

Draw-bot: Engaging Young Minds Through Interactive Geometry with Educational Robotics

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Abstract : This study investigates the effectiveness of an interactive educational robot, Drawbot, in supporting early childhood geometry learning through a multimodal teaching approach. Unlike conventional tools, Drawbot combines a motorized drawing mechanism with synchronized auditory explanations of geometric properties. Twenty primary school students aged 6–9 participated in a classroom intervention consisting of robot-assisted shape drawing and explanation sessions. A pre–post test design was employed to measure changes in shape recognition, understanding of sides and edges, and comprehension of area and perimeter concepts. Results revealed significant improvements across all dimensions, with the largest gains observed in conceptual understanding of area and perimeter. Observational data and teacher feedback indicated high levels of engagement, curiosity, and reduced math anxiety during the activity. These findings suggest that multimodal educational robots such as Drawbot can transform abstract geometry into tangible experiences, enhancing both cognitive outcomes and affective attitudes toward mathematics. Implications for integrating robotics into early childhood classrooms and directions for scaling the study are discussed.

Keywords: Educational Robotics, Early Childhood Education, Geometry Learning, Multimodal Learning, Human-Robot Interaction, Shape Recognition, STEM Education

1. INTRODUCTION

Curiosity and creativity are foundational aspects of human cognition and behaviour, driving the continuous pursuit of knowledge and innovation. The process of exploring novel ideas and acquiring information often leads to the generation of creative and impactful outcomes. Creativity is not restricted to any single field but extends across disciplines including art, science, business, and technology. It typically involves deliberate intellectual engagement, imaginative thinking, and the synthesis of new solutions or perspectives.

Educational robotics has emerged as a powerful tool to enhance early childhood learning by transforming abstract concepts into concrete, engaging experiences. Previous research has shown that socially interactive robots can foster motivation, collaboration, and creativity in children’s learning environments (Leite et al., 2025; Vogt et al., 2021; Benitti et al., 2012). Among various applications, mathematics—particularly geometry—presents unique challenges for young learners, as abstract notions of sides, angles, and formulas are often difficult to grasp through traditional instruction alone.

Human–Robot Interaction (HRI) is a dynamic interdisciplinary field that investigates the mechanisms through which humans and robotic systems communicate and collaborate. In educational settings, socially interactive robots are increasingly utilized as facilitators of joyful, creative, and meaningful learning experiences (Leite et al., 2025). These systems, capable of establishing effective verbal and non-verbal communication, play a significant role in scaffolding children’s learning processes.

Recent studies have introduced programmable and drawing robots, such as Doodle Bot, as hands-on platforms for supporting mathematics and programming education in primary school settings (Rosales et al., 2025; Baki et

al., 2024; Ali et al., 2021). These systems demonstrate the potential of robotics to make learning visual and interactive. However, existing robots are often limited to mechanical demonstrations without integrating multimodal features that combine visual, auditory, and interactive feedback to reinforce conceptual understanding.

The Doodle Bot is an example of an educational robot that exemplifies creativity in action. Designed for primary school students, the Doodle Bot is an open-source platform capable of drawing geometric shapes (Hsu et al., 2017) based on programmed instructions. It enables children to engage visually and interactively with abstract mathematical concepts. Drawing (Naranje et al., 2024) itself serves as both a creative outlet and a cognitive tool, allowing children to express emotions, convey ideas, and represent abstract notions through visual media (Rosales et al., 2025; Deborah et al., 2022).

The shift from traditional industrial robotics to expressive, interactive domains reflects a broader evolution in robotic design. Earlier robots were predominantly built for repetitive or hazardous tasks; in contrast, modern robots are increasingly capable of creative and autonomous operations, including real-time drawing (Mingxin et al., 2020) and educational interaction (Williams et al., 2024). These advances make robot-assisted learning more accessible and adaptive (Mazzoni et al., 2025).

Furthermore, math anxiety among early learners is a widely documented barrier that reduces engagement and confidence in mathematics (Nguyen et al., 2024). Multimodal learning strategies—those that integrate visual and auditory channels—have been shown to reduce cognitive load and improve retention, yet their application through autonomous educational robots in geometry instruction remains underexplored.

To address this gap, we designed Drawbot, an autonomous educational robot capable of drawing precise geometric shapes while providing synchronized audio explanations of their properties. By combining tangible visual representations with spoken narration, Drawbot aims to enhance engagement, reduce anxiety, and improve conceptual learning outcomes in early childhood geometry education.

The integration of robotic systems in education aligns with the interdisciplinary vision of Industry 4.0, where technological innovation transcends conventional domain boundaries. Robotic drawing, for instance, serves not only a functional role but also offers insight into machine learning processes and human cognition. Observing the interaction between children and drawing robots provides opportunities to refine both the technology and pedagogical practices, ultimately enriching learning environments and stimulating creativity.

Building upon prior research in human–robot interaction and multimodal learning, this study contributes an empirical evaluation of Drawbot in a classroom context. Specifically, it addresses the following research questions:

RQ1: How does interaction with Drawbot affect children’s ability to recognize and describe geometric shapes?

