Sapling & the Travelling Forest: A table-top mobile robot platform for child-robot games

Deanna Kocher*
Cornell University, Sibley School of Mechanical & Aerospace Engineering
drk225@cornell.edu

Emily Abbruzzese
Cornell University, College of Human Ecology
eha45@cornell.edu

Olivia Rodriguez
Cornell University, College of Human Ecology
olr5@cornell.edu

Julia Mayourian
Cornell University, College of Human Ecology
jjm468@cornell.edu

Keith Evan Green
Cornell University, Human Centered Design and Mechanical & Aerospace Engineering
keg95@cornell.edu

ABSTRACT

Mobile robots can provide unique and engaging experiences for child-robot gameplay, but are often overlooked due to challenges of setup, navigation, and space limitations. To combat these challenges, we designed "Sapling and the Travelling Forest," a small mobile robot that uses a table-top game platform to play games with children. The system was designed as a low-cost and travel friendly alternative to larger mobile robot setups, and can be used in any location with a power outlet. The robot, "Sapling," is an interactive agent that moves through the "Travelling Forest" platform which frames the system and contains the robot to the forest play area. The system currently offers three games focused on collaborative, spatial play. Radio frequency identification (RFID) enabled games allow Sapling to meaningfully interact with both the game elements and a child. In this paper, we present the technical design of the robot and its small, table-top platform, as well as the game design process for the three board games. The presented system is a convenient way to conduct single or multi-session child-robot interaction studies with mobile robots.

CCS CONCEPTS

• **Human-centered computing** → Interaction design; Interaction design process and methods; Activity centered design; • **Applied computing** → Education; Interactive learning environments; Education; Collaborative learning.

KEYWORDS

Child-robot interaction, collaboration, spatial thinking

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1 INTRODUCTION

Many children embrace opportunities to play games with robots, and doing so is shown to increase persistence, motivation, and positive affect in children (for a review of robots' affective and cognitive impact on children, see [3]). Children often rate playing with a robot as somewhere between playing alone and playing with a friend [13], and robots have the added benefit of being a novel technology for children to interact with. These peer-robot scenarios also result in greater cognitive and affective gains than robot tutors and scenarios where children teach skills to robots [4, 12].

Peer gameplay scenarios currently occur most frequently with humanoid robots [3]. Mobile robots, however, offer a unique opportunity to explore different types of interactions in child-robot games. These interactions include giving directions, perspective taking (as a mobile robot is in a different physical location), and increased movement for the child to track the robot and coordinate their movements. Previous studies show that these types of interactions can improve children's spatial, mathematic, and computational skills. Giving directions to a mobile robot allows children to practice using spatial language [9], while the physical motion of a robot and perspective taking can teach geometry concepts and mental rotation [6]. Especially for younger children, spatial skills and spatial play are shown to form the basis of many of these more advanced mathematics concepts [5, 14]. Mobile robots may therefore be a natural way to progress from early spatial play to more advanced mathematics concepts.

Despite these benefits, mobile robots in education and gameplay are plagued with the challenges of finding adequate floor space, timing lengthy installations and setup, and operating in poorly controlled environments that complicate autonomous navigation. Even relatively small, commercially available robots like *Sphero* and *Cubelets* require floor or table space beyond what might be available to an individual child in a classroom. Larger mobile robot systems can take over much of a classroom [6, 11]. Smaller tabletop robots are few and far between, and the majority of these are low fidelity prototypes used for co-design, rather than functional mobile robots [1, 10].

To create child-robot spatial and mathematics opportunities without involved installations or the need to rearrange classrooms, we created "Sapling & the Travelling Forest" – a small robot and its table-top platform for gameplay with children. Unlike other mobile robot systems, Sapling fits on a classroom desk and is contained within a box-frame platform that keeps the small robot from wandering away and disrupting others. Sapling can play three different puzzle-like games with children, focused primarily on improving children's spatial skills [7, 15]. Each of the three games was evaluated at a local science center to be age-appropriate and intuitive for young children to play, with little instruction from an adult.

