Università della Svizzera italiana

Faculty of Informatics

Bachelor Thesis

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Exploring the Learning by Teaching with Social Robots

Exploratory Studies on Learning by Teaching with Social Robots using Wizard-of-Oz Control

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Abstract

Abstract goes here ... You may include up to six keywords or phrases. Keywords should be separated with semi-colons.
Keywords:

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Approved by the advisor on Date:

Contents

1 Introduction

Will rewrite when working on the abstract, need to write about already existing tools. Currently, this is a mixup of the abstract and the introduction.

Social robots are increasingly finding their way into learning environments, where their role as collaborators, tutors, or learning companions is being actively explored. In particular, the paradigm of *Learning by Teaching* (LbT) offers a promising framework in which children can reinforce their understanding and social-emotional skills by teaching a robot. This approach has the potential to enhance engagement, improve soft skills, and support inclusive education.

This bachelor project is part of the broader TESORO initiative, for which an SNSF funding application has been submitted and is currently awaiting approval. My contribution focuses on a practical implementation: the design and development of a web-based dashboard that enables a Wizard-of-Oz control of a social robot during an exploratory experiment involving turn-taking with children.

The experiment consists of a Lego-building task performed by two children taking turns. The robot, remotely controlled via the dashboard, intervenes when turn-taking violations occur, aiming to regulate the interaction and reinforce collaborative behavior.

This report presents the background of the project, the research and implementation goals, the technical architecture of the system, and the planned experimental study. The developed dashboard serves as a starting point for preliminary studies and lays the groundwork for later stages of the TESORO project where the robot will learn these regulatory behaviors from various operators, including researchers, teachers, or even the children themselves. Additionally, it could also serve other projects that are based on Human-Robot Interaction (HRI) since it will be developed in a way that is re-usable for different scenarios.

1.1 Report structure

The rest of the report is organized as follows: Section 2 presents the related work and theoretical framework; Section 3 outlines the experiment scenario and research goals; Section 4 describes the dashboard's architecture and implementation; Section 5 presents the evaluation process and findings across three iterative walkthroughs, highlighting how user feedback informed the co-design of the final system; and Section 6 concludes with future directions.

2 State of the art

Here we will summarize the main findings, carefully explain the differences with our work and could have a small "background information" section.

Explain all acronyms and abbreviations. For example, the first time an acronym is used, write it out in full and place the acronym in parentheses. When using the Graphical User Interface (GUI) version, the use may...

3 Experiment Design and Goals

The experiment designed for this project aims to explore how a social robot can support children's learning through turn-taking regulation. The overall investigation is structured into three progressive stages:

- **Step 1: Robot as Regulator** - Two children collaboratively build a Lego tower by taking turns. The robot observes and intervenes in case of turn violations or inappropriate behavior, using multimodal cues such as LED lights, vocalizations, and gestures.
- **Step 2: Child as Regulator** - A child is tasked with regulating the interactions between the robot and another child that will perform a similar task to Step 1. This step exploits the LbT paradigm, where the regulator learns how to collaborate and keep turns.
- **Step 3: Robot Learns How and When to Intervene** - The robot applies the learned behavior during interactions with children in Step 1 and Step 2.

This report provides the foundational knowledge for implementing later stages of autonomous learning. The robot's interventions are controlled via a Wizard-of-Oz setup, and the primary goal is to assess the feasibility and effectiveness of such interventions in developing children's soft skills.

To be expanded

4 System Design and Implementation

4.1 System Architecture

Overview

The system architecture was designed to enable an operator to control a social robot in a Wizard-of-Oz fashion during experiments with children. The main components include a web-based dashboard for real-time control [2], a communication layer based on ROS2 (Robot Operating System 2) [6, 4, 3], and the RoboMaster EP robot [1]. The dashboard provides intuitive controls for triggering robot interventions and monitoring status, while the ROS2 integration ensures reliable communication and execution of commands. This architecture prioritizes usability, low latency, and safety, supporting the experimental requirements for responsive and effective interactions. The system was designed to facilitate iterative development and easy modifications, supporting a co-design approach as outlined in the TESORO project proposal [5]. This flexibility enables rapid adaptation of the dashboard based on feedback from stakeholders and participants during the study.