RQ2: To what extent does Drawbot improve students’ understanding of sides, edges, and basic geometric formulas (area and perimeter)?

RQ3: How do students and teachers perceive Drawbot in terms of engagement, motivation, and reduction of math anxiety?

By exploring these questions, this study aims to provide evidence for the educational value of multimodal robots in early mathematics instruction and offer insights for integrating such tools into diverse classroom settings.

1.1. Key Contributions

This work makes the following key contributions to the field of educational robotics and early childhood STEM education:

- Design and Implementation of Draw-bot

Developed a low-cost, autonomous educational robot capable of drawing geometric shapes with precision and delivering synchronized audio explanations tailored to early learners.

- Multimodal Learning Framework

Introduced a novel multimodal teaching approach that combines visual (shape drawing) and auditory (spoken geometry explanations) stimuli to support diverse learning styles and enhance conceptual understanding.

- Interactive Geometry Instruction

Enabled real-time, interactive geometry learning through a robot that articulates key properties of shapes, such as sides, edges, and area/perimeter formulas, while physically drawing them.

- Support for Independent and Classroom Learning

Designed the system for dual use cases: as a self-guided learning tool at home and as a supplementary teaching aid in classroom environments, promoting flexible deployment.

- Reduction of Math Anxiety in Early Learners

Addressed the challenge of math anxiety by making geometry learning playful, intuitive, and engaging, helping students build confidence through hands-on interaction.

- Empirical Evaluation of Learning Outcomes

Conducted experiments with 20 students and demonstrated significant improvements in shape recognition, geometric reasoning, and formula comprehension through pre- and post-activity assessments.

2. LITERATURE REVIEW

2.1 Educational robotics in early childhood education

Educational robotics has become an increasingly important tool in early childhood education, enabling children to learn abstract concepts through tangible, hands-on interaction. Prior studies have shown that robots can support children's learning in science, technology, engineering, and mathematics (STEM) (Kim et al., 2016) by offering opportunities for manipulation, exploration, and collaboration (Benitti, 2012). In particular, programmable robots have been introduced to cultivate computational thinking and problem-solving skills at an early age. These findings highlight the potential of robots to enrich learning experiences by providing developmentally appropriate, screen-free environments that combine play with conceptual learning.

2.2 Multimodal learning and mathematics education

Research in cognitive science emphasizes that learning is enhanced when multiple sensory channels are engaged simultaneously. Multimodal learning, which integrates visual, auditory, and kinesthetic elements, has been shown to reduce cognitive load, improve retention, and increase engagement (Hwang et al., 2023). In mathematics education, multimodal approaches can transform abstract notions into concrete representations, making them more accessible to young learners. However, existing classroom practices often rely heavily on visual instruction, limiting opportunities for auditory reinforcement or interactive exploration. Robots designed with multimodal features—such as drawing combined with verbal explanation—can bridge this gap by supporting diverse learning styles.

2.3 Drawing robots as educational tools

Drawing robots have attracted attention as low-cost platforms to introduce children to geometry and programming concepts. For example, the open-source Doodle Bot allows children to program geometric shapes, thereby connecting visual learning with computational logic (Rosales et al., 2025, Chun et al., 2017). These systems provide opportunities for creative expression while supporting the acquisition of mathematical knowledge. Moreover, drawing itself functions as both a cognitive and creative activity, enabling children to externalize abstract ideas in visual form (Melinda et al., 2001). Despite their promise, most drawing robots focus primarily on mechanical output, offering limited integration of feedback mechanisms to deepen conceptual understanding.

2.4 Human–robot interaction and engagement

Human–Robot Interaction (HRI) research highlights the importance of socially interactive robots in sustaining motivation and engagement in learning contexts. Robots capable of real-time feedback and natural interaction (e.g., speech, gestures, storytelling) have been shown to promote curiosity, creativity, and sustained attention in children (Vogt et al., 2021; Leite et al., 2025). Importantly, HRI studies suggest that robots can serve as mediators that reduce anxiety in subjects often perceived as challenging, such as mathematics (Nguyen et al., 2024). By combining interactivity with scaffolding, robots create supportive environments that encourage children to take risks in learning (Putra et al., 2016).

2.5 Research gap

While prior studies have demonstrated the benefits of educational robots, multimodal learning strategies, and drawing-based platforms, few empirical investigations have combined these elements to evaluate their effect on geometry learning in early childhood classrooms. Existing research largely focuses on programming kits and computational thinking, with limited attention to robots that integrate visual drawing and auditory explanation for mathematics. Moreover, the role of such multimodal robots in addressing math anxiety and enhancing student engagement remains underexplored. This study addresses these gaps by introducing and evaluating Drawbot, a robot designed to teach geometry through synchronized drawing and spoken explanations, and by analyzing its impact on children’s learning outcomes and perceptions.

