Doodlebot: An educational robot for creativity and AI literacy

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ABSTRACT

Today, Artificial Intelligence (AI) is prevalent in everyday life, with emerging technologies like AI companions, autonomous vehicles, and AI art tools poised to significantly transform the future. The development of AI curricula that shows people how AI works and what they can do with it is a powerful way to prepare everyone, and especially young learners, for an increasingly AI-driven world. Educators often employ robotic toolkits in the classroom to boost engagement and learning. However, these platforms are generally unsuitable for young learners and learners without programming expertise. Moreover, these platforms often serve as either programmable artifacts or pedagogical agents, rarely capitalizing on the opportunity to support students in *both* capacities. We designed Doodlebot, a mobile social robot for hands-on AI education to address these gaps. Doodlebot is an effective tool for exploring AI with grade school (K-12) students, promoting their understanding of AI concepts such as perception, representation, reasoning and generation. We begin by elaborating Doodlebot's design, highlighting its reliability, user-friendliness, and versatility. Then, we demonstrate Doodlebot's versatility through example curricula about AI character design, autonomous robotics, and generative AI accessible to young learners. Finally, we share the results of a preliminary user study with elementary school youth where we found that the physical Doodlebot platform was as effective and user-friendly as the virtual version. This work offers insights into designing interactive educational robots that can inform future AI curricula and tools.

CCS CONCEPTS

• **Human-centered computing → Collaborative and social computing devices**.

KEYWORDS

Social robots, education, creativity, collaboration

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1 INTRODUCTION

Young people actively interact with, learn about and are impacted by Artificial Intelligence (AI) systems [12, 15, 20, 31]. Despite AI's prevalence in several fields of work, prior work highlights that non-AI experts have limited knowledge of AI's role and how AI systems function [14]. Consequently, it has become increasingly important to educate all students about AI and its capabilities and limitations. This need has spurred a rise in AI literacy initiatives for the general public, and particularly in K-12 classrooms [38].

Educators often leverage educational tools such as online demos, programming platforms, hardware, and robots to make AI concepts more understandable to young learners. Robots, in particular, have been used as physical manipulatives to exemplify algorithms and as learning companions to guide students' learning [24, 25, 30, 40, 43, 44]. Although some robotic platforms for AI education exist, in our review, few are suitable for sustained use in K-12 classrooms and many are inaccessible to younger learners, inexperienced programmers, or resource-constrained classrooms. Additionally, these tools could be more beneficial if they were more versatile, able to cover a range of AI topics, and capable of filling different roles in students' learning.

To fill this gap in educational robotics, we designed Doodlebot, a social, mobile robot built for long-term use in K-12 classrooms. We make three claims about Doodlebot, that it is:

(1) Suitable for classroom use as a programmable and interactive educational robot,
(2) Versatile and useful for teaching a range of AI concepts,
(3) Effective and engaging for K-12 learners.

To support these claims, we describe how we designed Doodlebot to prioritize reliability, user-friendliness, and cost efficiency. These goals guided our decision-making through the design and implementation process. Next, we present three Doodlebot use cases that cover AI character design, autonomous mobile robots, and generative AI art. These examples expound upon Doodlebot's

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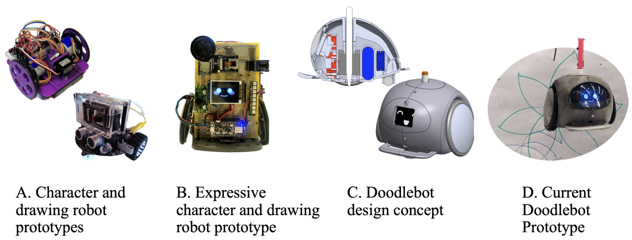

Figure 1: The evolution of Doodlebot portrayed through different prototypes. A. Doodlebot began as inexpensive character and drawing robots. B. We combined these two platforms to create a multi-sensory learning platform that could drive, sense and draw. C, D. The current version of Doodlebot can draw using a mounted pen and has an expressive face.

potential applications as a programmable tool and a learning companion. We conduct a preliminary study of Doodlebot's autonomous multi-agent navigation curriculum with primary and middle school youth. We assessed students' learning outcomes and gathered their feedback regarding Doodlebot's engagingness and usability.

In this paper, we delve into how we created a novel classroom-ready robotic platform to prepare learners for an AI-driven future.

