Outlook

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Para ANA CAROLINE DE OLIVEIRA BASTOS <ana.bastos@aluno.cefet-rj.br>
Cc RAFAELLI DE CARVALHO COUTINHO <rafaelli.coutinho@cefet-rj.br>; AMARO AZEVEDO DE LIMA <amaro.lima@cefet-rj.br>; GABRIEL MATOS ARAUJO <gabriel.araujo@cefet-rj.br>; MILENA FARIA PINTO <milena.pinto@cefet-rj.br>; FABRICIO LOPES E SILVA <fabricio.silva@cefet-rj.br>

Dear Ana Bastos:

Congratulations - your paper "A Low-Cost Social Robot for Gesture-Based Educational Activities and Human-Robot Interaction in Learning Environments" for WRE 2025 has been accepted.

The reviews are below or can be found at
https://nam10.safelinks.protection.outlook.com/?url=https%3A%2F%2Fjems.sbc.org.br%2FPaperShow.cgi%3Fm%3D248063&data=05%7C02%7Cgabriel.araujo%40cefet-rj.br%7C2f14111967d84d06b62408dddb98f693%7C8eeca404a47d4555a2d40f3619041c9c%7C0%7C0%7C638908172243550912%7CUnknown%7CTWFpbGZsb3d8eyJFbXB0eU1hcGkiOnRydWUsIlYiOiIwLjAuMDAwMCIsIlAiOiJXaW4zMiIsIkFOIjoiTWFpbCIsIldUIjoyfQ%3D%3D%7C0%7C%7C%7C&sdata=pFMoYQQfKQQrVC8MB6h1ZmlhcoRBqo59z1CxeaLgOTc%3D&reserved=0

Regards,
Conference Chairs

===== Review =====

*** Technical excelence (): 1: very poor 2: bellow average 3: average 4: good 5: excellent

Evaluation=good (4)

*** Readability, clarity, and organization (.): 1: very poor 2: bellow average 3: average 4: good 5: excellent

Evaluation=excellent (5)

*** General evaluation (.): 1: reject 2: weak reject 3: weak accept 4: accept

Evaluation=accept (4)

*** Additional comments for the author(s) (Please, provide the authors with detailed information regarding your decision on his/her paper): O artigo mostra a avaliação de um robô social de baixo custo que utiliza reconhecimento de gestos para interagir com as pessoas. O projeto foi realizado no âmbito do projeto "Meninas na Robótica" e é construído com um corpo de PVC, servomotores controlados por um Arduino para realizar gestos de "sim", "não" e "aceno", e um computador com câmera para fazer o reconhecimento de gestos. A validação foi feita de forma online e presencial, no qual foram avaliados 9 quesitos relacionados à interação e empatia, tendo médias acima de 3,5 em uma escala de likert de 1 a 5.

Pros - O artigo está bem escrito, claro e tecnicamente bom; - O reconhecimento de gestos e a interatividade com movimentos mostra a preocupação seu potencial de utilização na educação; - O desenvolvimento pelo grupo de Meninas na Robótica é uma política de ação afirmativa importante e necessária;

Contras - Apesar de utilizar materiais de baixo custo no corpo, o robô ainda necessita de um computador. Seria interessante testar seu desempenho com CPUs mais baratos como ESP ou Raspberry; - O pseudocódigo é grande, mas traz pouco conteúdo, poderia ser reduzido; - Senti falta de uma seção de trabalhos relacionados, mostrando outras iniciativas semelhantes; - Faltou caracterizar melhor a população usada para teste (idade, conhecimento em robótica, ...)

Por fim, parabenizo a equipe pelo bom trabalho realizado.

