GeoBot: A Geometry Quiz Robot for Classroom Education

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***Abstract*—Our interactive robot game is titled GeoBot, designed to help middle school students learn geometry through a quiz-style activity using the Turtlebot4. Students answer multiple-choice geometry questions by standing in one of four labeled zones, and the robot responds by moving toward the correct answer zone. The game uses physical positioning to make learning more interactive and engaging.**

The robot's control architecture uses a hybrid design, combining the deliberative layer with a finite state machine for movement sequencing and the reactive layer with LiDAR-based distance detection. The FSM manages turning, approaching, and text-to-speech producing, while the reactive layer processes real-time sensor data. The robot uses LiDAR data to evaluate whether students get the correct answers.

During gameplay, the robot asks geometry questions through text-to-speech. Students choose answer zones with their bodies, and the robot turns toward and approaches the correct zone. The robot communicates through movement, speech feedback, and position resets to signal readiness for the next round.

Participants then complete a post-game survey, evaluating the experience on the RoSAS scale. Results showed students understood the robot's actions well, enjoyed watching it approach their zone, and felt the robot made geometry more fun.

These findings demonstrate the potential of simple, readable robot movements in educational HRI contexts. The game shows how minimal sensing combined with clear motion design can create effective learning experiences.

I. Introduction

Our final project, GeoBot, is an interactive quiz robot that helps middle school students learn geometry through movement-based gameplay. Students answer questions by stepping into A/B/C/D zones while the robot responds with motion, orientation, and speech, turning abstract math concepts into a physically engaging activity.

GeoBot's design is inspired by a friendly "geometry teacher" character. Bright colors and math symbols give it an approachable, classroom-appropriate look that supports its role as a playful teaching assistant.

The robot interacts with players through speech and clear physical cues, turning toward the chosen zone, advancing, stopping, and returning home. Although it does not use screens or lights, its movement and spoken feedback create an intuitive and engaging interaction loop.

GeoBot is controlled by a hybrid system combining a deliberative finite state machine (FSM) with a reactive LiDAR layer. The FSM manages the sequence of turning, advancing, stopping, and resetting, while LiDAR distance readings determine how far the robot moves. This setup keeps behavior predictable for students while allowing real-time adaptation based on their presence in each zone.

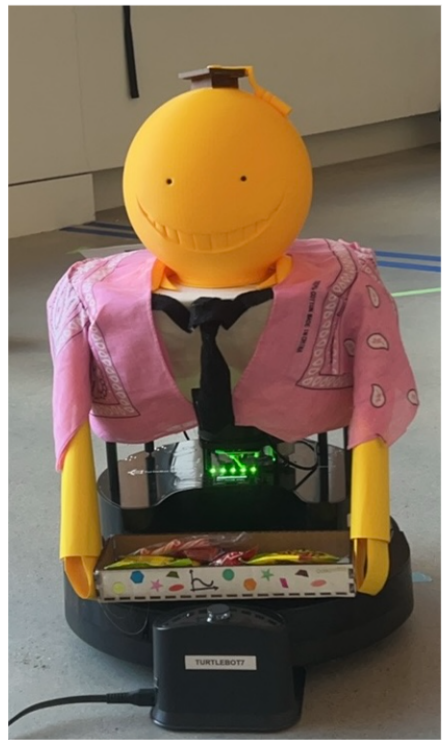

Fig. 1. GeoBot Physical Embodiement

The robot uses onboard LiDAR, odometry, and timed transitions to maintain consistent movement and orientation. No mapping or camera systems are used—only /scan data and velocity commands, making the system simple and reliable for classroom use.

We evaluated GeoBot through short user study sessions where students played multiple rounds of the quiz and then completed a brief self-report survey on engagement, clarity, and perceived learning. These sessions helped us understand how students interpreted the robot's behavior and how well the game supported geometry learning.

II. METHOD

A. Game Design

Please refer to this link as a video demonstration.

Our project, GeoBot Quiz Arena, is a movement-based educational game in which a Turtlebot4 robot asks multiple-choice geometry questions and students answer by physically moving into one of four labeled zones (A/B/C/D) arranged around it. Questions appear on a TV screen, students think individually, and then choose an answer by standing in a zone. GeoBot identifies the correct answer, turns toward that zone, drives forward, stops near it, celebrates with speech, and returns to its home position. Correct answers trigger positive feedback, while incorrect answers simply lead the robot to demonstrate the correct zone before continuing to the next round. The emphasis is engagement and learning rather than competition.