Despite the promising developments in educational robotics, challenges remain. These include designing intuitive interfaces, ensuring adaptive feedback, and integrating such tools effectively into traditional curricula. Additionally, the autonomous execution of creative tasks—such as freehand drawing—by robots remains an open research area, particularly in terms of balancing user control with machine autonomy. This study builds upon the existing literature by presenting an interactive educational robot that combines geometric drawing with real-time auditory feedback. The proposed system aims to enhance geometry learning in early education while also promoting curiosity, creativity, and technological literacy.

3. PROPOSED SYSTEM

Drawbot is an interactive learning robot designed particularly to assist students in learning geometric information by combining visual graphics with real-time audio instruction. The machine aims to bridge the theoretical knowledge-practical application gap through the use of an automatic drawing mechanism that can draw shapes geometrically as well as provide accompanying audio descriptions. The robot possesses a micro controller-based system applied to drive motors and execute precise movements for shape drawing purposes. The robot includes a simple interface which enables children to input their preferred shape through Verbal Input. Besides, the convenience of speech recognition through Google Gemini API provides voice command functionality and allows the learning process to be engaging and interactive.

The system consists of major hardware elements such as the Arduino UNO micro controller, Raspberry pi, CNC plotter, stepper motors, servo motors, and sound player. The micro controller translates user input into motion commands to the robot and the CNC plotter delivers accuracy in the drawing of shapes. The

inclusion of an audio feedback system enhances the educational value through description of the geometric characteristics of the shapes being drawn. The Drawbot is low maintenance and inexpensive to keep, which makes it a valuable resource for students and teachers alike in interactive learning environments. Figure 3.1 illustrates the flow of control from user input to the mechanical and auditory outputs of the system.

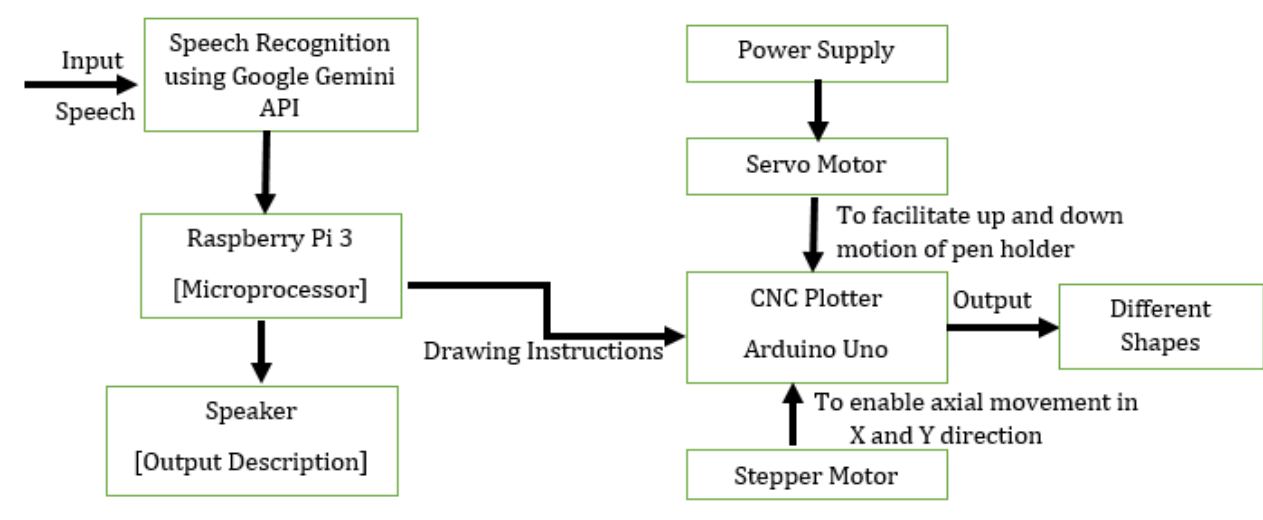


Figure 3. 1 Flow chart of proposed system

3.1 Hardware Components

The hardware components selected for the Drawbot are chosen for their availability, cost-effectiveness, and compatibility with educational settings as discussed in table 1.

Table 1. Hardware Components of Drawbot

Component	Specification	Function
Microcontroller	Arduino Uno	Central control unit
Motor Driver	L298N Dual H-Bridge	Controls the speed and direction of motors
DC Motors	12V, 100 RPM	Drives the wheels for movement
Servo Motor	SG90	Raises and lowers the pen
Audio Module	DFPlayer Mini MP3 Player	Plays pre-recorded audio files
Speaker	3W, 4Ω	Outputs audio feedback
Power Supply	12V Battery Pack	Powers the entire system
Chassis	Custom-built frame	Houses all components
Drawing Surface	A4 Paper on Flat Surface	Medium for drawing shapes

3.2 System Architecture

The Drawbot is developed as a modular system integrating mechanical, electronic, and software subsystems. The robot is designed to operate on a smooth surface, such as a desk or drawing board, and uses two drive wheels for mobility and a centrally mounted marker to render shapes. The core components include a microcontroller, motor drivers, an audio playback module, and a power management unit. The robot executes pre-programmed drawing instructions and synchronizes auditory outputs corresponding to each geometric shape.