===== Review =====

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Evaluation=excellent (5)

*** Readability, clarity, and organization (.): 1: very poor 2: bellow average 3: average 4: good 5: excellent

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A Low-Cost Social Robot for Gesture-Based Educational Activities and Human-Robot Interaction in Learning Environments

Ana Caroline de O. Bastos[1]; Milena F. Pinto[1], Rafaelli C. Coutinho[1], Fabricio L. Silva[1], Amaro A. de Lima[1], Gabriel M. Araujo[1]

[1] *Federal Center for Technological Education Celso Suckow da Fonseca - CEFET-RJ, Rio de Janeiro, RJ, Brazil. corresponding author: ana.bastos@aluno.cefet-rj.br*

***Abstract*—This work presents the design and implementation of a low-cost social robot intended for use in educational environments. The robot is constructed using affordable materials such as cardboard and PVC, and uses Arduino-compatible components for actuation and control. It is capable of recognizing and mimicking basic human gestures, such as waving, nodding, and head-shaking, through computer vision techniques using MediaPipe and OpenCV. The system architecture combines gesture recognition, real-time communication, and servomotor actuation to simulate socially meaningful interactions. Beyond its technical capabilities, the robot aims to enhance classroom engagement, support socio-emotional learning, and promote hands-on experiences in robotics and programming. The platform is designed for replicability and accessibility, making it particularly suited for public schools and STEM education initiatives.**

Social Robot; Project-Based Learning; Gesture Recognition; STEM

I. Introduction

In recent years, robotic platforms have gained significant traction in educational settings, particularly within engineering disciplines, due to their capacity to promote active learning, bridge theoretical knowledge with real-world applications, and support the development of essential technical skills [1], [2]. Robotics not only enables students to engage in hands-on activities but also allows them to explore complex domains such as algebra, probability, statistics, calculus, discrete mathematics, programming, and artificial intelligence through interactive and practical scenarios [3]. These subjects form the backbone of STEM (Science, Technology, Engineering, and Mathematics) education initiatives [4], [5], where the emphasis lies on cultivating problem-solving abilities, creativity, innovation, and collaborative skills—areas where robotic kits can offer substantial educational value.

Robotics-based educational platforms have stood out in engineering courses for facilitating students' immersion in practical experiences from the early stages of training. However, the introduction of robots in technical disciplines can present obstacles, especially for students who are not yet familiar with automation principles, sensors, actuators, and control systems [6], [7], [8], [9]. To overcome these barriers, an effective pedagogical strategy has been the adoption of project-based methodologies, in which students are challenged to assemble and program robots, integrating hardware and software knowledge in a contextualized manner.

Such project-based approaches encourage students to experiment with sensor-actuator interactions, analyze system responses, and gradually construct a foundational understanding of embedded systems. Over time, this foundation supports the implementation of more advanced control algorithms, enabling students to develop and test autonomous behaviors in real or simulated environments—an approach reflected in the outcomes of recent institutional research projects [8].

Furthermore, while robotics is recognized for its educational benefits, recent trends emphasize the need for these tools to go beyond functional and technical roles. There is a growing demand for robotic systems to embody social presence, providing learners with more personalized, empathetic, and engaging experiences [10]. As a result, educational robots are increasingly expected to perceive and respond to students' emotional and communicative cues, enabling richer interactions that align with human-centered pedagogical goals. This evolution in expectations has led to the emergence of socially assistive and emotionally intelligent robots, designed not only to instruct but also to motivate and adapt to diverse learner profiles [11], [12].

In recent years, several studies have investigated how educational and social robotics can be leveraged to enrich classroom experiences and support student development [13], [14], [15], [16]. These studies highlighted the potential of robots that extend beyond instructional tasks to engage with learners in emotionally aware and socially interactive ways. Embedding such responsive behaviors into educational robots has proven to be a promising strategy for assisting students with academic understanding, as well as developing their interpersonal skills and emotional well-being.

It is within this evolving landscape that the "Meninas na Robótica" outreach project at CEFET/RJ [17] identified a critical need for a tangible and engaging representation to deepen the emotional connection with its target audience – young students, especially girls, in public schools in the Baixada Fluminense region.

