Robot design and inclusive practices: a pilot study on gender equity in STEM

Laura Cesaro[1[0009-0007-5961-3169]] and Emanuele Menegatti[1[0000-0001-5794-9979]]

[1] Dipartimento di Ingegneria dell'Informazione
Università degli Studi di Padova, 35131 Padova, Italy
laura.cesaro@phd.unipd.it
emanuele.menegatti@unipd.it

Abstract. Despite growing efforts to promote gender equity in STEM education, girls remain underrepresented in computer science and robotics. This pilot study explores how robot design and inclusive classroom practices can influence engagement and perception among young students, with a specific focus on gender-related dynamics. The intervention integrated hands-on robotics activities into the regular curriculum and encouraged collaborative learning through inclusive pedagogical strategies. This approach made it possible to involve a broader group of learners, enabling the participation of students — particularly girls — who might not otherwise engage in extracurricular STEM opportunities. Data from surveys and observations suggest that robot appearance plays a role in shaping students' preferences, with designs incorporating human-like or biomimetic features demonstrating broader cross-gender appeal, particularly among female students. Moreover, the activities positively influenced students' enjoyment, perceived accessibility, and attitudes toward robotics. These findings highlight the importance of inclusive design and pedagogy in fostering equitable and engaging STEM learning environments.

Keywords: Educational Robotics, Gender equity, Robot design.

1 Introduction

Gender disparities in STEM participation remain a persistent issue globally, and girls remain underrepresented in fields like robotics and computer science [1, 2]. To address these gaps, inclusive and early exposure to hands-on STEM activities—aligned with the constructionist framework and Universal Design for Learning (UDL) principles—emerges as a promising pathway. In fact, constructionism emphasizes learning through the active creation of tangible artifacts, fostering deeper conceptual understanding through building and making [3], while UDL advocates for flexible educational practices that offer multiple means of engagement, representation, and expression, making learning accessible and motivating for all students [4].

In this context, educational robotics offers opportunities to engage all learners in creative, hands-on STEM experiences. However, the field itself has historically

reflected a male-dominated culture, not only in its workforce but also in the design and framing of educational tools and activities.

This gender imbalance in design and pedagogy may have influenced—and may still be influencing—girls' decisions to pursue studies in STEM fields in general, and ICT in particular, often due to a combination of sociocultural factors, including stereotypes about gender and technical ability, and limited exposure to hands-on STEM activities [5]. Robots and robotics programs are often developed within narratives—such as cars, space missions, or rescue scenarios—that tend to reflect the interests and imaginarium of young males. As a result, girls may feel less represented, less confident, and less inclined to participate.

Previous studies have also examined how educational robots are selected, considering aspects such as physical characteristics, hardware functionality, software systems, programming difficulty, and construction requirements (e.g., kit-based, pre-built, or ready-to-use) [6, 7]. However, the impact of these design characteristics on perception and engagement remains underexplored, especially regarding the different appeal that this can have in girls—whose preferences may not align with conventional robot designs [8].

Users often (more or less unconsciously) attribute gendered characteristics to robots [9, 10], and these perceptions—shaped by societal stereotypes—significantly influence interactions and preferences. For this reason, inclusive robot design should be increasingly recognized as a critical factor in promoting equity in human-robot interaction [11,12]. Studying how design elements can reinforce or challenge gender stereotypes is essential to avoid unintentionally alienating certain groups of students.

Robots can be perceived and accepted differently by males and females, and a deeper understanding of how different students relate to different robot aesthetics and interaction styles could be informative for designing more inclusive and equitable learning environments and educational tools, as many education legislation and policies guidance recommend [13, 14, 15].

To contribute to this area of research, we conducted a pilot study intending to explore how robot design might influence engagement and perceptions in young students. The study focused on three key research questions:

1. **Do students show gender-based preferences** when choosing between educational robots with different visual and morphological features (e.g., anthropomorphic vs. mechanical design)?
2. **Are certain types of robot aesthetics more appealing to one gender**, or do some designs have a more universal appeal across genders?
3. **Can participation in gender-inclusive robotics activities shift students' perceptions and attitudes** toward robotics and STEM in general?

These questions guided a structured investigation into students' initial preferences, their affective responses to various robot designs, and their overall evaluation of the classroom activities. By examining these interconnected dimensions, the study aims to provide insights into how inclusive design and pedagogy in educational robotics can support gender equity in STEM learning environments.