The architecture integrates:

- Control Layer: Arduino Uno for motor and audio coordination.
- Motion Layer: CNC plotter with stepper motors and servo-driven pen assembly for shape drawing.
- Audio Layer: DF Player Mini with speaker for shape narration (name, sides, formulas).
- Input Layer: Voice commands via Google Gemini API or manual selection via buttons.
- Power Management: Rechargeable battery system for portability.

During operation, user input (voice/button) is translated into shape parameters (sides, angles). The robot then executes movement sequences to trace the shape and simultaneously plays the corresponding audio description. The initial step in bringing Drawbot to life involves assembling its key hardware components: the Arduino UNO microcontroller, stepper motors, pen assembly, and sound system. These components are carefully integrated to ensure seamless functionality. The Arduino UNO, programmed using the Arduino IDE, acts as the central controller for managing motor movements and processing user inputs. A CNC plotter mechanism, along with the L293D motor driver, is configured to enable precise drawing operations. Additionally, the DFPlayer Mini module is used to store and play pre-recorded audio descriptions of various geometric shapes. After all components are connected, a basic functionality test is conducted to verify that each part operates correctly before proceeding to more advanced testing and calibration.

The interactive work flow of Robot involves the following steps:

1. Handling User Inputs

Since Drawbot is interactive, the user has multiple ways in which they can input. The user can select a shape by way of vocal command with speech recognition software. When a user inputs his or her preferred shape, the system takes input and decides on how to create the shape in terms of number of sides and angles required. The system also brings up related learning information that can be utilized with the drawing.

2. Tracing the Shape

Based on the input received, the shape-drawing algorithm activates. It decides the precise turn angles and step movements the motors need to complete in order to draw the shape correctly. A pen mechanism by servo motors deploys the pen to the drawing surface and picks it up as needed. Drawing-bot follows a loop- based programming structure to slowly follow its predetermined path and complete the shape. Once the shape is drawn, the system restores for the subsequent input. The pen steps down using G code and comes back to the initial position in order to prepare for the next drawing. Similarly the next drawing starts from the initial position and move to the subsequent points. Audio Explanations Embedded to allow for a good learning experience, Drawbot not only draws shapes—it also reads them! When a drawing has been completed, the system does an audio explanation through the DF Player Mini. The explanation breaks down the details of the shapes, such as number of sides, angles, and applications in everyday life. It's double learning where geometry is fun and easier to grasp for students.

3. Voice Control Option

To incorporate an even greater level of immersion, Drawbot has speech recognition via the use of the Google Gemini API. The functionality enables users to issue voice commands for the robot to execute, which is a special assistance for younger children or individuals with disabilities. The system identifies the voice commands, converts them into words, and then continues to convert into drawing commands. This hands-free aspect adds more to the learning process as even more fun and convenient.

3.3 Software Implementation

The software is programmed in C/C++ using the Arduino IDE. The shape-drawing logic is implemented using coordinate geometry and path planning algorithms.

The software, programmed in C/C++ (Arduino IDE), includes:

- Shape-drawing algorithm: Uses coordinate geometry and path planning to render polygons with 3–10 sides.
- Lookup table: Maps each shape to motor instructions and associated audio files.
- Interaction features: Pause/resume control, low-battery alerts, and auto-calibration routines.
- Voice recognition module: Integrates Google Gemini API to process speech commands into drawing instructions.

The robot draws shapes with 3 to 10 sides by executing a sequence of straight-line movements and rotational turns based on predefined angle calculations. Each shape routine is paired with an audio file that is triggered at the beginning of the drawing process. The audio description includes:

- The name of the shape
- The number of sides and edges
- Basic formulas for calculating area and perimeter

A lookup table maps each shape to its respective audio and movement instructions. Additional features include pause/resume controls, auto-calibration routines, and low-battery alerts.

3.4 Interaction Protocol

The Drawbot is designed to support both self-guided learning and teacher-assisted activities. Students can select shapes through physical buttons or a simple mobile interface (enabled by an optional Bluetooth module). During operation, the robot provides synchronized visual and auditory output: learners observe the drawing process in real time while listening to explanations that highlight shape properties and real-world applications. This multimodal protocol reinforces conceptual understanding, accommodates diverse learning styles, and maintains engagement.

In classroom settings, multiple students can take turns selecting shapes and observing the robot's execution, fostering collaborative learning. The robot's performance was evaluated in a controlled classroom environment with children aged 6 to 9. Observational studies were conducted to assess student engagement, shape recognition accuracy, and ease of interaction, providing insights into the effectiveness of the Drawbot as an educational tool.

3.5 Evaluation Criteria

The system was evaluated based on:

- Accuracy of drawn shapes (measured against standard templates)
- Clarity and timing of auditory feedback
- User engagement, assessed through observation and short surveys
- Ease of use, rated by teachers and students

These metrics helped determine the effectiveness of the robot in supporting geometry learning in early education.