The “Meninas na Robótica” initiative is a gender-focused educational outreach program. It seeks to empower girls and young women and inspire their interest in science, technology, engineering, and mathematics (STEM). By providing an emotionally engaging and inclusive experience, the real robot of its mascot serves as a symbolic and practical tool for reducing gender gaps in technological education. The design choice directly reflects the project’s foundational objective to create an approachable and engaging figure that fosters an emotional connection with young students, making complex technological concepts less intimidating. Its friendly appearance and interactive capabilities are specifically tailored to serve as a tangible symbol of the initiative, significantly enhancing student engagement during school presentations, workshops, and general outreach activities.

A. Main Contributions

The social robot developed in this work is conceived not only as a playful and interactive educational tool for classroom environments, but also as an agent of social transformation. By fostering engagement through affective and socially-oriented interaction, the robot supports both formal educational practices and outreach activities linked to gender inclusion initiatives. Its construction prioritizes accessibility and affordability, utilizing low-cost materials such as cardboard for the chassis and Arduino-based electronics, which are widely supported and easy to program. The robot integrates Arduino-compatible sensors and actuators, enabling simple interactions such as gestures, movements, and light or sound responses, making it ideal for introductory educational activities in robotics and programming. It is essential to note that by simulating basic social behaviors, the platform facilitates the development of socio-emotional competencies, collaborative work, and problem-solving skills. The contributions of this work are summarized as follows:

- A low-cost, modular social robot platform using cardboard and Arduino. This educational system supports the teaching of robotics and programming logic at both early and intermediate levels.
- Facilitation of socio-emotional learning through simulated social interactions, and engagement of students in hands-on, project-based activities using accessible and replicable materials.
- Promotion of inclusive technological education by integrating playful, affective robotics into initiatives aimed at promoting equity and diversity in STEM learning environments.
- A key element of the “Meninas na Robótica” project, serving as an icebreaker and immediate point of fascination during presentations and events held in public schools.

B. Organization

The remainder of this paper is organized as follows. Section II describes the proposed robotic platform, detailing its architecture, components, and operational logic. Section III discusses the educational relevance of the robot and its potential for use in project-based learning environments. Section IV presents the preliminary results and discusses their implications in terms of student engagement and technical performance. Finally, Section V concludes the work and gives the future directions of the proposed robot.

II. Developed Platform

The robot developed in this project was designed to imitate simple human gestures using a low-cost, modular structure inspired by the mascot of the “Meninas na Robótica” project. Its primary goal is to simulate basic interactions such as nodding (“yes”), shaking the head (“no”), and waving, all triggered by real-time gesture recognition through computer vision using MediaPipe and OpenCV. Figure 1 presents the developed robot. Note that the physical body is constructed using cardboard and PVC, emphasizing affordability and accessibility in educational environments. The robot’s joints and parts were designed in SolidWorks, allowing for digital prototyping and future 3D printing.

Fig. 1: Physical prototype of the social robot constructed with cardboard and PVC.

The robot is divided into three primary subsystems:

- Visual Recognition Subsystem: Responsible for detecting human gestures via webcam, processed by MediaPipe and OpenCV.

- Motion Execution Subsystem: Receives commands and controls servomotors to reproduce head and arm gestures.
- Control and Communication Layer: Arduino-based control handling real-time actuation and data reception via serial communication.

Table I presents a summary of the main components employed in the project, including their roles within the system. The focus on affordable and widely available materials reinforces the project's commitment to providing a replicable solution suitable for educational contexts.

TABLE I: Component Table.