2 BACKGROUND AND RELATED WORK

Despite AI's widespread impact on daily life, most people lack a baseline knowledge of AI's role and function [14]. Thus, calls for AI education for children and adults have emerged from industry, academia, and government [42, 50]. Several AI literacy frameworks have been developed, encompassing a wide range of competencies from understanding decision-making systems to conversational agents and AI ethics [28, 38, 42]. To make these AI concepts more accessible to young learners, educators often employ hands-on tools, including robots, that do not require learners to have advanced math or digital literacy skills [23, 27, 29, 33, 46–49]

Robots serve three primary roles in educational settings: surrogates for remote learners, programmable artifacts, and interactive learning companions [8, 41]. In this paper, we focus on the latter two uses. Programmable robots are often used to teach computer science and engineering concepts, although they are sometimes leveraged in cross-disciplinary lessons in math, science, English, and more [38]. Programmable robots, such as LEGO Mindstorms, have already achieved widespread use in computer science and AI curricula, building off of STEM education research which shows that tangible manipulatives promote student engagement and learning achievements [35]. AI learning companions often play integral roles in skills-based language, mathematics, and social skills learning [8]. For example, socially assistive robots have helped students gain cognitive skills such as language literacy skills or mathematics and logic [6, 17], as well as valuable learning behaviors such as creativity, curiosity and growth mindset [1, 3, 16, 36].

Robot platforms are primarily used as programmable artifacts in computer science and AI courses. The majority of the work using robotics for AI occurs in university classrooms. Researchers at this level have demonstrated that using programmable robots increases engagement and enhances student understanding by making abstract concepts more tangible [10, 21, 24, 25, 30, 40]. In K-12 AI education, commercial and research platforms like (see Table 1) have enabled learners to engage with machine learning, conversational agents, and autonomous vehicles [10, 44–46, 49]. However, there is a scarcity of tools that cover the full range of AI topics, plus obstacles like cost, setup, and maintenance hinder widespread adoption [24, 25, 40, 46]. There is room for improvement before these tools become practical for sustained classroom use.

Some tools blur the lines between being programmable artifacts and learning companions. Researchers have conducted studies using either fully autonomous and Wizard-of-Oz robots to explore the impact of having learners program interactive agents [22, 47]. Jung et al. worked with high school students working on electronic prototyping projects alongside a social agent embedded into the Arduino they were program. They found that the embedded agent positively influences learners' engagement and performance with the task [22]. Williams et al. found that preschool-aged children benefited from having a learning companion embedded in a programmable social robot. The social capabilities of the robot helped students grasp abstract AI concepts they might otherwise struggle to understand [47]. These studies show substantial potential in designing educational robots that can function both ways.

In conclusion, there are many benefits to using robots in AI education, but there is a shortage of suitable platforms for young learners. Current K-12 AI education platforms tend to be expensive and focus on a narrow range of topics, leaving room for more cost-effective and versatile options. Furthermore, there is untapped potential in exploring the use of programmable robots as active learning companions in the classroom.

3 DOODLEBOT: DESIGN PROCESS

The complete Doodlebot system, as shown in Fig. 2, consists of a physical robot and a host device, either a computer or mobile device, that controls the robot. The host device displays a user interface for controlling the robot and handles large computational processing tasks. Data transmission between the robot and the host device occurs over Bluetooth Low Energy (BLE). An onboard camera streams images directly to the host device using an HTTP web server. As compared to existing robotic education toolkits, Doodlebot is a significantly lower cost platform, is primarily designed for AI learning, designed to facilitate human-robot interaction (using its multi-sensory support, social interaction, user data integration), incorporates novel human-machine collaborative drawing, is accompanied by child-friendly interfaces for training the robot using ML and planning policies.

3.1 Robot Features and Components

Doodlebot's components include a liquid crystal display (LCD) screen, two stepper motors, a retractable pen, environmental sensors, an onboard camera, an optional overhead camera, and an optional Bluetooth audio module. The LCD screen can display text and 15 face animations, each representing different emotions (e.g. neutral, happy, sleeping, wink).

The primary controller is an Adafruit Feather nRF52840 Sense microcontroller with built-in BLE, inertial measurement unit, color,

Table 1: Educational robots similar to Doodlebot or used to teach AI, sorted by cost

		Key features			
Company and product name	**Cost**	**Commercially available**	**Social agent**	**Autonomous driving**	**Drawing**
Amazon Alexa[1]	$50	●	●	-	-
Micro:bit robots (Yahboom Tiny:bit[2] and Elecfreaks Cutebot[3])	$55-$60	●	-	◐	-
iRobot Root[4]	$129.99	●	-	●	●
Arcbotics Sparki[5]	$149	●	◐	●	●
Ozobot Evo[6]	$175	●	◐	●	-
Parallax Scribbler 3[7]	$179	●	-	●	●
ANKI Cozmo[8]	$250	-	●	●	-
LEGO Mindstorms	$469	●	-	●	◐
Jibo[9]	$899	-	●	-	-
Doodlebot	Estimated: $90-136	-	●	●	●

