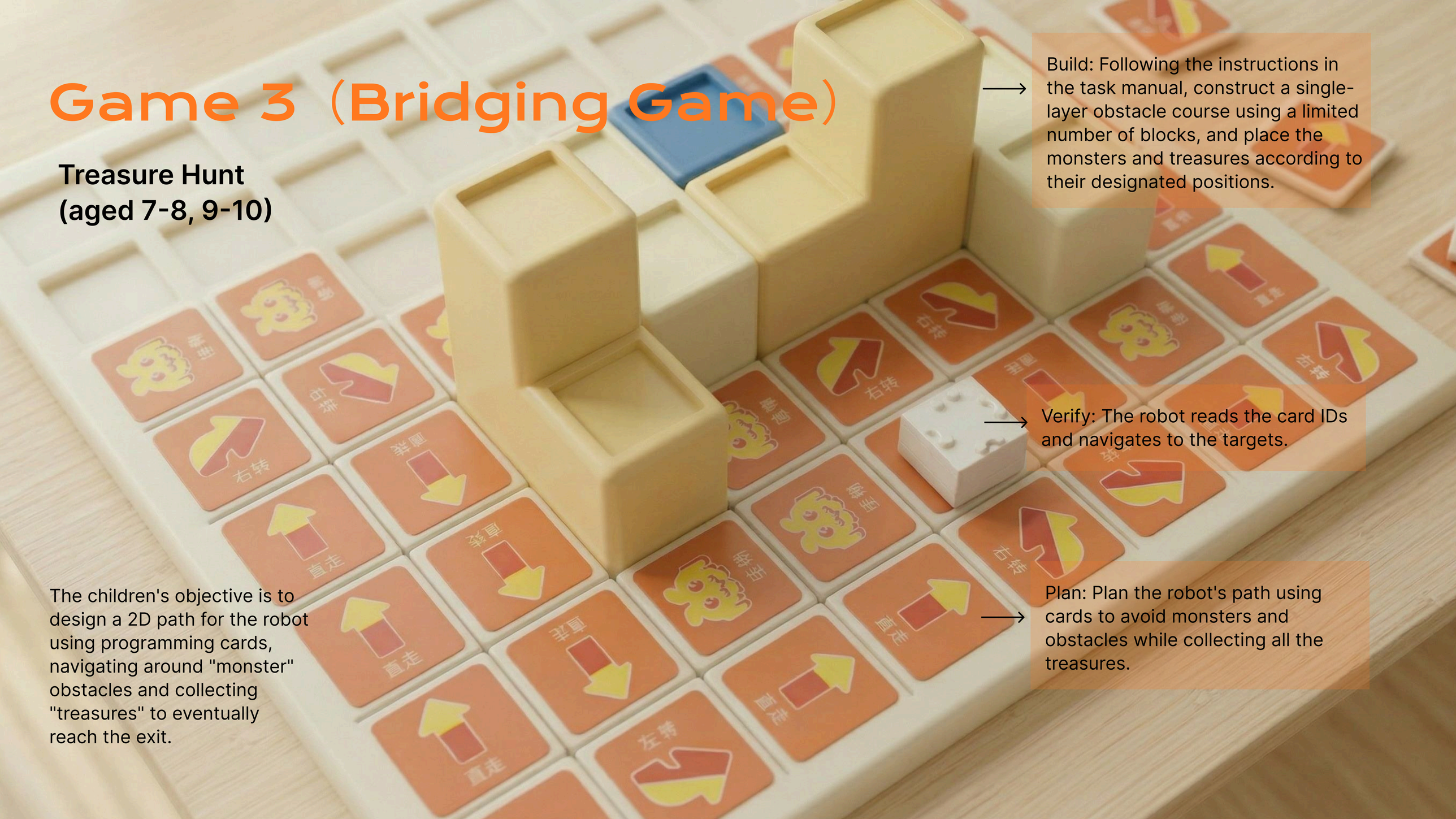
Puzzle Master (aged 7-8)

The children's objective is to construct a specific 3D target structure using a limited set of irregular blocks, based on the 2D multi-view orthographic projections (front, top, and side views) provided in the task manual.