Component	Description
Webcam (USB)	Captures real-time video feed
Computer with Python	Runs MediaPipe and OpenCV algorithms
Arduino Uno	Microcontroller for motor actuation
SG90 Servomotors	Actuate head and arms
Cardboard and PVC tubes	Used for chassis and structural parts
5V Power Supply	Powers the Arduino and servos
SolidWorks (CAD software)	3D modeling of robot body and joints

Algorithm 1 presents a high-level pseudocode that describes the interaction between the computer vision module and the Arduino-based actuation system. This algorithm helps to understand the internal logic of the robot's operation. The algorithm begins by initializing the required resources for video capture, gesture recognition, and serial communication. In a continuous loop, the system processes video frames in real-time to detect gestures such as waving, nodding, or head-shaking. Once a gesture is recognized, the corresponding command is transmitted to the Arduino, which then actuates the servomotors to reproduce the gesture physically.

Algorithm 1: Gesture-based Social Robot.

```
Data: Live video from webcam
Result: Robot executes corresponding gesture
Initialize camera;
Initialize MediaPipe pose/hand detection;
Initialize serial connection to Arduino;
while True do
    Capture frame from camera;
    Process frame using MediaPipe;
    if gesture recognized then
        if gesture == "wave" then
            Send command "WAVE" to Arduino;
        else
            if gesture == "nod" then
                Send command "NOD" to Arduino;
            else
                if gesture == "shake" then
                    Send command "SHAKE" to
                      Arduino;
                end
            end
        end
    end
    else
        Continue monitoring;
    end
    Wait short delay;
end
Arduino Side:
Receive command via serial;
if command == "WAVE" then
    Move right arm servo up/down;
end
if command == "NOD" then
    Move head servo forward/backward;
end
if command == "SHAKE" then
    Move head servo left/right;
end
```

III. Educational Relevance

One of the distinguishing features of this robot is its ability to simulate social behaviors, which can assist the development of socio-emotional skills, such as empathy, communication, and collaboration. This aligns with contemporary trends in education that emphasize not only technical literacy but also emotional intelligence and interpersonal competencies. In classroom settings, the robot can be integrated into multidisciplinary projects and adapted to various educational levels. Table II summarizes how the platform supports learning objectives at different stages of education.

In addition to its technical contributions, the robot can help demystify technology and encourage inclusion in STEM fields. By promoting gender diversity and accessibility, the platform contributes to broader educational and social goals, including the United Nations Sustainable Development Goals (SDGs) related to quality education and reduced inequalities. For more information about SDGs, the authors refer to [18]. Table III provides an overview of the core competencies developed through interaction with the robot in educational contexts.

IV. Results and Discussion

This section presents the preliminary results obtained from the implementation and evaluation of the proposed social robot platform. The focus is on evaluating the effectiveness of the gesture recognition system and the robot's ability to respond appropriately to user input in real-time. To this end, a series of tests were conducted to measure the accuracy of gesture detection using the MediaPipe and OpenCV libraries, as well as the responsiveness of the system in executing corresponding physical gestures. Additionally, visual feedback from the MediaPipe framework is analyzed to illustrate the landmark detection process and support future improvements in user-robot interaction.

Figure 2 illustrates the application of the MediaPipe library for real-time pose and face landmark detection, which serves as the basis for gesture and orientation analysis in the proposed robotic system.

In red, we highlight the body landmarks detected by the *MediaPipe Pose* module, which are used to calculate the angles of the arms and head. These angular measurements allow the

TABLE II: Adaptability of the Robot Platform Across Educational Levels.

Educational Level	**Learning Objectives and Applications**
Primary / Middle School	Introduction to robotics through block-based programming and interaction with pre-defined gestures. Emphasis on logic, teamwork, and creativity using visual coding platforms.
High School	Exploration of basic electronics, programming in Arduino (C++), and understanding of sensors and actuators. Encourages problem-solving through guided robot modifications and interaction experiments.
Undergraduate	Integration of embedded systems, control algorithms, computer vision, and human-robot interaction. Enables interdisciplinary projects involving gesture recognition, motor control, and communication protocols.

TABLE III: Competencies Developed Through the Robot-Based Learning Activities.