The learning goal is to make geometry more intuitive by combining spatial reasoning, physical movement, and robot-guided feedback. Through gameplay, students reinforce concepts such as shapes, angles, and basic measurement, observe how robots use sensors and programmed rules to make decisions, and experience how physical motion can represent abstract ideas, such as turning toward a correct answer.

The game is designed for an open classroom space with enough room for the Turtlebot4 to rotate and move safely. The robot starts at a fixed center position facing forward, with zones A, B, C, and D at the front, right, back, and left. Students begin outside these zones and enter them only after hearing a question. They are expected to stay within boundaries and avoid touching or crowding the robot.

GeoBot uses onboard LiDAR (`/scan`) as its sole perception input. LiDAR is used to detect a participant in the selected direction and compute how far the robot should move. All other behavior follows a time-based finite state machine: after receiving the correct answer on `/quiz_correct`, the robot turns, advances, stops, celebrates, turns back, returns home, and resets its heading without manual intervention. The system is intentionally simple, requiring no mapping, RGB sensing, or waypoint navigation.

The classroom is set up as a "Geometry Quiz Arena," with colorful markings and a cardboard GeoBot costume that includes math symbols and a ruler prop. These decorations help make the robot feel like a friendly teaching assistant rather than a machine. The main components supporting the game are the Turtlebot4 with its costume, the four floor-marked answer zones, LiDAR sensing for distance estimation, and text-to-speech for questions and feedback. Together, these elements create a clear and engaging interaction loop.

Students interact with GeoBot by choosing zones and observing how the robot responds through movement and speech. The primary challenge is selecting the correct zone based on the geometry question; the physical commitment encourages active learning. Students must stay inside the marked zones, avoid blocking the robot, and not interfere with its movement.

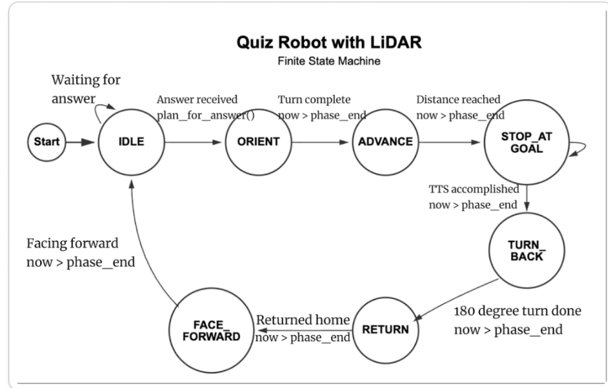

Fig. 2. Illustration of the finite state machine, summarizes the states, conditions, and outputs of the FSM.

The robot follows a predictable, autonomous motion pattern and does not track individuals or navigate beyond the arena.

Throughout the game, GeoBot acts as a friendly quiz host, guiding students through each question and reinforcing correct answers with expressive behavior. The interaction remains simple, intuitive, and designed to support participation from multiple students at once.

B. Finite State Machine (FSM)

The quiz robot FSM consists of 7 states that control the complete interaction cycle. The robot begins in the IDLE state and waits for the start of the quiz. When an answer arrives, it plans the motion, turns toward the target direction, moves forward to approach the user, stops and celebrates with speech, then returns to the starting position.

GeoBot's behavior is defined by a 7-state finite state machine that controls one full quiz cycle:

- **IDLE** – Robot is stopped and waits for a correct answer message on `/quiz_correct`. When a new answer is received, `plan_for_answer()` computes motion timing, and the FSM transitions to ORIENT.
- **ORIENT** – Robot rotates toward the target answer direction by commanding angular velocity on `/cmd_vel`. When the planned turn duration has passed (`now > phase_end`), it transitions to ADVANCE.
- **ADVANCE** – Robot drives forward at constant linear speed toward the answer zone. When the forward duration has passed (`now > phase_end`), it transitions to STOP_AT_GOAL.
- **STOP_AT_GOAL** – Robot stops, triggers text-to-speech on `/say_text` to announce the reward, and waits for a short stop duration. When the stop timer expires, it transitions to TURN_BACK.
- **TURN_BACK** – Robot rotates 180° to face back toward its starting position. When the turn duration has elapsed, it transitions to RETURN.
- **RETURN** – Robot drives forward for the same distance used in ADVANCE to return near the starting position.