Build: Guided by 2D multi-view projections (front, top, and side) of totem-like letters with color cues, children reconstruct 3D shapes within the sandbox. This process involves a limited set of irregular blocks with specific positional and occlusion constraints. Children must first employ Mental Rotation (MR) skills to map the 2D views into 3D space, and subsequently utilize Spatial Visualization (SV) skills to reason about the spatial relationships between the blocks.

Game 3（Bridging Game）

Treasure Hunt
(aged 7-8, 9-10)



The children's objective is to design a 2D path for the robot using programming cards, navigating around "monster" obstacles and collecting "treasures" to eventually reach the exit.

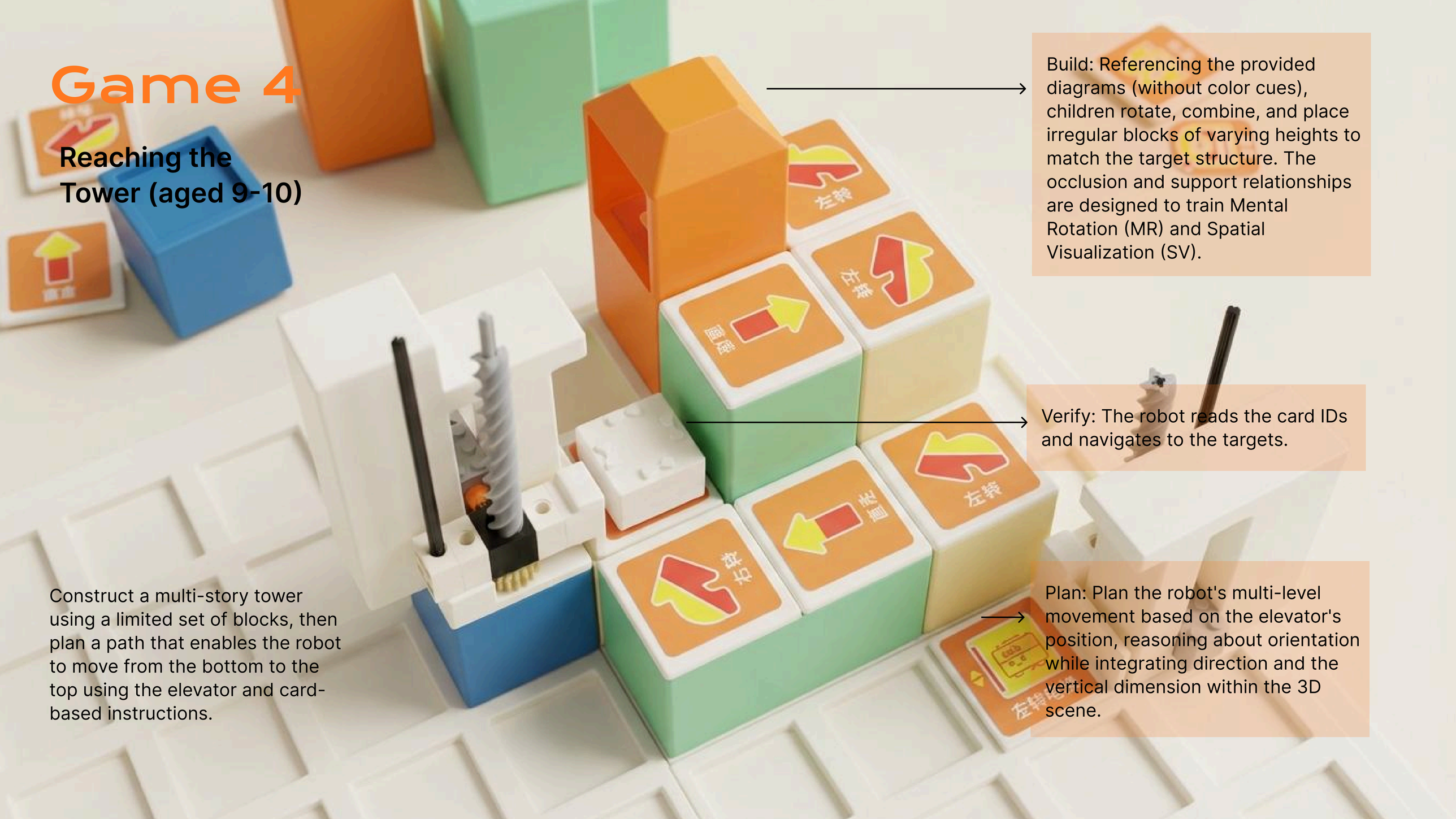
Build: Following the instructions in the task manual, construct a single-layer obstacle course using a limited number of blocks, and place the monsters and treasures according to their designated positions.