●: Provides property; ◐: Partially provides property; -: Does not provide property;

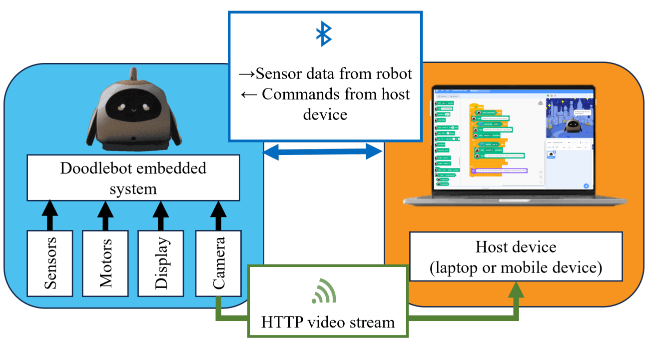

Figure 2: Doodlebot's architecture: The microcontroller passes sensor data and receives commands from the host device via a BLE connection. The camera streams images to the host device using a wireless HTTP connection.

humidity, temperature, and barometric pressure sensors. Doodlebot also features front and rear bumper sensors, a forward-facing distance sensor, and a battery level sensor. The onboard camera is an ESP32 camera placed above Doodlebot's screen.

Doodlebot's chassis features a three-wheeled differential-steered design, with two side-mounted stepper motors and a single ball-bearing caster wheel at the rear. The stepper motors can rotate at different speeds for specific numbers of steps, enabling them to create accurate lines, corners, and arcs. Additionally, Doodlebot incorporates an actuated pen slot through its center for drawing and other manipulation tasks.

Finally, an optional speaker "backpack" utilizes a separate Bluetooth audio connection to play sounds from the host device. This onboard speaker enhances the user experience by enabling the robot to play sounds and speech processed on the host device. A table detailing Doodlebot's API commands can be found in the Appendix.

3.2 Robot Design Goals

We crafted Doodlebot as an educational robot for classroom use by primary and middle school teachers and students (ages 6 to 14). To achieve success with our target age range, we refined Doodlebot through a series of user testing prototypes (see Fig. 1) to understand which properties of educational robots led to success in the classroom. An example key insight we gained from educators was the importance of long battery life and replaceable batteries for teachers with back-to-back robotics class sessions. After garnering feedback from students and educators, we decided to prioritize reliability, user-friendliness, and versatility in Doodlebot's design.

3.2.1 Reliability. We designed Doodlebot to withstand regular classroom use for at least three years. We achieved this by incorporating a drop-resistant shell and selecting components known for their durability. We used a battery with enough capacity to allow Doodlebot to drive continuously for at least 20 minutes without recharging.

3.2.2 User-Friendliness. We wanted Doodlebot to be easy to set up, maintained, and repaired for teachers and trained students without special technical skills. Doodlebot features a rechargeable battery compatible with standard USB-C cables. Students can pair their Doodlebot using any Bluetooth 4.0-enabled device with Internet connectivity and a modern Internet Browser. We created various control interfaces for Doodlebot, including a block-based programming platform and graphical user interfaces. We give more details about these interfaces in later sections.

3.2.3 Versatility. Cost is a significant concern when designing educational robots for the classroom [7, 38, 46]. As shown in Table 1, comparable platforms range in price from $30 to $250. The Cost of Goods (COG) for our prototype lands at the higher end of that range at just under $227, though we anticipate reducing its cost by 40-60% when manufacturing at scale. To enhance Doodlebot's cost-effectiveness, we equipped it to serve multiple use cases and to support teaching several AI topics.

One of Doodlebot's core functions is as a personified agent, capable of perceiving and expressing social behavior as it interacts with users. Doodlebot's onboard camera allows it to engage in first-person interactions with users, leveraging object recognition, affective computing, and speech recognition models processed on its host device. Doodlebot responds to users leveraging its screen, body, and optional onboard Bluetooth speaker to perform animations and display or dictate speech. This enables us to utilize Doodlebot to help students learn about natural interaction and AI's social impact. Doodlebot's second core functionality leverages its stepper motors, bumper sensors, and distance sensors to perform autonomous navigation. In addition to onboard cameras, Doodlebot can be used with overhead cameras connected to its host device to enable multi-agent coordination. Decision-making and computer vision algorithms running on the host device allow different robots to recognize each other and any nearby obstacles. This enables Doodlebot to be used in representation and reasoning curricula. Doodlebot's third core functionality, enabled by its autonomous driving capabilities, is as a drawing robot. Doodlebot can grasp generic thin, felt-tipped markers. Its retractable pen-holding mechanism maintains consistent pressure and placement to reduce drawing errors as much as possible. Doodlebot is capable of drawing simple shapes using its stepper motors. But, with its overhead camera plus computer vision and image processing algorithms running on its host device, it can also engage in interactive drawing activities where users collaborate with Doodlebots on a single piece. This capability enables Doodlebot to be used for students' creativity development and realizing creative collaboration with a machine.