4. METHODOLOGY

The Drawbot is designed as an educational tool that integrates mechanical, electronic, and software components to draw geometric shapes and provide auditory feedback. The system's architecture is modular, ensuring ease of maintenance and scalability.

4.1 Participants

The study was conducted with 20 primary school students (aged 6–9 years) from a local school. Two mathematics teachers facilitated the classroom sessions and assisted with observation and feedback. All participants had prior exposure to basic geometric shapes but no experience with robotics-based learning tools. Informed consent was obtained from school administrators, teachers, and parents prior to the study.

4.2 Instruments

Three instruments were employed to evaluate the effectiveness of Drawbot in supporting geometry learning are:

Learning Achievement Test (Pre–Post Quiz): A 20-item assessment designed to measure students' understanding of (a) shape recognition, (b) number of sides and edges, and (c) basic concepts of area and perimeter. The quiz was administered before and after the intervention.

Observation Checklist: Teachers recorded student behaviors during the activity, focusing on engagement, attention span, participation, and curiosity.

Student Feedback Survey: A short, emoji-based survey was administered to gauge children's enjoyment and attitudes toward learning with Drawbot.

4.3 Procedure

The study followed a pre–post experimental design conducted in three stages:

Pre-test phase: Students completed the learning achievement quiz individually to establish baseline knowledge.

Intervention phase: Students participated in a 30-minute session where Drawbot demonstrated the drawing of geometric shapes (triangle, square, pentagon, hexagon, and octagon). For each shape, the robot provided synchronized audio commentary describing sides, edges, and relevant formulas. Students took turns selecting shapes using simple input options and observed the robot's performance.

Post-test phase: Students completed the same quiz after the session. Additionally, teachers administered the feedback survey and documented their observations.

4.4 Drawing Algorithm

The Drawbot's drawing algorithm is based on geometric calculations to render regular polygons. The process involves the following steps:

1. **Input Selection:** The user selects the desired shape (e.g., triangle, square, pentagon) via buttons or an interface.

2. Angle Calculation: The internal angle for the polygon is calculated using the formula:

$$\text{Internal Angle} = \frac{(n-2) \times 180^\circ}{n}, \text{ where } n \text{ is the number of sides.}$$

3. Movement Execution:

- The robot moves forward a fixed distance to draw one side.
- It then rotates by the external angle, calculated as 180° Internal.
- This process repeats n times to complete the shape.

4. Auditory Feedback: Simultaneously, the audio module plays a pre-recorded message describing the shape's properties, such as the number of sides, edges, and formulas for area and perimeter.

This algorithm ensures that students receive both visual and auditory information, reinforcing learning through multiple sensory channels.

The Drawbot was designed as an interactive teaching robot that can recognize voice commands, draw geometric patterns, and give spoken explanations. Building various electronic modules, configuring the voice recognition system, and enabling seamless user-robot interaction is all part of the hardware implementation process.

The following describes the main processes involved in putting the hardware into practice.

1. Components

The first step in implementing hardware is to gather and prepare all necessary components.

The main pieces of hardware are:

The Arduino UNO microcontroller is used to regulate motor movements, control the system, and carry out commands.

Speech Recognition Module: Google Gemini API + Microphone - Captures speech commands and translates them into shape-drawing instructions.

Stepper and servo motors are two types of motors. Stepper motors govern precise movement, while servo motors manage the pen-lifting procedure.

L293D is the motor driver. Motor Driver: Provides power to the motors based on the microcontroller's signals.

2. User Input Speech Recognition

Drawbot is designed to take voice orders through a microphone, as opposed to more traditional input methods like buttons or Bluetooth commands.

The system is equipped with a microphone module that allows users to issue voice commands.

The voice input is interpreted, converted to text, and the shape of the requested geometric figure is ascertained by the Google Gemini API.

Following identification, the Arduino determines how to draw the appropriate shape using the collected data.

The Drawbot is easier to use thanks to its voice-activated interface, especially for young children and individuals with disabilities.

3. Motor Control Drawing

The Drawbot uses both servo and stepper motors to draw shapes in response to spoken user commands. Stepper motors are employed to move the CNC plotter precisely along the X and Y axes for drawing geometric shapes, with their motion controlled by the L293D motor driver. The system calculates the required angles and movements to complete each design accurately. Meanwhile, a servo motor is used to control the pen's lifting mechanism — lowering the pen onto the drawing board during sketching and raising it when moving to a new position. Through the coordinated control of both motors, the Drawbot is able to produce accurate and well-defined shapes.

4. Using Audio Feedback to Learn

After shape sketching, Drawbot provides audio description to enhance the learning process. Pre-recorded MP3 files that describe each shape's characteristics are stored and played using the DF Player Mini module. The module has a speaker connected to it, which allows the system to describe shapes in real time. When the drawing is complete, the audio file associated with the drawn shape starts playing automatically. Students may learn and retain geometric concepts more effectively thanks to this capability, which makes learning more dynamic and interesting.