4.2 Component Description

Dashboard

The dashboard is a web-based interface developed using Next.js, with the user interface built on Material UI (MUI) components for a modern and consistent look. It allows the operator to monitor the robot's status and trigger interventions in real time. Communication with the robot is achieved via `roslibjs` [9], which enables the dashboard to send and receive ROS messages over the network.

Middleware Server

Due to a known limitation in `roslibjs` when interacting with ROS2 action servers, a minimal middleware server was implemented within the dashboard system. This server is built with Express and uses `rclnodejs` [7] to interface directly with ROS2, acting as a bridge between the dashboard and ROS2 action servers. This ensures reliable execution of complex robot actions and exposes additional functionalities to the web interface.

ROS Communication Layer

The communication layer is based on ROS2 and uses `rosbridge_server` [8] running on the Ubuntu machine that controls the robot ROS2 drivers. This layer handles the communication between the dashboard and the robot, allowing for real-time updates and command execution.

Robot Control and Action Servers

The Ubuntu machine runs several ROS2 nodes and action servers, including:

- `robomaster_ros` [4]: ROS2 drivers for the RoboMaster EP robot, providing low-level control and sensor access.
- `robomaster_hri` [3]: Custom packages for high-level robot control and human-robot interaction.
- Security and safety action servers: Allow the operator to immediately halt robot actions or trigger safety protocols as needed.

RoboMaster EP Robot

The RoboMaster EP robot [1] is the physical platform used for the experiment. It connects to the Ubuntu machine via its dedicated access point, ensuring a stable and isolated communication channel. The robot executes commands received from the ROS2 action servers and ROS2 nodes, and provides feedback to the dashboard.

Network and Deployment

All components are deployed on a local network to ensure low latency and reliability. The dashboard can be accessed from any device on the network, while the Ubuntu machine acts as the central hub for ROS2 communication and robot control. Since the RoboMaster EP robot connects wirelessly and provides odometry data, the system is not restricted to a laboratory setting. This flexibility allows experiments and interactions with children to take place in more neutral or familiar environments, which can be beneficial for naturalistic studies and participant comfort.

4.3 Safety Considerations

Ensuring the safety of participants and equipment was a primary concern throughout the system design. To address this, a dedicated ROS2 node was developed to act as an emergency stop mechanism. This node can immediately halt all ongoing robot actions and stop the RoboMaster EP's motors.

A prominent "Emergency Stop" button is integrated into the dashboard interface, allowing the operator to trigger this safety mechanism at any time during an experiment. When activated, the command is sent via the ROS2 communication layer to the safety node running on the Ubuntu machine, ensuring a rapid response. This feature is essential for experiments involving children, as it provides the operator with immediate control to prevent unintended or unsafe robot behavior. The system was tested to ensure that the emergency stop reliably overrides all other commands and brings the robot to a safe state.