Verify: The robot reads the card IDs and navigates to the targets.

Plan: Plan the robot's path using cards to avoid monsters and obstacles while collecting all the treasures.

Game 4

Reaching the Tower (aged 9-10)



Construct a multi-story tower using a limited set of blocks, then plan a path that enables the robot to move from the bottom to the top using the elevator and card-based instructions.

Build: Referencing the provided diagrams (without color cues), children rotate, combine, and place irregular blocks of varying heights to match the target structure. The occlusion and support relationships are designed to train Mental Rotation (MR) and Spatial Visualization (SV).

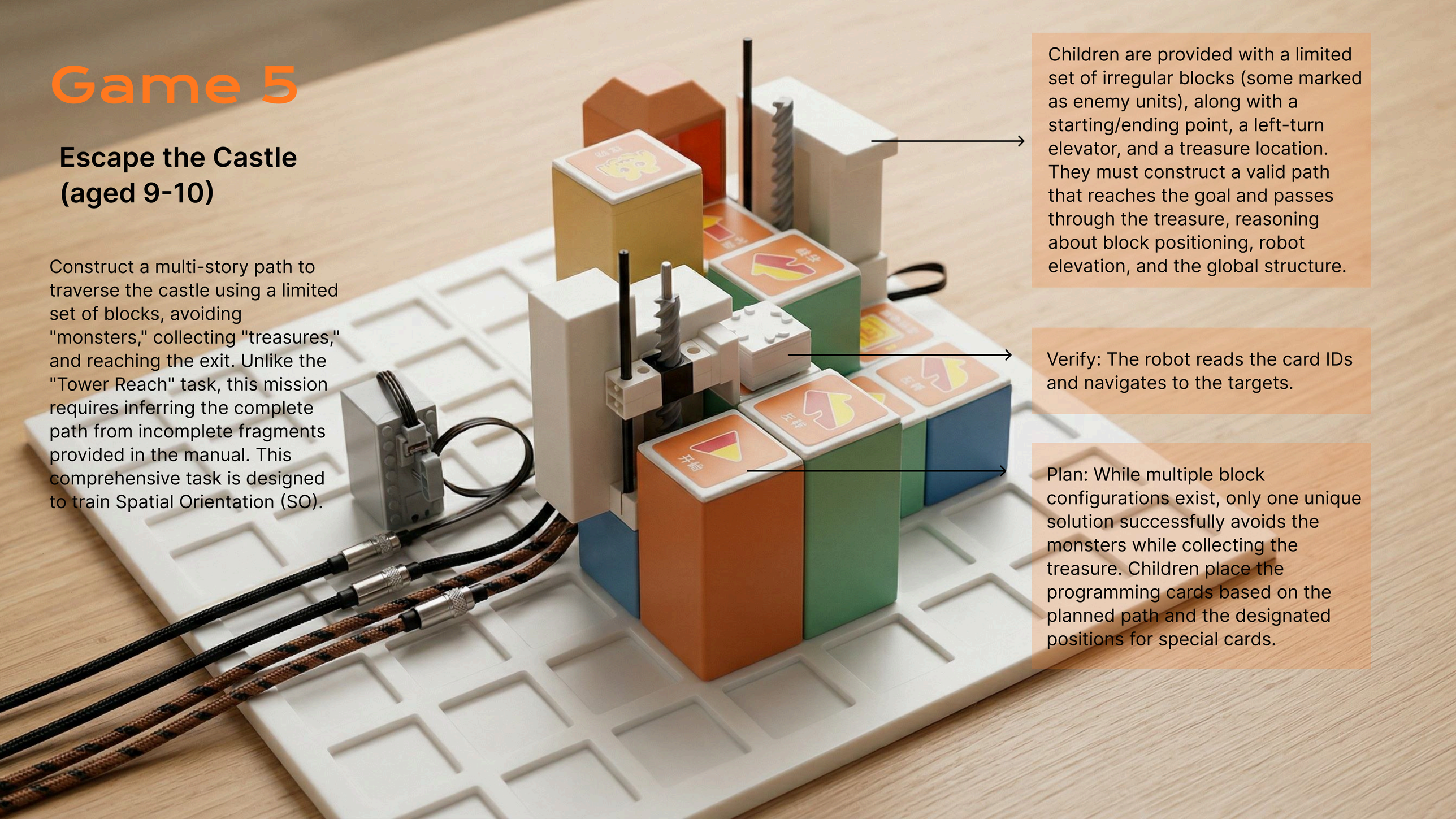
Verify: The robot reads the card IDs and navigates to the targets.