FSM Transition Table

Current State	Condition	Next State	Action
IDLE	Answer received	ORIENT	Calculate timing, start turning
ORIENT	Turn time complete	ADVANCE	Start moving forward
ADVANCE	Distance reached	STOP_AT_GOAL	Stop and start TTS
STOP_AT_GOAL	Stop time complete	TURN_BACK	Start 180 degree turn
TURN_BACK	Turn complete	RETURN	Start moving back
RETURN	Distance raveled	FACE_FORWARD	Start final turn
FACE_FORWARD	Turn complete	IDLE	Ready for next question

Fig. 3. State transitions and outputs for the finite state machine

When the return duration has passed, it transitions to FACE_FORWARD.

- **FACE_FORWARD** – Robot rotates 180° again to restore its original heading. When this final turn duration has elapsed, it transitions back to IDLE, ready for the next question.

C. Robot Control Architecture

1) Architecture Type and Elaboration: We use a hybrid control architecture that integrates three layers: deliberative, reactive, and the middle coordination layer. External input arrives via `/quiz_correct` (String: "A", "B", "C", or "D") from the game system, and LiDAR sensor data flows from the physical environment through `/scan`. Within the `robot_quiz_lidar_node.py`, the deliberative layer (top) contains the 7-state FSM cycle. The middle layer implements coordination logic: `plan_for_answer()` receives answers from the deliberative layer, queries the reactive layer for distance, calculates timing parameters, and initiates state transitions; `loop()` generates velocity commands based on current state and triggers transitions when `phase_end` is reached. The reactive layer (bottom) subscribes to `/scan` and provides the `estimate_distance()` function for sensing. Outputs flow to the motor controller via `/cmd_vel` for physical motion and to the TTS system via `/say_text` for speech. This architecture enables the robot to autonomously execute quiz interactions by combining planned sequences with real-time sensing.

2) ROS2 Implementation: Our system is implemented using two ROS2 nodes. The main control node (`robot_quiz_lidar_node.py`) integrates all three architectural layers. It subscribes to `/scan` (`sensor_msgs/LaserScan`) for LiDAR data and `/quiz_correct` (`std_msgs/String`) for quiz answers. The node publishes velocity commands to `/cmd_vel` (`geometry_msgs/Twist`) for motor control and text messages to `/say_text` (`std_msgs/String`) for speech output. The separate TTS node (`simple_tts_node.py`) subscribes to `/say_text` and uses `pyttsx3` to synthesize speech.

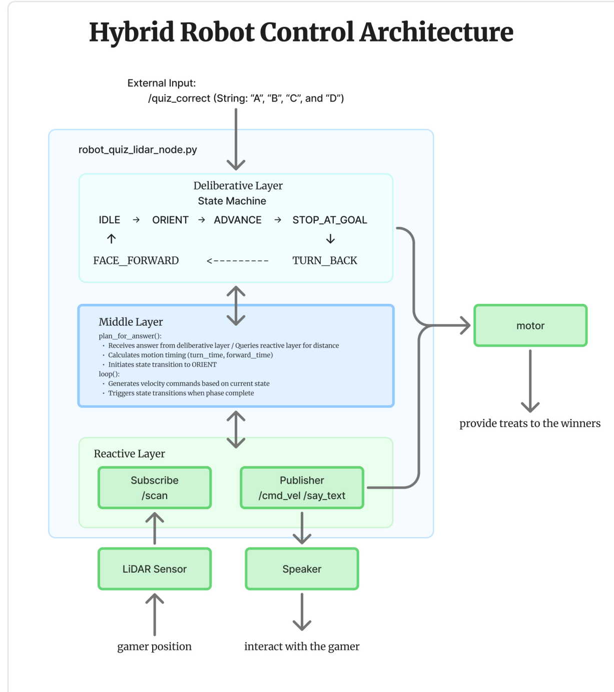

Fig. 4. caption of the robot prototyping artifacts.

When `/quiz_correct` arrives, `plan_for_answer()` queries the reactive layer's `estimate_distance()` function to calculate motion timing parameters (`turn_time`, `forward_time`). At `STOP_AT_GOAL`, the system checks LiDAR data again: if participants are detected in the target zone, it says "Congratulations, you get the correct answer!"; if no one is present, it says "Sorry, no one gets the correct answer." The `loop()` function continuously monitors phase completion and triggers state transitions based on time checks (`now > phase_end`).