4.4 System Architecture Diagram

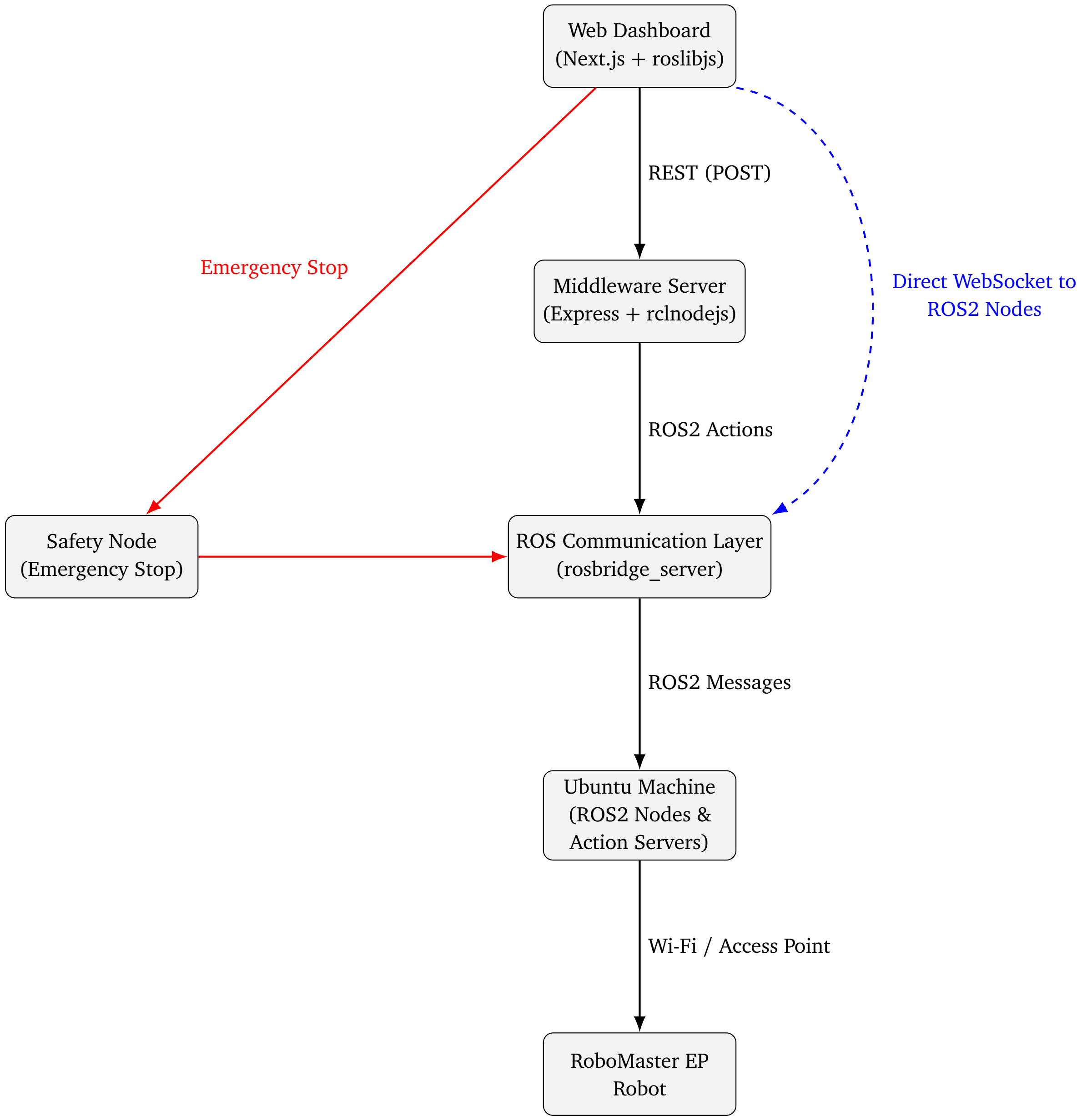

Figure 1. System architecture for Wizard-of-Oz control of the RoboMaster EP robot. The dashboard communicates with the middleware server via REST (POST request), and can also communicate directly with the ROS2 nodes using WebSocket (roslibjs).

4.5 Dashboard Interface

Here we will describe the final dashboard interface, including the main features and functionalities. We will also include screenshots of the dashboard to illustrate its design and layout.

5 Evaluation and Iterative Co-Design

This section presents the evaluation of the system through three exploratory sessions, each structured as an iterative walkthrough. These sessions aimed to assess the usability and flexibility of the dashboard, understand the dynamics of child-robot interaction, and collect feedback to inform the design of both the interface and the robot's behavior. Each evaluation contributed to the co-design process by revealing user needs and contextual challenges in real time.

The sessions included: (1) a walkthrough with HCI and accessibility experts, who role-played as elementary or middle school students; (2) a session with high school students working in pairs and simulating collaborative behavior on the shared floor mat; and (3) a pilot study with middle school children, which evolved into a semi-structured discussion and informal walkthrough focusing on robot behavior and social interaction patterns.

The following subsections describe the setup, key observations, and design implications of each session, followed by a summary of the iterative changes implemented in response to user feedback.

5.1 Walkthrough with Experts

Setup and procedure

The first evaluation session was conducted in an office setting and involved two PhD researchers with expertise in Human-Computer Interaction (HCI) and accessibility. They were asked to role-play as two children collaborating on a Lego tower building task. Initially, they were seated on the floor approximately one meter apart, with the RoboMaster EP robot placed slightly in front of them at the midpoint of this distance, not directly between them.