Plan: Plan the robot's multi-level movement based on the elevator's position, reasoning about orientation while integrating direction and the vertical dimension within the 3D scene.

Game 5

Escape the Castle (aged 9-10)

Construct a multi-story path to traverse the castle using a limited set of blocks, avoiding "monsters," collecting "treasures," and reaching the exit. Unlike the "Tower Reach" task, this mission requires inferring the complete path from incomplete fragments provided in the manual. This comprehensive task is designed to train Spatial Orientation (SO).



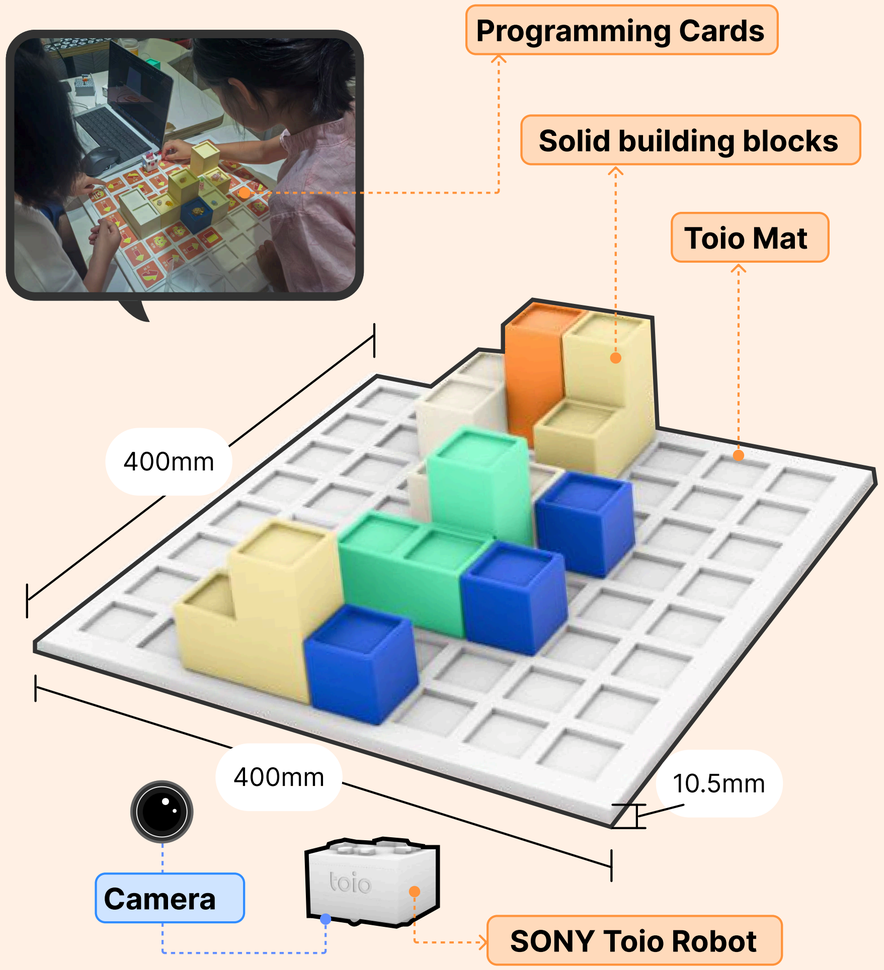
Children are provided with a limited set of irregular blocks (some marked as enemy units), along with a starting/ending point, a left-turn elevator, and a treasure location. They must construct a valid path that reaches the goal and passes through the treasure, reasoning about block positioning, robot elevation, and the global structure.

Verify: The robot reads the card IDs and navigates to the targets.