4 DOODLEBOT USE CASES

We developed three learning use cases that employ Doodlebot as a pedagogical tool: (1) programming socially assistive robots that focuses on teaching students about natural interaction and societal impact of AI, (2) collaborative generative drawing that focuses on developing students' creativity skills and enabling creative collaboration with AI and (3) Frientelligent: exploring multi-agent autonomous navigation that focuses on representation and reasoning respectively. Intended learning outcomes were motivated from previous work in AI literacy for K-12 students that outline skills required for students to be successful in an AI driven future [2, 5, 26, 42].

4.1 Programming socially assistive robots

The first use case we implemented for Doodlebot was connecting it with the AI Playground, a programming platform branched from Scratch's open-source repository. We developed a Doodlebot blocks extension in the AI Playground with commands to control Doodlebot's display screen, play built-in animations (e.g. the "play happy animation" shows the happy face then bounces the pen twice), control the motors, raise/lower the pen holder, read from sensors, and enable the onboard camera. Images of all of the blocks and what they do can be found in the Appendix.

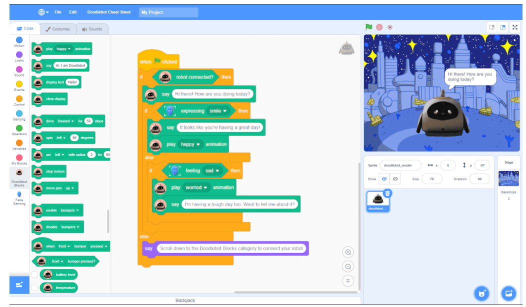

Figure 3: The AI Playground extension for Doodlebot. The programming interface displays an example project that uses Doodlebot and other blocks.

These blocks can be combined with other Playground extensions that perform image classification, gesture recognition, natural language processing, and affective computing to create more robust programs. With these extensions, the AI Playground interface allows students to use Doodlebot to explore machine perception, reasoning and planning, machine learning, and social robotics.

4.1.1 Chatbots for Mental Health Curriculum. Leveraging the AI Playground, we created a middle school curriculum about Chatbots for Mental Health (example in Fig. 3) that introduces students to designing social agents. Students first learn how to define AI, then program Doodlebot to become a social agent that can support socioemotional health in some way, for example by providing entertainment, guiding users through exercises, or providing information about health concerns.

Doodlebot also serves as a learning companion in this curriculum, complementing the AI Playground's built-in tutorials and automatic code assessment tool. Doodlebot verbally explains the text for the tutorials of different extensions as users navigate it. It specifically provides advice on integrating new blocks with the Doodlebot extension. For the automatic code assessment tool, called LevelUp, Doodlebot reinforces the tool's positive feedback and offers challenges to encourage users to meet all best practices for designing machine learning models [37]. The idea suggestions and positive reinforcement provided by Doodlebot align with prior research on AI agents promoting creativity in construction tasks [1].

4.2 Collaborative, generative drawing

The second use case we implemented for Doodlebot was for creative learning through generative drawing. Doodlebot has a unique creative potential because it can draw. When coupled with an overhead camera, we can track where Doodlebot is located and what the current drawing state is. We developed a collaborative drawing platform, where children and the Doodlebot can collectively make a drawing. This involved children completing Doodlebot's drawing, Doodlebot completing children's drawings, or children and Doodlebot taking turns to complete a drawing (Figure 4).

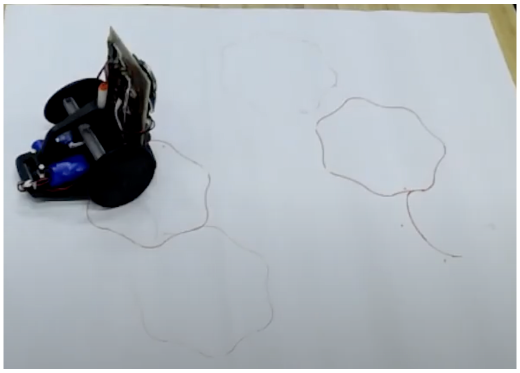

Figure 4: Doodlebot completing a balloon drawing after the human drew the string of the balloon