The system was operated by an evaluator seated nearby at a desk, with a direct line of sight to the play zone. A third researcher took notes throughout the session, while two additional observers with expertise in educational technology and human-robot interaction silently monitored the interaction and its outcomes.

Although the scenario was designed around pre-defined robot positions, the participants quickly moved from their initial spots, rendering the static positions ineffective. However, the dashboard's joystick feature enabled the operator to adapt in real time by manually repositioning the robot and triggering actions. The session unfolded as a dynamic and playful interaction between the two participants and the robot, including episodes of joint play, interaction breakdowns, and regulatory robot interventions.

After the active session, all participants engaged in an open-ended discussion, which yielded critical reflections on the interface's design, the robot's perceived role, and the effectiveness of various robot behaviors. These observations and insights directly informed the next iteration of the dashboard.

Key observations

- The pre-defined movement positions were quickly invalidated when the "children" moved from their expected spots. The experts stressed the importance of allowing the operator to improvise and react dynamically.
- Negative robot feedback, such as "shaking the head" by spinning on the spot, was perceived as entertaining, rather than corrective. This could encourage children to misbehave just to see the robot react.
- Experts observed that opening the box with the gripper and presenting it to a participant invited them to place something inside. This could be used as a form of collaborative engagement or de-escalation.
- Experts emphasized the importance of distinguishing between different levels of feedback, both positive and negative. For positive reinforcement, a scalable approach could include combinations of lights, sounds, and movement, ranging from a simple LED blink to a celebratory motion sequence. Negative feedback, on the other hand, should be kept minimal and neutral: limited to red lights, with no sound, and little to no movement, possibly just a slight backward motion to signal withdrawal. Sound should be excluded from negative interventions entirely to prevent the robot from becoming a source of entertainment.
- The robot was perceived more as a "peer" than an authority figure, prompting the need to frame it accordingly in both behavior and design.

- Experts advised against focusing the robot's attention too much on one child, as this could lead to perceptions of unfairness.

- Introducing the robot to children before the task might help reduce distractions during the experiment, as curiosity would be partially satisfied beforehand.

- Large Lego Duplo bricks limited complexity of the task; smaller pieces might offer a more engaging challenge.

Design implications

- The role of the robot as a peer should be reinforced through behavior that is cooperative, inclusive, and friendly rather than disciplinary.

- Feedback must be clearly divided into positive and negative categories, with minimal overlap in how they are perceived.

- The dashboard should support a broader set of robot actions, including flexible movement, and the ability to give nuanced feedback.

- Following this session, the dashboard was updated to provide broader control over robot functionalities, including gripper manipulation and advanced LED options such as color selection, blink timing, and speed adjustments. Although joystick control for custom movement was already available, the session reinforced its importance in enabling operator improvisation. Feedback actions were reorganized into clearly defined positive and negative categories with different intensity levels, and the use of sound was restricted to positive feedback only. These changes aimed to improve the system's responsiveness and better align robot behavior with user expectations.

5.2 Walkthrough with High School Students

Setup and procedure

The second evaluation session was conducted in a spacious conference room. A large children's floor mat was added to define a playful zone, following recommendations from the first experiment. The robot used the updated Version 2 of the dashboard interface, which incorporated changes such as feedback intensity levels and different LED color options.

The session involved four high school students, divided into two pairs. Each pair was asked to role-play as younger children (elementary or middle school age) participating in a turn-taking Lego activity. The robot was operated by an evaluator from a nearby desk. Before the session began, the robot was introduced to the participants to reduce initial distraction, another refinement based on the previous walkthrough.

Each pair of students participated in two stages:

- **Step 1: Robot as Regulator** - The two "children" were asked to collaborate on building a Lego tower while occasionally engaging in simulated turn-taking violations. The robot was expected to intervene using visual and movement-based feedback.

- **Step 2: Child as Regulator** - One student built a Lego structure with help from the robot, while the second student acted as a mediator. The robot would occasionally behave incorrectly (e.g., bringing the wrong Lego piece or running away), prompting the mediator to "teach" the robot how to behave, following the Learning by Teaching paradigm.