3) Sequential and Parallel Components: The deliberative FSM defines sequential behavior through seven states: IDLE → ORIENT → ADVANCE → STOP_AT_GOAL → TURN_BACK → RETURN → FACE_FORWARD → IDLE. Each state executes specific motion commands and transitions when its phase timer expires. Parallel processes run continuously in the background: the `/scan` subscriber updates LiDAR data asynchronously, enabling real-time distance estimation during planning and presence detection at the goal. The TTS node synthesizes speech independently while the control loop continues executing the FSM. This design maintains simple, ordered game logic while leveraging ROS2's asynchronous communication for perception and feedback.

D. Robot Design and Prototyping

We prototyped GeoBot using a combination of sketching, paper prototyping, cardboard prototyping, laser cutting, and 3D printing. Early sketches helped us determine the robot's friendly "geometry teacher" appearance. We then laser-cut the box from cardboard to hold candy as treats for students. GeoBot's embodiment was inspired by a cheerful classroom teaching assistant, which guided our use of bright colors and math symbols. A 3D-printed warm orange smiley face helped the robot appear more social and approachable during game-play. These design choices made the robot visually engaging and reinforced the educational theme.

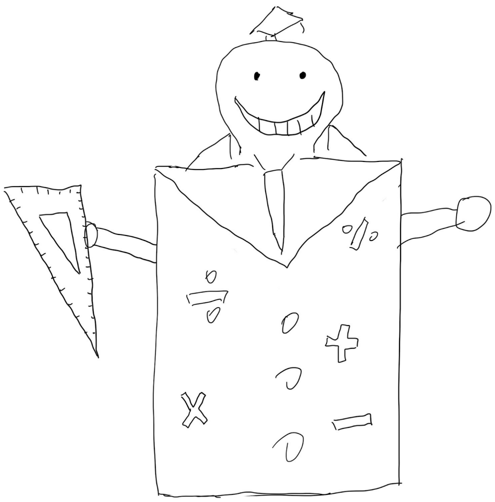

Fig. 5. Early sketches exploring GeoBot's friendly geometry teacher appearance and layout options.

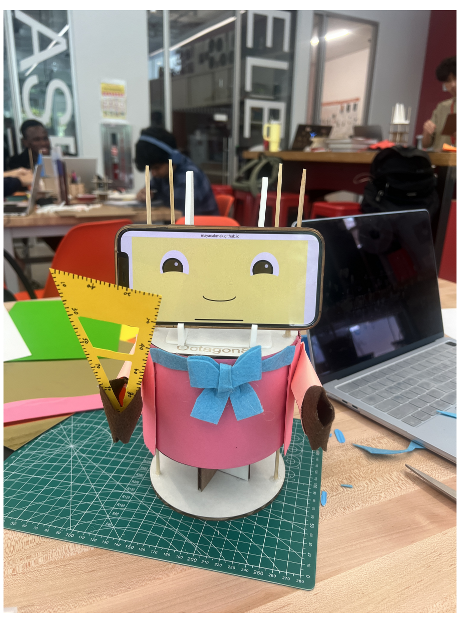

Fig. 6. Paper prototype testing overall design.

1) Fabrication and Materials: The robot's body is constructed from two pieces of cardboard, chosen for its light weight, ease of cutting, and compatibility with the laser cutter. The math symbols displayed on the front of the box were laser-cut and hand-colored, adding visual contrast and helping students quickly associate the robot with geometry content. The bow tie is made from a soft, felt-like furry material to give GeoBot a playful detail, and the robot's jacket is made of colorful pink fabric to make it more appealing to middle school students.

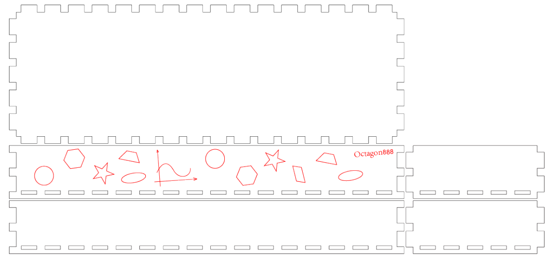

Fig. 7. Laser cutting files and process for the cardboard body and math symbol decorations.