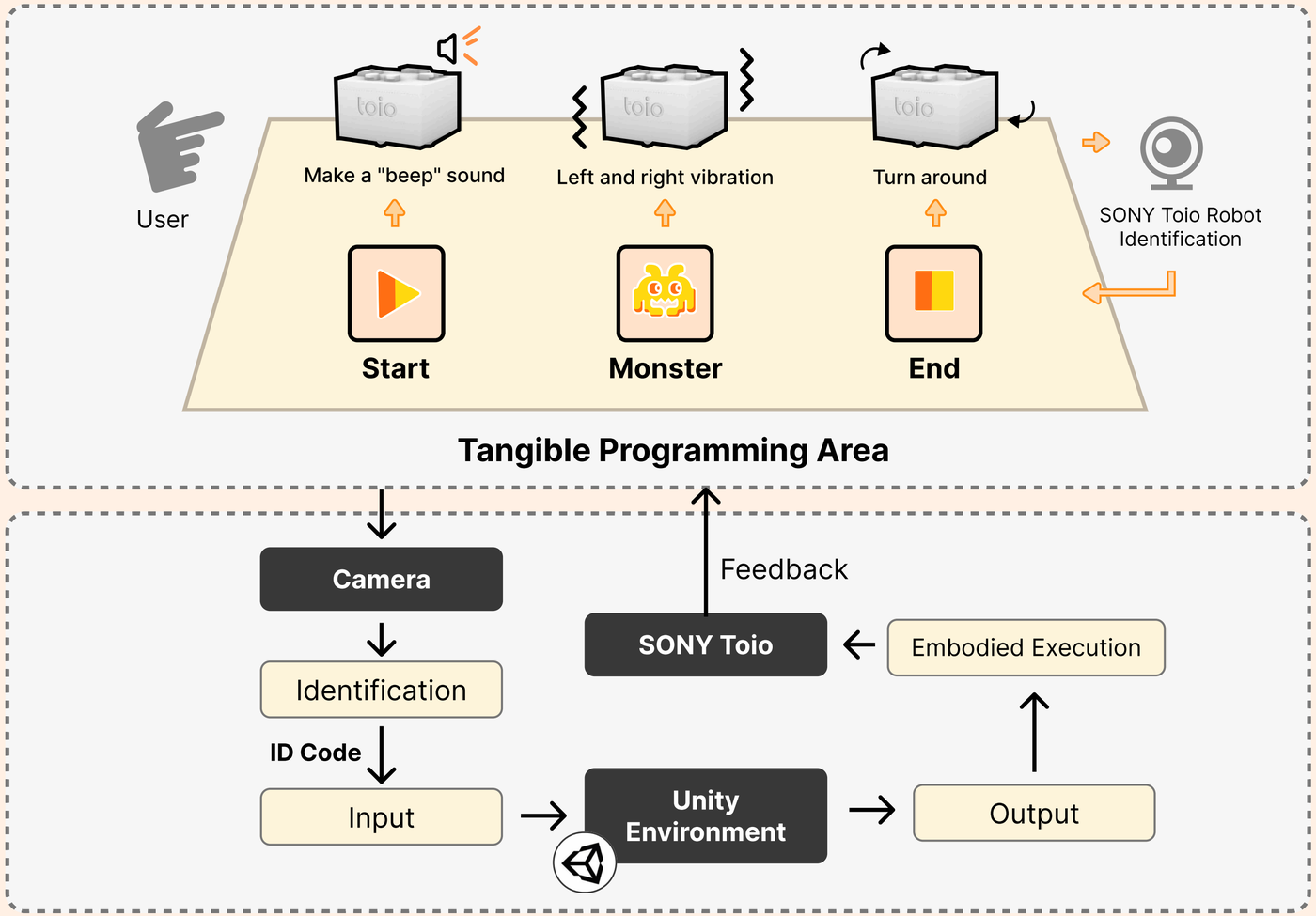
Plan: While multiple block configurations exist, only one unique solution successfully avoids the monsters while collecting the treasure. Children place the programming cards based on the planned path and the designated positions for special cards.

Prototype Design

Overall System



System Workflow



Prototype Design

We deployed our functional prototype with children on-site. The participants reported a high level of immersion in the gameplay and found the integration of the robot particularly engaging. Furthermore, all participants demonstrated an improvement in their spatial reasoning abilities.