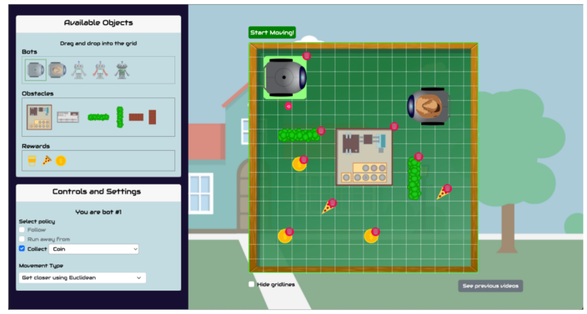

Figure 5: The interface of the Virtual game mode. Users can drag bots, obstacles, and rewards and select their bot policy from the menu on the left.

We utilized an overhead camera to capture both Doodlebot's position and images of the drawing. Tracking a color marker on the robot's pen allowed us to determine its x and y coordinates relative to the camera's field of view. To process images of the drawings, we computationally removed the white paper background and converted the result to a .png image. We fed that .png files into Sketch-RNN by Magenta [13, 18], a predictive algorithm for doodles, to generate the next drawing strokes based on the user-selected image category.

The available drawing categories included 35 everyday objects (e.g. strawberry, butterfly, chair). Our collaborative drawing algorithm, trained on human doodles from the QuickDraw dataset [18], produced .json files of sketch strokes. We converted the coordinates in these files into arcs that Doodlebot could draw. By calculating the delta between x and y coordinates, we determined both the angle and distance the robot should move. However, due to the intricate nature of the drawings, a simplifying path algorithm was necessary to estimate movement angles accurately. This process, while reducing granularity, ensured feasible robot drawings.

Through collaborative drawing, students learned about the robot's creative ability and limitations, and generative algorithms such as Sketch-RNN. Furthermore, Doodlebot demonstrated AI creativity in a manner while also motivating users to express their own creativity [1, 4]. As the robot and user took turns adding to a drawing, the robot also offered positive affirmations, expressions of positive affect, and creative scaffolding to further encourage users' creativity.

4.2.1 Collaborative Drawing Curriculum. In the curriculum we built around collaborative drawing, students collaborate with Doodlebot to create an object or scene. The robot and student take turns selecting objects and finishing each other's drawings. If the student leads the turn,they decide the creative direction, but if the robot leads then the student is challenged to collaborate with the robot's direction. Along the way, students explore more of the Quickdraw dataset. Afterward, we evaluate students' comprehension of generative drawing and their perception of the robot's creativity. We ask questions about the dataset they used, how they thought the robot worked, how they would rate the robot's creativity, and how they would rate their own creativity.

4.3 Frientelligent: Exploring multi-agent autonomous navigation

Finally, we implemented a game-based interface called Frientelligent where multiple Doodlebots and multiple users navigate a map simultaneously. The interface allows students to explore multi-agent collaboration and competition where students learn AI concepts related to path planning, distance metrics, and policy making. There are two game modes, a *Virtual* mode and a *Physical* one. In both modes, the Bot's behavior is determined by the kind of distance metric (Euclidean, Manhattan, or Dijkstra) they use and the kind of policy they follow. Users can select policy options that include following other Bots, avoiding other Bots, collecting rewards, or combining the aforementioned options.

In the *Virtual* mode, students access the user interface on separate laptops. They can drag and drop different icons onto the virtual 2D grid (see Fig. 5) and select the policies and distance metrics their bots will use. When all users are ready, they can start the simulation and watch their bots complete the map.

In *Physical* mode, objects placed on the map are identified with unique ArUco codes [10]. ArUco codes allow the robot controller to locate objects and distinguish whether they are a Bot, obstacle, or reward. The ArUco codes marking objects and the corners of the map grid are detected with an overhead camera (Fig. 6). Users set up their map by physically placing objects within the map's borders. The maps users create are then projected onto the screen of a single host computer that communicates with the Doodlebots using BLE connections.

The game between users is synchronized such that both users join a "Game Room" and progress through different levels together. This synchronization leverages a Firebase database for scalability and easy deployment. First, users complete tutorials that explain the three distance metrics, show demos of each in action, and explain the different path-planning policies that Bots can follow. Then, users set up their maps, select policies for their robots, and watch the action play out on the map when all users are ready.