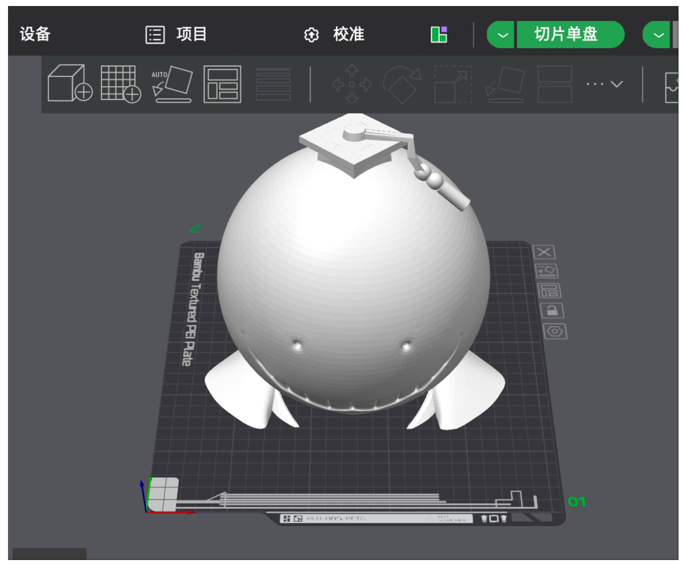

Fig. 8. 3D-printed file of an orange smiley face with a doctor hat

These materials were selected because they are inexpensive, easy to assemble, and straightforward to attach to the Turtlebot plate. The tactile textures, bright colors, and familiar math icons help engage students by making the robot instantly recognizable as part of a geometry activity. Each material serves a clear purpose: cardboard for structure, laser-cut cardboard for decoration, felt for personality, and 3D-printed plastic for the expressive face. Together, they create an embodiment that is both functional and appealing to participants.

III. Procedure

A. Participants

Participants were recruited by our professor, where attendees were invited to participate in the robot quiz game on a voluntary basis.

A total of 8 participants took part in the study, resulting in 8 completed post-game surveys. Participants' ages ranged from approximately 12 to 13 years old, reflecting a mix of middle-school-aged students.

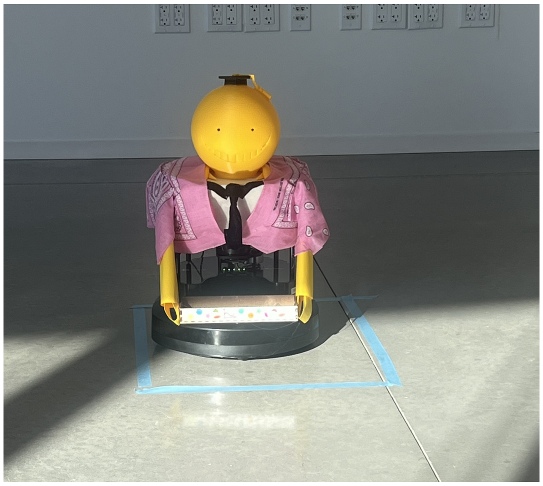

Fig. 9. Final assembled GeoBot on the presentation Day.

We employed a convenience sampling technique, recruiting participants who were readily available and willing to engage with the robot during the event. No personally identifying information was collected.

B. *User Studies*

The user study was conducted in an open indoor space configured as a quiz interaction area. The environment was instrumented using floor tape to mark four distinct answer regions labeled A, B, C, and D, each corresponding to a multiple-choice answer option. The robot's home position was marked at the center of the interaction area.

The robot was equipped with a mobile base capable of differential drive motion and was controlled through a ROS 2-based control architecture. A speaker was used to provide audio cues and feedback during gameplay, while rewards (e.g., candy) were delivered physically by the robot as it navigated to the correct answer location.

Prior to the study, the robot underwent pre-study setup procedures including:

- calibrating motion timing parameters for forward motion and rotation,
- defining fixed navigation trajectories toward each answer region,
- configuring finite state machine variables controlling orientation, movement, stopping, and return-to-home behaviors.

No autonomous mapping or localization was used; instead, navigation relied on time-based, pre-calibrated motion suitable for a controlled demonstration environment.