2 DESIGN

Our design of Sapling and the Travelling Forest focused on a child-friendly theme (a forest) and non-humanoid robot which "lives" in the forest (see Figure 4). The robot's design was derived from previous work on creating child-friendly robot form factors [8] but was scaled to be palm-sized for this application. At this small size, the platform can easily travel to rural school districts and reach children or families who may not have the resources to come in for lab studies.

For the games themselves, our goal was to develop three puzzles that would give children practice with spatial concepts. To do this, our puzzle games utilized jigsaw-style pieces or images that required children to manipulate and rotate pieces [15]. The games also had to: a) have a role for both the child and the robot, b) require minimal scaffolding from an adult once the game had been introduced, and c) be appropriately difficult for 5–7-year-olds. The three early game concepts developed were *Buried Acorns, The Storm* and *High Tide.* To create the best user-experience with the games, we arranged proof of concept interactions with young children at our local science center.

2.1 Science Center Testing

Each of the three games (*Buried Acorns, The Storm,* and *High Tide*) underwent two play sessions at a local science center. Three to four researchers were present for each session: one researcher observed and took basic notes of the interactions (e.g. notes on interest, types of support needed, and amount of support required), while the other researchers moved a looks-like prototype of Sapling through its tasks. To support the idea that only Sapling could complete parts of the game, Sapling and the game pieces were embedded with magnets that helped children judge when Sapling had found or achieved something in the course of the game. The embedded magnets also served to deter children from doing tasks themselves, which would not be possible in the final version of the design. The games were set-up atop different tables in a single room, and children were encouraged to try each game while they were visiting our area.

Three games were designed for the system (Figure 1): *Buried Acorns*, *The Storm*, and *High Tide. Buried Acorns* is based on an existing board game, Labyrinth, where puzzle pieces slide through tracks to create a path. In the game, children help Sapling move across the board to reach the area where it could dig for treasure. *The Storm* is an interactive variation of a traditional puzzle where children work on rebuilding – with puzzle pieces – a forest that had been destroyed in a storm. As the puzzle is completed, Sapling searches for the "special places" where trees can be planted. When Sapling finds one of those special pieces on the board, the child can plant a tree onto that puzzle piece. Lastly, *High Tide* is a block building game where children use Velcro blocks to create a bridge across a river. While children build the bridge, Sapling searches for the strongest and safest place to install the bridge.

2.1.1 *Buried Acorns – Early Revisions.*

Children struggled to slide the puzzle pieces in the tracks of the board for *Buried Acorns*; the experimenter often had to do this for them. Instead of struggling to slide pieces into the board, children removed pieces from the tracks to build a path. In the second science center session, we removed the mechanical tracks and had children instead focus on building a single path. Sapling would move from piece to piece and orient itself to suggest where the child should place pieces next. This version of the game was much more successful and took children under 10 minutes to complete.

2.1.2 *The Storm – Early Revisions.*

The Storm was the most popular game among all children. The first iteration of the game used tangram-shaped puzzle pieces commonly found in spatial thinking studies; unfortunately, these were very difficult for children to place and align, requiring near-constant support from the researchers to progress. Despite this difficulty, most children did at least one third of the puzzle and placed one tree prior to giving up. For the second session, we switched the tangram shapes to a jigsaw pattern and added more plants to the board to make the puzzle easier. With these changes, children required only occasional support from a researcher, and spent 10-20 minutes finishing the puzzle.

2.1.3 *High Tide – Early Revisions.*

For High Tide, many children struggled with the idea of bridging the Velcro blocks. Once children figured out how to use the blocks, they stacked blocks vertically or horizontally, but few were able to build a structure with vertical and horizontal elements. Among those children, none built the traditional archway shape we expected. The second version of this game tried two new versions of the bridge: one that was flattened down into a jigsaw puzzle and one that was a series of flat blocks with a bridge image on one side and small pieces of Velcro near the ends. Children were equally successful with both types of bridges, although the jigsaw puzzle bridge took longer for them to complete (possibly because the pieces were very small). Children spent 3-10 minutes building each bridge.