5. Integration of Hardware and Software

Following assembly, the hardware components are integrated with the software system to enable smooth operation. The audio module, voice recognition system, motors, and microcontroller are all in sync. Voice commands are translated by the Arduino, which then interprets them as drawing instructions and draws shapes. The appropriate audio description of the sketched shape is activated by the DF Player Mini.

4.5 Data Analysis

Quantitative and qualitative analyses were performed:

Quiz Scores: Pre- and post-test results were compared using descriptive statistics (mean scores, percentage improvements) to determine learning gains. Where appropriate, paired-sample t-tests were applied to assess statistical significance.

Performance Metrics: The accuracy of Drawbot's drawings was measured by comparing outputs to standard templates, using digital overlay analysis to calculate mean deviations.

Engagement Indicators: Observational data and student surveys were analyzed to capture patterns of attention, excitement, and anxiety reduction during the sessions.

This methodological design enabled the study to examine both the cognitive impact (learning outcomes) and affective impact (engagement and anxiety reduction) of integrating Drawbot into early childhood geometry learning.

5. RESULTS AND DISCUSSION

5.1 Experimental Setup

The Drawbot was evaluated in a real classroom environment involving 20 primary school students aged between 6 and 9 years. The evaluation focused on three main aspects:

- System performance (drawing accuracy and audio synchronization)
- User engagement (student interest and interaction)
- Learning outcomes (improvement in shape recognition and understanding of geometric properties)

Two teachers facilitated the sessions and recorded observations using structured checklists. Each session lasted 30 minutes, during which students selected different shapes and observed the robot drawing them while listening to the corresponding audio explanations.

5.2 Shape drawing process

The procedure for drawing a triangle using G-code is mentioned as follows:

This section describes the step-by-step procedure followed to draw a triangle as shown in figure 5.1 using CNC-compatible G-code instructions. The triangle is defined by three vertices at specific Cartesian coordinates, and the G-code commands control the motion of the drawing tool to trace the shape accurately.

Step 1: Define Triangle Coordinates

The triangle is specified using the following vertex coordinates:

- Vertex A: (5, -15)
- Vertex B: (25, -25)
- Vertex C: (25, -5)

These coordinates are input into the G-code program to control the movement of the pen (or drawing tool) along the desired path.

Step 2: Initialize the Pen Position

- The pen is lifted to a Z-height of 3 mm using `G1 Z3` to prevent any contact with the drawing surface during positioning.
- The feed rate is set to 100 mm/min using `F100`, which determines the movement speed of the tool head.

Step 3: Move to Starting Point

- The pen is moved to the first vertex of the triangle (Vertex A at (5, -15)) using the command `G1 X5 Y-15`.
- Once the pen reaches the starting point, it is lowered to the drawing surface using `G1 Z0`.

Step 4: Draw Triangle Edges

The triangle is drawn by sequentially moving the pen along its edges:

1. Edge AB: Drawn from Vertex A (5, -15) to Vertex B (25, -25) using `G1 X25 Y-25`.
2. Edge BC: Drawn from Vertex B to Vertex C (25, -5) using `G1 X25 Y-5`.
3. Edge CA: Drawn from Vertex C back to Vertex A, closing the triangle, using `G1 X5 Y-15`.

Step 5: Final Steps

- After completing the triangle, the pen is lifted again to a Z-height of 3 mm using `G1 Z3` to avoid any unwanted marks.
- The tool is then returned to the home position (0, 0) using `G1 X0 Y0`.
- The pen is lowered using `G1 Z0` in preparation for subsequent operations.

This G-code-based approach ensures precise plotting of geometric shapes using CNC or plotter-based systems. The lifting and lowering of the pen, combined with accurate movement commands, help prevent unintended marks and enable clean, repeatable drawings.

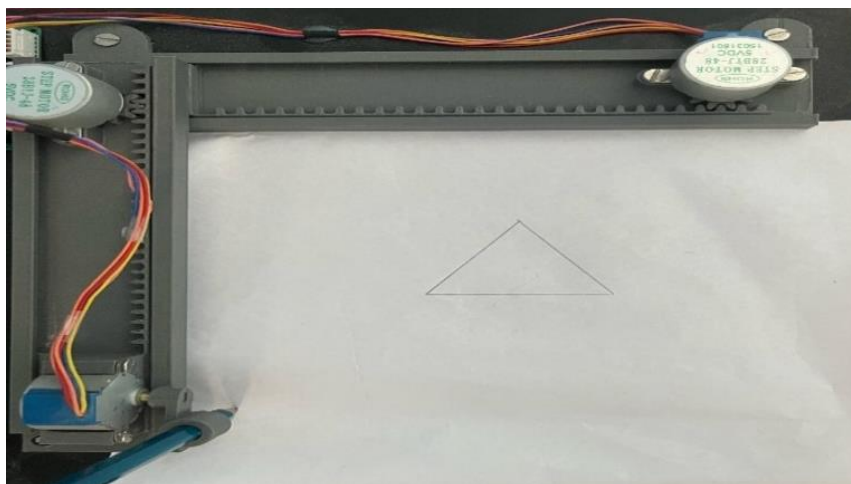


Figure 5.1 drawing a triangle using G-code

5.3 Student Engagement and Feedback

Engagement was measured using teacher observations and a simplified emoji-based survey for students. Teachers noted that:

- 90% of students remained attentive throughout the session
- 85% eagerly waited for their turn to select a shape
- 80% asked follow-up questions related to the audio explanations (e.g., "What's the formula for the area of a hexagon?")