Each session followed a short, structured procedure. First, we introduced ourselves and explained the goal of the activity: to play a geometry quiz game with GeoBot and observe how the robot responds to student answers. We briefly described the four answer zones (A/B/C/D) and instructed students to choose an answer by standing in one of the zones after each question. During gameplay, GeoBot asked a series of questions using text-to-speech, then autonomously executed its movement sequence—turning toward the correct zone, advancing forward, stopping and celebrating, turning back, and returning to its home position. Students watched the robot's motion and adjusted their zone choices across multiple rounds. After gameplay concluded, we administered a short self-report survey measuring students' perceptions of the robot and the interaction experience.

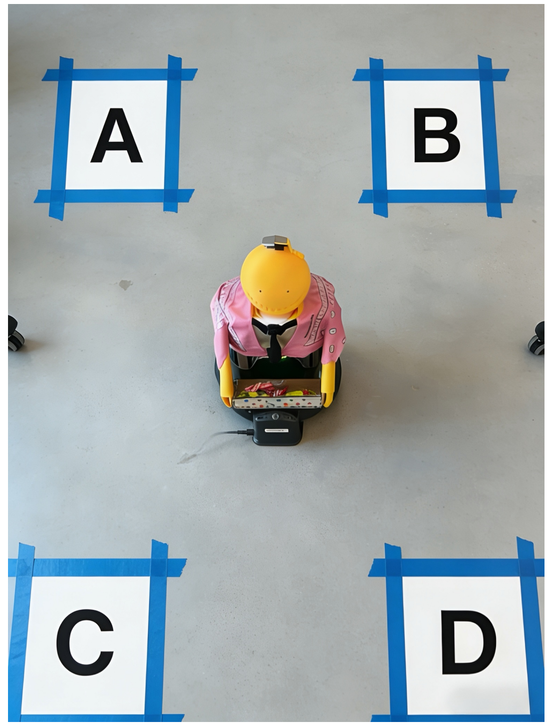

Fig. 10. caption of the robot user study testbed.

C. *Evaluation Metrics*

We evaluated the robot using the Robotic Social Attributes Scale (RoSAS), a validated self-report instrument used in HRI to measure perceptions of a robot's Warmth, Competence, and Discomfort. Each item is rated on a 1–7 scale (1 = not at all, 7 = very much). After the gameplay session, all eight participants completed the scale. RoSAS allowed us to quantify how middle school students perceived GeoBot's social qualities, particularly whether the robot appeared friendly, expressive, safe, or unsettling during the interaction.

D. *Results*

Analysis of the RoSAS self-report data revealed clear trends in how middle school participants perceived GeoBot during the interactive quiz activity. Overall, students rated the robot extremely low on all discomfort-related attributes, indicating that GeoBot was experienced as safe, approachable, and unintimidating. Items such as Dangerous, Strange, and Awful all received an average score of 1.00, the minimum possible value. Similarly, Aggressive averaged 1.13, and both Scary and Awkward averaged 1.13 and 1.25, respectively. These

TABLE I
ROSAS SURVEY RESULTS BY AVERAGE ATTRIBUTE RATING

Attribute	Average Rating
Dangerous	1.11
Awkward	1.43
Aggressive	1.01
Feeling	2.62
Strange	1.88
Knowledgeable	4.06
Reliable	3.53
Happy	4.71
Compassionate	3.09
Awful	1.96
Competent	4.12
Social	5.01
Responsive	4.10
Scary	1.76
Capable	3.73
Emotional	2.46
Interactive	5.28
Organic (Non-mechanical)	2.85

consistently low scores suggest that the robot's appearance, motion patterns, and interaction style did not provoke fear or unease, which is especially important when working with younger participants.

In contrast, competence-related attributes received some of the highest ratings in the dataset. Students perceived GeoBot as knowledgeable, reliable, and responsive, with Knowledgeable receiving the highest average score across all items at 6.38. Additional competence attributes, including Responsive, Reliable, Capable, and Social, all scored between 5.00 and 5.38. These results reflect the robot's predictable FSM-driven behaviors, consistent motion sequences, and clear speech feedback, which together helped students interpret its actions as intelligent and purposeful.