Competency Area	**Skills Developed**
Technical	Programming (C/C++), electronics, motor control, and computer vision.
Cognitive	Problem-solving, logical reasoning, creativity, and d ebugging strategies.
Socio-Emotional	Collaboration, communication, empathy, and engagement through social interaction with the robot.
Pedagogical	Active learning, interdisciplinary integration.

system to infer directional cues, such as whether the user is facing the robot or which quadrant of the field of view they are in, so the robot can adjust its "gaze" accordingly.

The blue dot at the center of the image denotes the image midpoint, serving as a spatial reference to compute head orientation relative to the camera.

Additionally, white points represent the eye landmarks (iris centers), captured using *MediaPipe Face Mesh*. These points are being used in preliminary tests to estimate the user's distance from the camera, enabling potential future adjustments in interaction based on proximity.

In order to evaluate the acceptance, receptivity and general impressions of potential users of the robot, a questionnaire was designed and provided to subjects considering two scenarios, in-person and on-line answers. Table IV presents the statements associated to theirs numbers to be graded by the test subjects. The on-line participants watched a video on-line presenting the functionalities and showing the design details of the robot. The in-person participants were able to watch a live presentation with the same content as the video, but with the advantage of having the opportunity to interact with the robot. In total were 105 subjects, where 60 assessed in-person

Fig. 2: Visualization of pose and face landmarks used for gesture and distance estimation. Red points represent pose landmarks, while white points denote irises, and the blue dot indicates the image center.

TABLE IV: Questionnaire to assess the subjects's perception of the robot's appearance and functionality. The grade varies discretely from 1 to 5, where 1 means totally disagree and 5 totally agree.

Number	**Statement**
1	The gestures made by the robot were easy to understand.
2	The robot's movements were smooth and natural.
3	It was easy to recognize the "yes" and "no" gestures made by the robot.
4	Interacting with the robot was a pleasant experience.
5	The robot seemed to respond appropriately to my gestures.
6	I would like to interact with this robot again.
7	The robot's design was friendly and inviting.
8	The robot's appearance is suitable for its educational purpose.
9	The robot seems to be made of accessible materials.

and 45 on-line as it is detailed in Figure 3.

Figure 4 shows a big picture of the mean questionnaire results over the subjects, i.e., the mean score of the 9 statements were calculated for each participant and presented in ascending order. It is worth noticing that the lowest mean score and its standard deviation were 3.22±0.83, while the

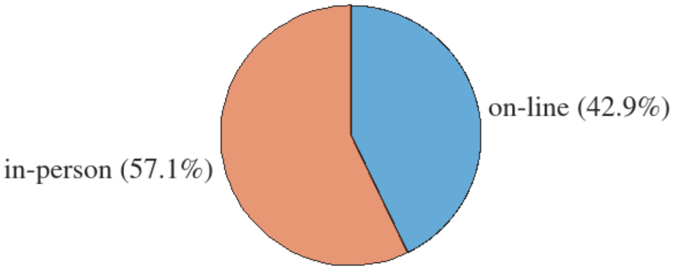

Fig. 3: Pie chart comparing the subjects that rated the questionnaire in-person and on-line.

highest were 5.00±0.00. It can be concluded that the overall perceived impression is closer to grade 5 than 1, which reflects the statistics of less than 6% of the subjects obtained mean score lower than 4.00, about 32% reached between 4.00 and 4.50, and 62%, approximately, hit over than 4.50.