[10]https://docs.opencv.org/4.x/d5/dae/tutorial_aruco_detection.html

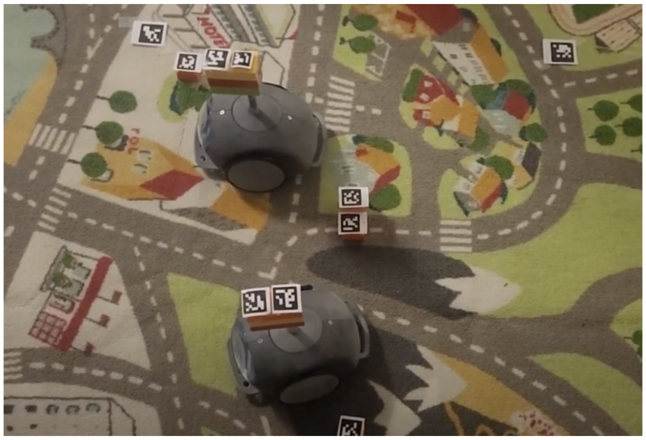

Figure 6: Objects in the physical playground are assigned unique ArUco Codes to detect their type and keep track of their movement.

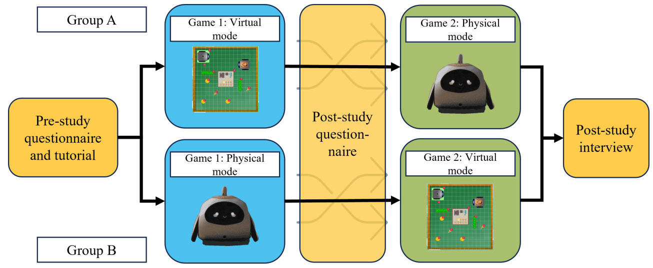

Figure 7: Overview of the study design. Participants completed the pre-study questionnaire and video tutorials, the played two games with the Frientelligent system. We pre-assigned participants to Group A or Group B to determine which mode they played first. Participants completed a post-study questionnaire between game modes and we concluded with interviews.

5 USER STUDY: AUTONOMOUS NAVIGATION CURRICULUM

We designed the Autonomous Navigation Curriculum for primary and middle school youth (ages 6 to 14). We designed a user study to answer two research questions: (1) How effective was the Autonomous Navigation Curriculum in teaching students about autonomous navigation, and (2) How does the *Physical* Doodlebot interface compare to the *Virtual* one? We used a mixed methods approach to collect and analyze data to help us answer these two questions.

5.1 Participants

We recruited eight (7 female, 1 male) children between the ages of 9 and 11 (avg. 9.6-years-old) to participate in the study. All participants and their parents signed informed consent documents in accordance with the procedures outlines by our institution's research ethics review board. Each study session lasted approximately 60 minutes, with students working in pairs at each session.

5.2 Procedure

As shown in Fig. 7, participants first completed a pre-questionnaire, then completed the tutorials for the Frientelligent interface. We separated participants into two conditions, Group A where participants completed the Virtual version of the game then the Physical version, and Group B where participants started with the Physical version. Everyone tried both versions of the game, but the crossover study design allowed us to compare the impact of different modes on how much they learned and their perceptions of Doodlebot.

First, participants completed the pre-study questionnaire and completed the video tutorials for the Frientelligent system. Then they began playing a multi-agent game with either the Physical or Virtual interface. After participants finished the first version of the game, we had them complete a post study questionnaire, then participants played the game again using whichever game mode they had not played yet. After the second game, students completed a post interview discussion about their experience.

5.2.1 Pre and post study questionnaire: The pre and post study questionnaire included knowledge-based questions related to the curriculum that the study introduces. The questionnaires were identical so that we could measure how much participants learned after interacting with the first game mode. The full questionnaire can be found in the Appendix.

5.2.2 Post-study group interview: At the end of the session, we conducted a short informal interview with both participants to get their feedback. We asked about the virtual and physical modes separately, collecting notes on what they liked or did not like, what they found easy and hard, and what they would change in how we carried out the study for future improvements. The interview question worksheet can be found in the Appendix.

5.2.3 Synchronous and recorded observations: As the study went on, two observers took notes on students' engagement, comments, and behaviors. The observation form can be found in the Appendix. The entire study was also video recorded for reference during analysis.

5.3 Data Analysis and Results

5.3.1 Virtual Doodlebot user interface: On the post-study questionnaires questions about the usability of the virtual Doodlebot interface, most students indicated that they considered the interface flexible, fun, and exciting to use. However, two students stated that it was confusing having many policy and distance options in the interface to select from. Additionally, the availability of different themes in the virtual interface was a point of engagement for participants. Two participants bonded over their shared interest in Pacman.