Warmth-related items showed more variability. Although students rated GeoBot as moderately warm on attributes such as Happy (average 4.75) and Interactive (average 4.38), they gave lower ratings to more human-centered emotional qualities. For example, Compassionate averaged 3.50, while Feeling and Emotional received averages of 2.75 and 1.50, respectively. This pattern suggests that while students recognized some social presence in the robot—likely due to its speech output and celebratory behavior—they did not attribute deeper emotional traits, which is expected given GeoBot's simple voice and lack of facial expression beyond the phone screen.

Taken together, the descriptive statistics show that GeoBot was perceived as highly competent and extremely safe, with moderate levels of warmth. The robot successfully avoided discomfort-related impressions while maintaining a clear and legible presence in the classroom. These outcomes support the effectiveness of the robot's simple hybrid control architecture and its classroom-friendly geometric teacher embodiment.

A bar chart visualizing the average rating for each RoSAS item is included below to illustrate the distribution of scores across the three social dimensions.

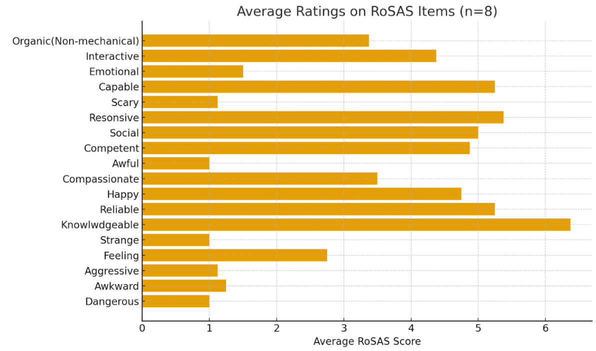

Fig. 11. Average score for each RoSAS attribute

E. Conclusion

One surprising result of our study was the relatively high Competence ratings reported by participants, despite the robot's simple navigation strategy and limited expressive capabilities. This suggests that predictable, legible motion and clear task execution alone can strongly influence perceptions of robot capability, even in the absence of advanced autonomy or rich social cues.

If we were to redesign this system in the future, we would place greater emphasis on adaptive feedback and interaction timing. In particular, incorporating more dynamic speech, visual feedback, or responsiveness to participant behavior could further enhance perceived Warmth and engagement. We would also explore more robust navigation strategies to reduce dependence on time-based motion calibration.

This study has several limitations. The sample size was small and drawn from a convenience population at a public event, limiting the generalizability of the findings. Additionally, the robot's behavior relied on pre-calibrated, open-loop navigation in a controlled environment, which introduced sensitivity to surface conditions and motor variance. Finally, the interaction duration was short, capturing only initial impressions rather than longer-term perceptions.

Future work could investigate longer-term interactions, larger and more diverse participant populations, and more autonomous perception and navigation capabilities. Lessons learned from this project highlight the importance of robust system design for public-facing deployments and demonstrate that even simple embodied behaviors can meaningfully shape human perceptions of robots when designed with clarity and consistency.

IV. Team Member Contributions

A. Technical Contributions

Xinwei Xie implemented the LiDAR-based robot control node (`robot_quiz_lidar_node`), which subscribed to laser scan data and used a finite state machine to control robot behavior. The node detected participants in predefined directional regions (A/B/C/D) using LiDAR range data, computed distances to the closest person, commanded robot motion via Twist messages, and managed state transitions for turning, advancing, stopping, and returning to center.

Rui Chen developed the text-to-speech node (`simple_tts_node`), which subscribed to text topics and generated spoken feedback. This member also configured ROS package dependencies, defined console script entry points in `setup.py`, and integrated the TTS node with the LiDAR control node through ROS topics.

Zifan Yang contributed to system integration, testing, and deployment of the two-node architecture. This included assisting with tuning LiDAR detection thresholds, verifying finite state machine transitions, and testing robot motion behavior in the user study environment. This member also supported runtime debugging and ensured stable execution of both `robot_quiz_lidar_node` and `simple_tts_node` during study deployments. text

B. *Writing Contributions*

Xinwei Xie took primary responsibility for writing the system implementation and technical sections of the report, including the robot architecture and control design.

Zifan Yang contributed to writing the user study methodology, including the Participants, Procedure, and Evaluation Metrics sections, and assisted with revising the Results section.

Rui Chen contributed to writing the Introduction, Game Description, and Conclusion sections, and assisted with overall editing, formatting, and proofreading of the final report

V. APPENDIX

1) GitHub Repository
2) Video Demonstration
3) Slides