Students expressed excitement about seeing the robot in action and associated the shapes with fun and storytelling (e.g., "The triangle looks like a mountain").

5.4 Effect of Drawbot on shape recognition

A simple pre- and post-activity quiz assessed student improvement in recognizing and understanding geometric shapes.

5.4.1 Assessment Design

Pre-Activity Quiz (Before Using Drawbot): Conducted to gauge the students' baseline understanding.

Post-Activity Quiz (After Using Drawbot): Same or similar questions are asked to measure what students learned after the session.

Each quiz is short (10–15 minutes) and includes the following types of questions as described in table 5.1.

Table 5.1 Quiz format

Question Type	Example	Format
Shape Identification	"Circle the square from these images."	Multiple Choice with Pictures
Number of Sides and Edges	"How many sides does a hexagon have?"	Multiple Choice
Area and Perimeter Understanding	"Which shape covers more space: a triangle or square?"	Conceptual
Listening Comprehension	"What did the robot say about the area of a square?"	Short Answer

5.4.2 Implementation Procedure

- Before the Activity:**
 - Brief students without introducing the robot yet.
 - Administer the **Pre-Quiz** in a fun, low-pressure way (e.g., with colourful worksheets or clicker tools).
 - During the Activity:**
 - Let students interact with the Drawbot or observe its drawing.
 - Ensure they hear the audio explanations clearly.
 - After the Activity:**
 - Administer the **Post-Quiz**, either immediately or the next day to measure retention.
 - Use the same format as the pre-quiz but shuffle questions to avoid memorization.
 - Scoring and Evaluation**
 - Score each quiz out of a total 20 points.
 - Compare average scores across the class.
- Calculate improvement using the formula:

$$\text{Improvement} = \frac{\text{Post-test score} - \text{Pre-test score}}{\text{Pre-test score}} \times 100\%$$

Table 5.2 Learning Improvement (n=20)

Metric	Pre-Test (%)	Post-Test (%)	Improvement (%)
Shape Recognition Accuracy	68	91	+23
Correct Identification of Sides/Edges	60	89	+29
Understanding of Area/Perimeter	42	77	+35

Results in table 5.2 showed significant improvement across all metrics, with the largest gains in understanding area and perimeter concepts that are typically abstract and hard to grasp at a young age. Pre- and post-test scores demonstrated a significant improvement in children's ability to identify and describe geometric shapes. The mean recognition score increased from 55% (SD = 12.4) in the pre-test to 88% (SD = 8.7) in the post-test. A paired-sample t-test confirmed that the gain was statistically significant ($t(19) = 7.36$, $p < .001$). The largest improvements were observed in recognition of polygons with more than four sides (pentagon, hexagon, octagon), which were initially poorly identified in the pre-test. Figure 5.2 shows the improvement in overall test scores before and after the intervention.

Fig 5.1: Average pre- and post-test scores of students (N = 20)

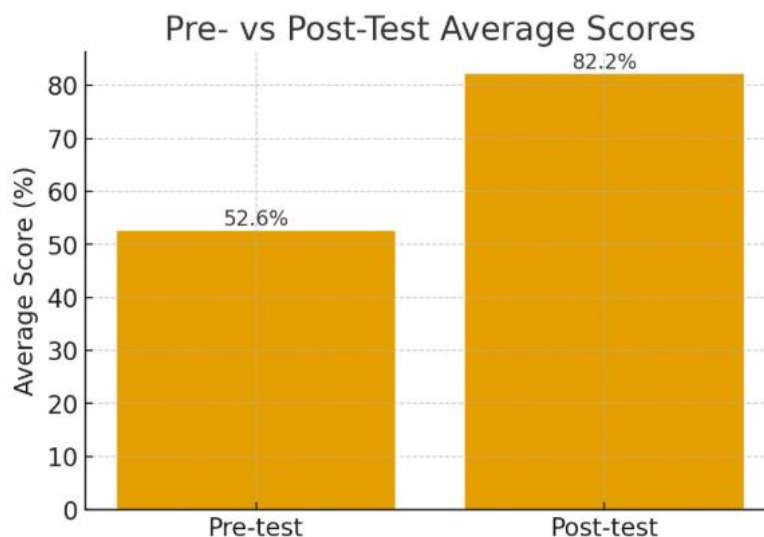


Figure 5.2 Average pre- and post-test scores of students (N = 20)

5.4.3 Understanding of sides, edges, and formulas

Students demonstrated notable gains in conceptual understanding of sides, edges, and perimeter/area formulas. On average, the accuracy of responses to formula-related questions increased by 35%, with the mean post-test score rising from 42% to 77%. The greatest improvement was observed in identifying the correct formula for the perimeter of polygons, while a smaller but still significant improvement occurred in understanding area calculations. These findings suggest that the combination of visual drawing and synchronous auditory explanation facilitated deeper comprehension of abstract mathematical concepts. Figure 5.3 presents a breakdown of learning gains across three key domains: shape recognition, sides and edges, and formula application.