5.3.2 Physical Doodlebot: Participants also gave physical Doodlebot high ratings on its usability. Students were excited about seeing the robot move, and one exclaimed to their parent, "Mom, can we have this at home?" (S1). The student's comments indicated that students could make connections between the physical Doodlebot and examples of AI they had encountered in the real world "I like

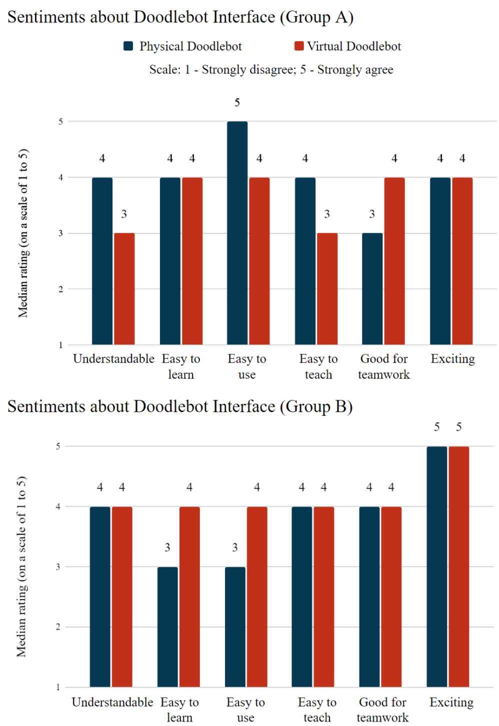

Figure 8: The average scores each mode received from the students in each group: A (Virtual first) and B (Physical first). In general, we saw participants rating the mode that they played last more highly.

how it puts AI and the real world together, reminds me of Tesla!" (S2).

5.3.3 Virtual vs. physical modes: Across both condition groups, we observed participants' excitement, engagement, and creativity throughout the session, with results shown in Fig. 8. Participants tended to display a slight preference for the *second* mode they interacted with, whether that was the virtual or physical mode. In the questions we asked directly comparing the two versions, we only observed a slight preference for the Physical mode (see Fig. 9).

On the virtual mode, observers noticed that students spent more time designing their maps versus only spending a couple minutes arranging maps when working with physical Doodlebot. In the physical game mode, students were more interested in starting the game quickly so they could see the robots move.

5.3.4 Learning outcomes: Overall, the different game modes did not seem to have a significant impact on learning outcomes. Students performed well on the pre-test, achieving an average score of 7.6 correct answers out of 10 questions. This left little room to grow in the post-test (mean = 7.8). This finding pointed towards using assessments that were more appropriate for the learning materials. We asked students to self-assess their familiarity with the keywords and skills discussed in the lesson. The results displayed in Table 2 show slight, but not significant increases in students' self-declared familiarity with key terms like AI, autonomous navigation, bot

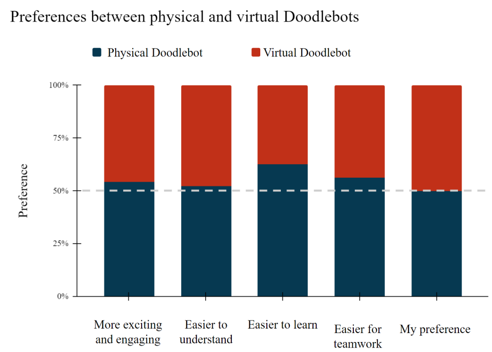

Figure 9: The average scores each mode received from all the students with regards to which mode they preferred better. There was a slight preference for physical Doodlebot.

Table 2: Participants' self-assessed familiarity with AI skills and keywords, pre vs. post test

Question item		Min	Max	Median
Artificial Intelligence	Pre-test	2	5	3.5
	Post-test	2	5	4
Autonomous vehicles	Pre-test	1	5	2
	Post-test	2	5	3.5
Bot policy	Pre-test	1	3	1
	Post-test	1	5	2.5
Path planing algorithm	Pre-test	1	5	1
	Post-test	1	5	3
Planning the best path to reach a goal	Pre-test	2	4	3
	Post-test	1	5	3.5
Designing maps that accurately reflect the real world	Pre-test	2	4	2
	Post-test	2	5	3
Using AI to have positive, societal impact	Pre-test	1	5	1
	Post-test	1	5	2

Scale: 1 - I've never heard of this;
5 - I understand this very well and can teach it to someone else;

policy, and path planing algorithms, and skills like planning the best paths, designing maps, and using AI to have positive impact.

We conclude that both a fully-virtual and a physical interface are powerful in delivering information to children. With an engaging web-based interface, participants had more flexibility to design their maps. Additionally, the virtual interface is easier to extend and deploy in any educational space. A physical interface, however, takes more effort to setup and there will always be a limited number of objects one can use to create the map. Nonetheless, students find it engaging and interesting.