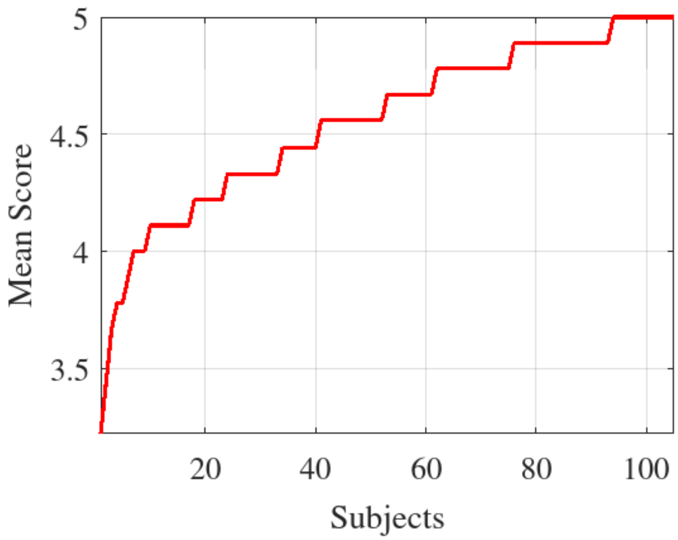

Fig. 4: The mean score over the 9 statements for each subject.

Figures 5 and 6 present the mean score over each of the 9 statements over the subjects, separated by their response method origins, in-person or on-line, respectively. The in-person situation achieved mean scores and standard deviations of 4.50±0.60, 3.62±0.85, 4.40±0.94, 4.75±0.63, 4.03±0.86, 4.65±0.68, 4.65±0.82, 4.60±0.64, and 4.70±0.56, respectively for the 9 statements, while the group that answered on-line got 4.87±0.34, 4.07±0.75, 4.93±0.33, 4.64±0.53, 4.42±0.75, 4.98±0.15, 4.89±0.32, 4.84±0.37, and 4.76±0.57, also respectively for the 9 statements. Although it seems to have a certain positively grade bias for the on-line scenario, i.e., numerically most of the mean scores are higher than the in-person scenario, statistically the mean scores are equivalent for both groups, since their standard deviations provide enough uncertainty to conclude that both groups achieve the same performance for each statement.

It can be seen that the profile, the trend of both Figures 5 and 6 are similar, reaching 85% of Pearson's correlation and

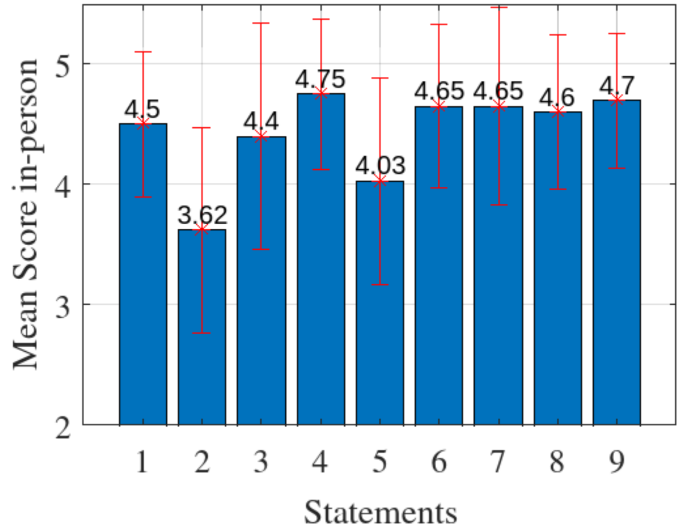

Fig. 5: The mean score and its standard deviation over the 60 subjects that rated the questionnaire **in-person**.

showing the lowest scores for statements 2 and 5. Therefore, there is no reason to compute the groups separately, and a combination of overall performance is preferable.