- **Step 3: Co-Design Discussion** - After the interaction tasks, students were invited to openly discuss their experience with the robot, suggest new behaviors, and reflect on what they would expect from a social robot in this context. The session was semi-structured and aimed at eliciting child-led ideas to inform future iterations.

The same three-stage procedure was repeated with the second pair of students. During the first round, all four students were present and participated in observing or acting. However, for the second round, only the second pair remained, as the first group had to leave the session early due to other commitments.

Key observations

- Red LED signals alone were insufficient to attract attention, especially due to ambient lighting and the robot's position on the floor.
- The lack of sound in negative feedback led to the robot being ignored during turn-taking violations. Participants were focused on the Lego task and did not notice subtle visual cues.
- A more effective attention-grabbing strategy was to have the robot "invade" the children's personal space with a quick approach motion.
- The robot being named by the students helped increase its perceived presence and relational value during interactions.
- One participant suggested that the robot could turn around and "walk away" when reacting negatively, simulating being upset or "offended."

Design implications

- Visual-only feedback may be insufficient in real-world conditions, especially on the floor, so movement patterns should be enhanced to compensate for the lack of sound.
- Slightly intrusive or exaggerated motions (e.g., quick approaches, turning away) can be effective in drawing attention and reinforcing robot personality.
- Allowing children to name the robot may enhance engagement and relational dynamics, particularly in long-term deployments.
- These results confirmed the need for flexible, expressive robot behaviors and validated many of the improvements made after the first expert walkthrough.
- Based on the needs of Step 2 in the interaction task, where the robot requests a specific colored brick from the regulator, additional LED color options were added to the interface to support clearer and more flexible signaling.

5.3 Walkthrough with Middle School Students

Setup and procedure

The final evaluation session was conducted in the same spacious conference room used in the previous walkthrough. A children's floor mat was again placed at the center of the space, but this time smaller Lego bricks were provided to increase task flexibility and challenge. The robot was operated using the final version of the dashboard interface. Three girls who had recently started middle school participated in the session. They were told beforehand that the experiment was a Wizard-of-Oz setup, and the robot was introduced at the beginning of the session to help mitigate distractions.

The team consisted of the operator, an observing researcher, and an additional facilitator who sat on the floor with the participants, guiding them through each experimental step and prompting them for feedback. The session followed the same structure as previous walkthroughs but was run with all three children at the same time.

- **Step 1: Robot as Regulator** - The children were asked to collaboratively build a Lego tower while occasionally breaking the turn-taking rule. The robot attempted to intervene using lights, movement, and audio cues. However, the feedback signals were often ignored or went unnoticed due to high ambient noise and the robot's position on the floor.
- **Step 2: Child as Regulator** - Two children played with the robot while the third acted as a regulator. The robot sometimes performed incorrect or disruptive actions (e.g., stealing pieces or pretending to help but failing), prompting the regulator to guide or correct the behavior. The robot responded with positive or negative signals based on this guidance.
- **Step 3: Social Behavior and Emotion Teaching** - In a final interaction, children were asked to teach the robot about concepts like personal space, polite requesting, and emotional understanding. The robot performed incorrect distances or behaviors, prompting the children to explain or demonstrate appropriate actions.

Key observations

- The robot continued to be perceived more as a pet (e.g., a dog) than as a peer or authority figure, reinforcing previous observations.
- Children named the robot and began interacting with it socially, including petting it on the box/head and decorating it with Lego bricks.
- Visual feedback like LEDs remained mostly ineffective; participants suggested that a table-based setup could raise the robot to eye level and improve visibility.
- Fast and unpredictable movements were effective at capturing attention, sometimes even surprising the participants.
- Positive feedback involving lights, sound, and movement ("dances") was appreciated and engaging.
- Participants showed strong interest in how the robot could recognize human emotions and tailor its behavior accordingly.
- During Step 2, children experimented with rewarding the robot for good behavior, and teaching it when to stop disruptive actions.
- In Step 3, they proposed using facial expressions, tone of voice, and environmental context to assess emotions and social cues.
- They also expressed a desire for the robot to have an onboard interface to communicate or show its own internal emotional state.
- After extended time with the robot (over one hour), the children continued to engage with it playfully while discussing social and emotional aspects.