6 DISCUSSION

As AI literacy curricula spread outside of university CS classrooms, educational robots like Doodlebot will be increasingly employed to support K-12 students learning about AI. By designing Doodlebot, developing several curricula, and running a user study we gleaned crucial insights toward the design of future educational robots.

Collaborate with educators to successfully design low-cost, classroom-ready educational robots.

Educational robots hold great potential for supporting AI curricula, but making them classroom-ready is a challenging task. Collaborative design with teachers and students ensured that Doodlebot aligned with classroom needs and contributed to an enriching learning environment.

In response to educator feedback, we aimed for a price point for Doodlebot below $100 and selected components to meet this low cost without sacrificing important features. As socioeconomic disparities continue to hinder many students from learning about CS and AI [7, 9, 11, 38], fostering inclusivity requires technologists to design more affordable robots. Previous studies with teachers also highlighted that issues with setup and repairs significantly impact learning experiences, especially among younger learners [24, 25, 40, 46]. To lower barriers to entry and enhance usability, we developed browser-based tools for Doodlebot, utilizing a familiar programming platform in the Chatbots for Mental Health curriculum, and offering tangible objects for interaction in the Collaborative Drawing and Frientelligent curricula [19, 46]. We realized the importance of these design choices thanks to our collaboration with educators.

Enhance cost-effectiveness by enabling multiple use cases across a range of learning topics.

We designed multiple AI curricula that address various AI topics and enable different pedagogical approaches. Across different frameworks for AI literacy, there is consensus around the importance of comprehensive coverage of AI topics [28, 38, 42]. However, as many researchers have pointed out, there is an overrepresentation of curricula on machine learning to the exclusion of other topics [32, 38]. We sought to make Doodlebot a more versatile tool by using it to teach different AI subjects.

Our three curricula showcase examples of pedagogical approaches that utilize Doodlebot. The Chatbots for Mental Health curriculum utilizes a constructionist, learning-by-design approach [34] where students work on real-world AI projects. The Collaborative Drawing curriculum uses human-robot collaboration on a creative task [1, 4]. Frientelligent uses collaborative, game-based learning to encourage students to apply their AI knowledge to complete tasks. Further, Doodlebot can act as an intelligent learning companion that scaffolds activities and personalizes tutoring, a key area of innovation in using AI in classrooms [4, 38]. We believe that with increased versatility other educational robots could become more practical for classroom use.

Ensure that robots are effective, engaging, and connect technical concepts to real-world experiences.

Although the small sample size of our user study limits our ability to generalize broadly, our the results offer positive encouragement for expanding the use of Doodlebot into the classroom. Participants found physical and virtual Doodlebot equally user-friendly and observed similar learning gains in both modes, indicating that physical Doodlebot did not distract from key learning goals.

Interestingly, the physical version did not emerge as significantly more engaging. As we expand our studies of this platform, we will continue to look for justification for the physical Doodlebot version, as prior research indicates that physical robots can increase engagement in learning, especially for students from groups underrepresented in tech [38, 39]. Specifically, we look forward to physical Doodlebot sparking engagement in real-world issues as students work on projects, create artifacts, and have Doodlebots navigate their classrooms. We expect that the tangible manifestation of technical ideas in students' physical space will ultimately lead to students forming deeper connections with the material.

7 CONCLUSION

In this work, we introduced Doodlebot, a mobile, social, drawing robot designed for K-12 AI curricula. As efforts toward AI literacy expand, educational robots like Doodlebot that can engage learners, help them make sense of complex algorithms, and enable hands-on practice will become increasingly essential tools.

Based on feedback from educators on previous prototypes, we prioritized reliability, user-friendliness, and versatility in our design. As a result, our current prototype contains three machines in one - an autonomous mobile robot, an interactive social agent, and a drawing tool. We developed multiple user interfaces and curricula that explore the breadth of these functions. Furthermore, Doodlebot can be used as a learning companion, capable of scaffolding and encouraging learners.

The positive feedback from the pilot study highlighted Doodlebot's intuitiveness and ability to engage learners. While this work focuses on the design of the Doodlebot platform, future work will focus on further validating the platform by working with educators and more students, as well as conducting deeper qualitative and quantitative analysis about students' learning experiences and interaction with the robot and their AI learning gains. This includes integrating Doodlebot into classrooms and collecting long term student interaction and learning data. We will also measure Doodlebot's long-term durability in classrooms including performance metrics, battery life, student safety and physical damage. The insights gained from this work include understanding gaps in existing educational robots, designing features to meet educators' specified needs, and studying an educational robots' impact on learning.

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