2.2 Technology & Materials

The tiny robot, Sapling, and the base platform we call "the travelling forest" were designed to be a low-cost, small-scaled alternative to larger mobile robot systems. To keep Sapling as small as possible for the scale of the game, the majority of the hardware is contained in the base platform. The prototype presented in this paper was built for under $400.

2.2.1 *The Travelling Forest: Base Design & Hardware.*

The Travelling Forest is set up as a cartesian coordinate system (x, y, θ) that is driven by three stepper motors (Figure 3). The final frame of the box measured 16.25" x 16.25" x 3.25" or roughly the size of a board game box. The frame of the box is 1/8" craft plywood, with

Figure 1: Early game concepts at the science center. Buried Acorns (left), The Storm (center), High Tide (right).

Figure 2: Iterated games at the science center. Buried Acorns (left), The Storm (center), and High Tide (right).

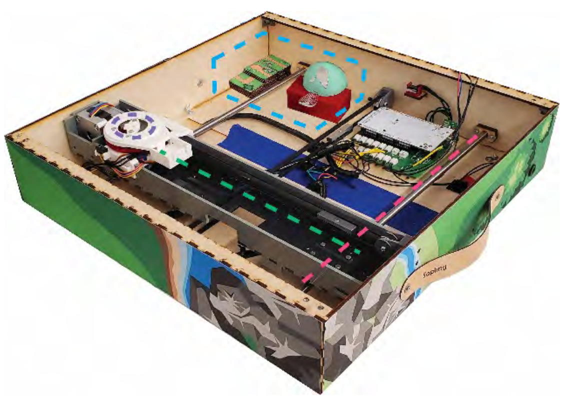

Figure 3: Travelling Forest hardware with x-axis (green), y-axis (pink), orientation theta (purple), and storage area (blue).

a removable top panel that serves as the game board. To reduce friction and noise, the sliding y-axis gantry was made of acrylic. The system uses off-the-shelf 3D printer hardware for the belt and pulleys and operates on an Arduino Mega. A 5V barrel jack adaptor plugs in to the outside of the box frame to supply power. The main axis stepper motors can operate at up to 40rpm (roughly ~0.5in/s), a reasonable speed for most of our games.

The system magnetically connects to Sapling to move our small robot to move through the forest in x, y, and θ. Data is sent between Sapling and the forest with a radio frequency (RF) transmitter and an RFID tag system. Each game is assigned to a unique RFID tag which controls Sapling's behavior for the duration of a game. The tags used are less than $1.00 each so that new games can be created for only a few dollars.

2.2.2 Sapling: Design & Interactivity. Sapling is made up of a 3D printed body, two aluminum leaf-shaped touch panels, and an etched acrylic fin (Figure 4). To communicate to children, Sapling's multi-color LED changes the color of the fin during the game. The leaf-shaped touch sensor panels allow children to respond to Sapling, letting them know when they are ready to progress or that they understood Sapling's message. Sapling runs on a 3.7V lithium-ion battery which can be charged from inside the forest box.

3 CONCLUSIONS AND FUTURE WORK

We presented Sapling & the Travelling Forest, a low-cost, easy to use platform which can be taken to schools, science centers, or homes to play spatial games with children. Games were play-tested with children to ensure they were appropriately challenging. Using this platform, we can conduct future studies on child-robot interaction and spatial skills in a variety of classrooms without a large, semi-permanent system. We are planning new games for the platform

Figure 4: Sapling the table-top mobile robot

offering older children geometry challenges like calculating and estimating turn angles.

4 EXPECTED DEMO EXPERIENCE

Sapling & the Travelling Forest will be available to play games with conference attendees. During the demo, attendees will be able to play either *Buried Acorns* or *The Storm* with Sapling. In either game, Sapling will search the gameboard for the respective items (either acorns or plants) and will light up when it has found its goal. Once attendees have placed the respective board pieces, they can tap Sapling to indicate it can continue searching for the next item. Attendees will also be able to pick up Sapling and view the interior of the Travelling Forest to understand setup and the system's overall operation. A video of this interaction can be found here: https://youtu.be/8omYOAbfDZ8

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