Design implications

- The perceived identity of the robot needs to be considered in designing its role, children strongly leaned toward viewing it as a pet-like companion rather than a peer or authority.
- Improvements could include elevating the robot or providing auxiliary displays to improve visibility of LED signals.
- Positive and negative feedback should be multimodal and vary in intensity, with fast or exaggerated motion reserved for high-salience cues.
- Emotional awareness features, such as interpreting user tone, expressions, or distance, were seen as valuable and could shape future autonomous behavior modules.
- An on-device interface could support more direct, child-driven interaction with the robot and enhance mutual understanding.
- The co-design insights collected during this session support the idea of tailoring robot behavior based not only on task logic but on social context and emotional interpretation.

5.4 Summary of Key Iterative Changes

This section summarizes the major interface iterations informed by each evaluation session. Screenshots of each version are included to illustrate the progression from the initial prototype to the final deployed interface.

Version 1 - Initial Prototype

- Basic joystick and pre-defined movement controls.
- Minimal bad-behavior feedback capabilities (red LED, spin, sound).
- No dedicated gripper control (box could only be opened/closed by moving the arm); no feedback intensity levels.

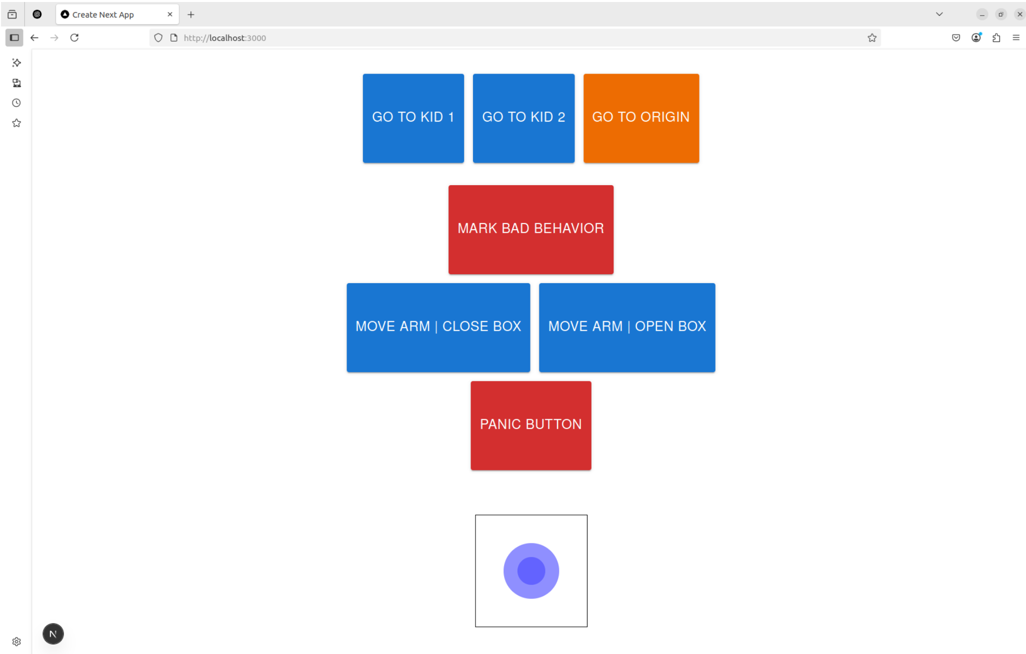

Figure 2. Version 1 - Initial prototype with limited robot control and feedback options.

Version 2 - Post Expert Walkthrough

- Added gripper controls and advanced LED configuration (colors, blink timing, speed).
- Introduced feedback modes: positive and negative with scalable intensity.
- Refined movement control and added panic button.
- Macro-scenarios for quick intervention.
- UI layout was reorganized into functional panels or "zones" to streamline operator access to robot features.