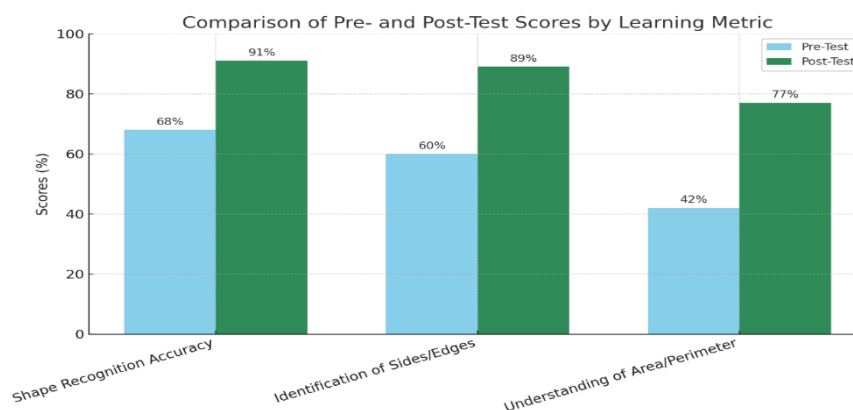


Figure 5.3 Comparison of Pre and post test scores

5.5 Performance Evaluation

The accuracy of shape drawing was assessed by comparing the robot's output to pre-printed geometric templates using digital image overlay analysis.

Table 5.3 Shape Drawing Accuracy

Shape	Number of Sides	Mean Deviation (mm)	Accuracy (%)
Triangle	3	1.5	97.2
Square	4	1.8	96.8
Pentagon	5	2.2	95.6
Hexagon	6	2.4	95.0
Octagon	8	3.1	93.5

The robot achieved over 95% accuracy across all tested shapes as shown in Table 5.3. Slight deviations increased with shapes having more sides, likely due to cumulative motor error and friction on the drawing surface. The audio module demonstrated reliable synchronization, with 98% of the audio clips playing at the correct stage during the drawing process.

The results validate the effectiveness of Drawbot in early geometry education. By combining drawing with synchronized auditory feedback, the robot supported multimodal learning, leading to better engagement and retention. The autonomous and repeatable nature of the robot also made it easy for teachers to integrate the tool into regular lessons without the need for extensive training or setup. Moreover, the Drawbot reduced math anxiety in students who traditionally struggled with geometry. The tangible representation of shapes, combined with playful narration, helped transform abstract formulas into relatable visual content.

6. CONCLUSION

This paper introduced **Drawbot**, an interactive educational robot designed to improve early childhood learning of geometric concepts through a multimodal teaching approach. The system integrates a motorized drawing mechanism with synchronized audio feedback to make abstract geometry concepts more tangible and engaging for young learners. In addition to the **quantitative improvements** observed in shape recognition, edge identification, and understanding of area and perimeter, **qualitative feedback** from students and educators provided valuable insights into the system's impact:

- **Student Engagement:** Learners demonstrated heightened interest and enthusiasm during sessions with Drawbot. The physical drawing action paired with real-time narration captured attention more effectively than traditional static images or verbal instruction alone.

- **Comprehension through Observation:** Teachers reported that students were better able to visually associate geometric terms (like "sides" and "edges") with their actual representations, leading to more accurate and confident responses during discussions.
- **Reduced Math Anxiety:** The playful, interactive nature of the robot fostered a stress-free learning environment, particularly benefiting students who typically showed hesitance toward mathematical tasks.
- **Improved Retention:** Anecdotal evidence suggests that students retained shape properties and related formulas more effectively when they experienced the content through both visual and auditory modalities.

Overall, Drawbot proved to be not only an effective educational tool in improving test scores, but also a valuable asset in building student confidence, curiosity, and enjoyment in learning geometry. These qualitative outcomes support the robot's potential to become a powerful aid in early mathematics education, especially in diverse and inclusive classroom settings.

Future improvements for the educational robot could include proximity sensors for responsiveness, activating when kids approach or providing visual feedback. Machine learning algorithms may allow it to adapt lessons based on a child's pace and answer questions dynamically. Enhancements like a colour-changing pen and additional drawing tools could help develop artistic and geometric skills. Advanced software updates could introduce interactive storytelling and deeper mathematical concepts. A wireless version, controlled via a tablet or mobile app, would offer greater flexibility for educators and parents. Cloud connectivity could track learning progress, helping teachers and parents identify areas for improvement.

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