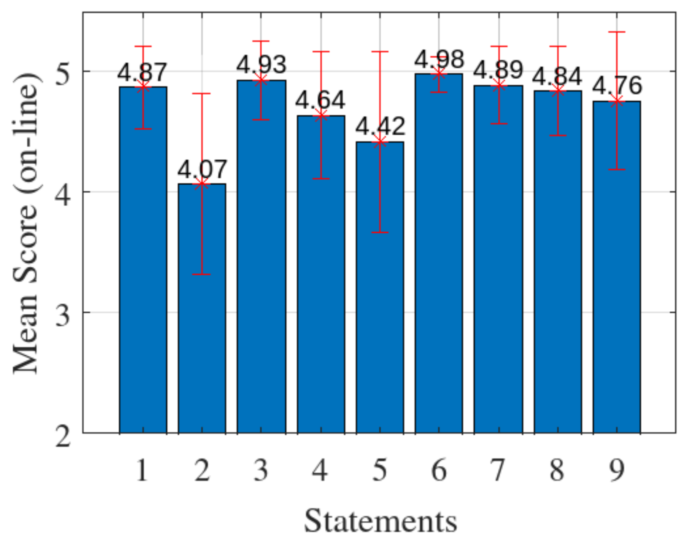

Fig. 6: The mean score and its standard deviation over the 45 subjects that rated the questionnaire **on-line**.

The performance combining all subjects as a whole into a single group is shown in Figure 7, where the mean scores and standard deviations for 105 subjects are calculated generating the numerical performance of 4. 66±0.53, 3.81±0.83, 4.63±0.79, 4.70±0.59, 4.20±0.84, 4.79±0.55, 4.75±0.66, 4.70±0.55 and 4.72±0.56, respectively, for the 9 statements.

The overall performance confirmed the lower scores of statements 2 and 5, which are "The robot's movements were smooth and natural", and "The robot seemed to respond appropriately to my gestures", respectively. This draws attention to the control subsystem, where improvements could be studied to provide a better dialog between the electronic and

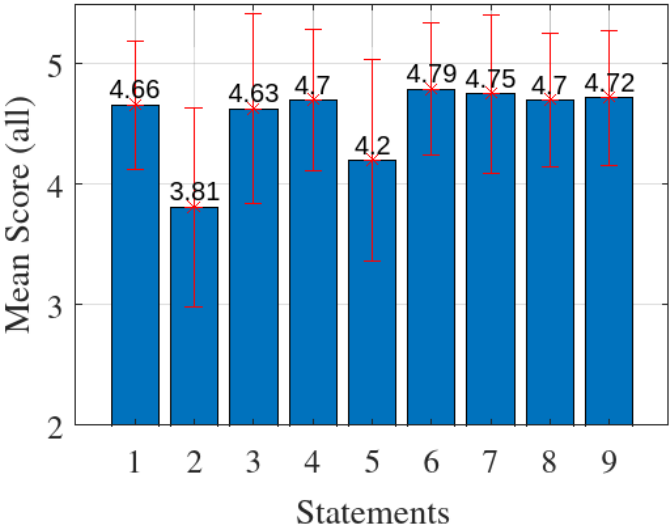

Fig. 7: The mean score and its standard deviation over **all** 105 subjects that rated the questionnaire.

mechanical parts with the aim of emulating a more natural movement. In addition, the recognition and tracking of body parts could also be improved, perhaps with the addition of depth sensors, to improve the user experience and increase the robot's average score, which could positively affect the robot's application in educational scenarios.

V. Conclusion and Future Work

This paper presented the development of a low-cost social robot designed to support gesture-based interaction in educational environments. The proposed platform integrates computer vision techniques with simple electromechanical systems to recognize and reproduce human gestures, providing an engaging and interactive tool for learning. Its construction, based on accessible materials such as cardboard, PVC, and Arduino-compatible components, reinforces its suitability for use in public schools and other contexts where resources may be limited.

Several future works are intended in this project. The current system is restricted to recognizing a small set of predefined gestures and is sensitive to variations in lighting and camera positioning. Besides, the cardboard-based structure, while effective for prototyping, may limit long-term durability in frequent classroom use. In this sense, future works are intended to replace the current cardboard-based chassis with more resilient materials, such as foam board or recycled plastic, without compromising the platform's low cost and replicability. From an educational perspective, future iterations should explore the robot's scalability and adaptability across different classroom settings, evaluating its effectiveness with larger groups of students from varied backgrounds.

VI. Acknowledgements

The authors would like to thank the following Brazilian Agencies FAPERJ and CNPq. The authors also want to thank CEFET/RJ for supporting this research. This work was carried out with the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

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