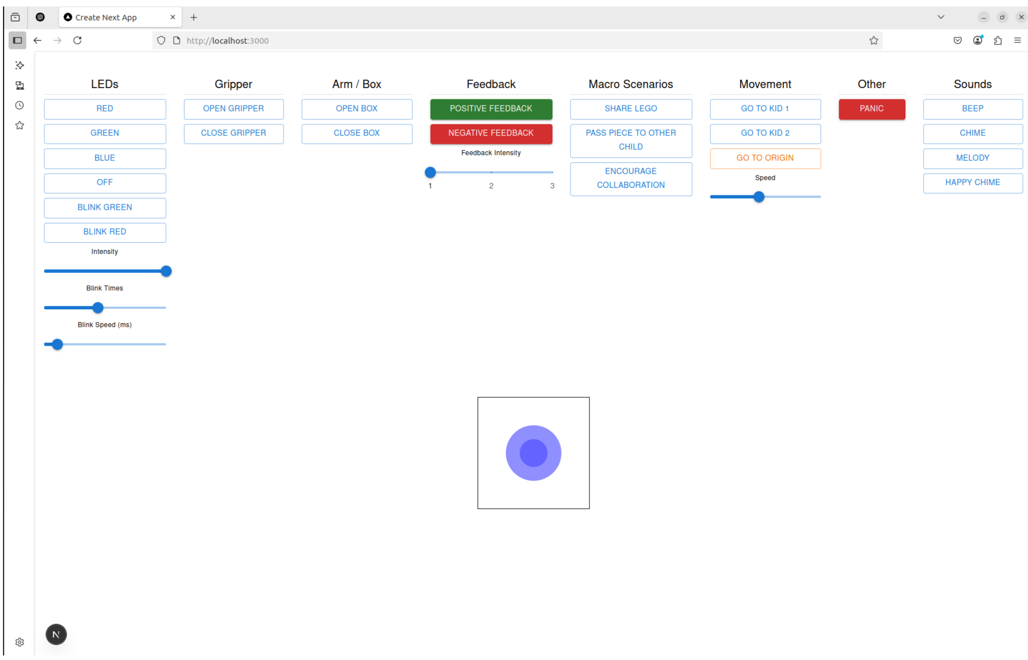

Figure 3. Version 2 - Refined interface after expert feedback, supporting greater flexibility.

Version 3 - Final Version for Pilot Study

- Further expanded LED signaling options for color-specific communication.

- Audio feedback support for positive cues only.
- Increased the size and visual prominence of the panic button to improve operator responsiveness during high-pressure scenarios.

Figure 4. Version 3 - Final dashboard interface used in the pilot experiment.

Co-Design of Robot Behavior

Beyond interface adjustments, each walkthrough also shaped our understanding of effective robot behaviors in child-facing settings. Feedback from participants informed refinements in how the robot expresses negative vs. positive cues, how it maintains neutrality, and how children interpret its social role. Key insights included:

- **Framing of the Robot:** Children consistently perceived the robot as a playful companion or pet, rather than an authority figure. This influenced design decisions toward peer-like, non-disciplinary behaviors.
- **Feedback Intensity:** Both experts and children emphasized the importance of scalable, multimodal feedback (e.g., lights + movement + sound), especially for positive interactions. Negative feedback should remain neutral and minimal to avoid encouraging misbehavior.
- **Social Engagement:** Naming the robot, petting it, and attributing personality to it emerged naturally, suggesting personalization features may enhance engagement.
- **Learning by Teaching:** Children actively guided the robot using verbal and physical cues, validating the LbT framing. Tasks like teaching the robot to maintain distance or follow polite commands proved intuitive and effective.
- **Emotion and Context Awareness:** Middle school students suggested that robots should use emotional cues, facial expressions, and context to decide how and when to interact.

These behavioral reflections informed the structure of robot actions available through the dashboard and laid the groundwork for future development of semi-autonomous and emotionally aware systems.

6 Conclusions

This project presents the design and implementation of a web-based dashboard to enable Wizard-of-Oz control of a social robot used in a Learning by Teaching experiment with children. The system is part of the larger TESORO initiative and lays the groundwork for studying how social robots can assist in learning soft skills like turn-taking.

To be expanded

6.1 Future Work

Here we will write about future work like the ones mentioned in the TESORO project proposal like :
Long-term goal: enabling real-time learning from the child's regulatory actions and shifting toward semi-autonomous robot behavior.

References

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