To address the research questions, the study was structured around three interconnected components:

1. an observation of students' initial preferences when offered a choice between robots with different designs;
2. a survey-based evaluation of students' interest in a range of robot aesthetics beyond the ones used in class; and
3. a reflection on their overall experience with the robotics activities, including changes in expectations and perceived engagement.

Together, these components provide a multifaceted perspective on how robot morphology and inclusive pedagogical strategies can shape engagement in STEM learning, particularly among girls.

2 Methodology

The study involved 86 students (45% female), aged 10 to 11, attending four fifth-grade classes in two public primary schools located in Padova, Italy. All activities were carried out during regular school hours and integrated into the standard curriculum over one week, with each class participating in daily two-hour sessions (10 hours total).

Students were first organized into same-gender pairs, following team-building exercises designed to foster trust and cooperation. The learning sequence began with an introductory session on the basic structure and functioning of a robot, covering core components such as processors, sensors, and actuators. This introduction was supported by hands-on activities using LEGO Spike Prime kits, where students built and programmed mobile robots in classroom-based tasks. These activities were contextualized in everyday scenarios to increase relevance and emotional engagement. They were designed to support the progressive acquisition of knowledge—from simple movements to sensor-driven behaviours.

A quantitative research design was adopted to investigate students' preferences, experiences, and perceptions. Data were collected through:

- structured surveys, including Likert-scale items and closed-ended questions;
- direct observations of student choices and interactions during the activities.

The instruments aimed to capture three main aspects: (1) robot design preferences, (2) engagement with different robot aesthetics, and (3) the overall perception of the learning experience, including any changes in students' attitudes toward robotics and STEM.

Collected data were analyzed using descriptive statistics and chi-square tests to examine potential associations between gender and engagement or design preference.

The study received approval from the Ethics Committee of the University of Padova, and written informed consent was obtained from all participating families.

3 Robot Choice

In the first phase of the study, we investigated students' preferences regarding the design of the robots they would build and program. Working in same-gender pairs, students were presented with two LEGO Spike Prime models. The first robot, named "Starter Bot" (Figure 1), featured visual elements resembling eyes and a head, giving it a more human-like or animal-like appearance. The second, called "MTA Bot" (Figure 2), had a simpler, more mechanical look, similar to a wheeled vehicle. Both robots were mobile and offered structural components for customization and programming.

***Figure 1**: Starter Bot*

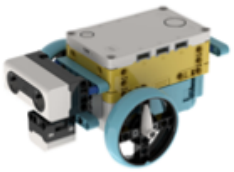

***Figure 2**: MTA-Bot*

Each pair was asked to select one of the two robots to work with. Their preferences were recorded and analysed to identify possible gender-based patterns (Figure 3).

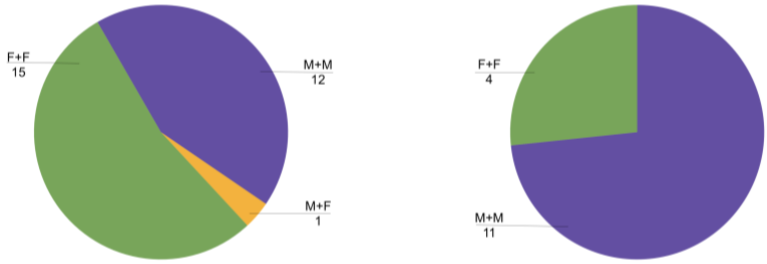

***Figure 3**: Distribution of preferences by pairs*

A chi-square test revealed a statistically significant association between gender and robot selection ($p = 0.02034$). Female pairs tended to prefer the Starter Bot, while male pairs more frequently selected the MTA Bot. The anthropomorphic design of the Starter Bot was also chosen by several male pairs and by one mixed-gender pair—the latter formed in the class with an uneven gender distribution. This may indicate that the anthropomorphic design is more inclusive, or that it facilitated agreement in cases of divergent preferences, due to a broader appeal across genders.

These initial findings highlight a connection between robot morphology and perceived affinity, particularly among girls. Such results may inform the design of more inclusive educational robots by acknowledging the importance of aesthetic and

symbolic elements in supporting engagement and help to inform future educational initiatives aimed at gender inclusivity.

4 Robot Design

To further investigate how robot appearance influences engagement, we conducted a follow-up survey with the same group of fifth-grade students. The aim was to explore students' aesthetic preferences for educational robots beyond the LEGO Spike Prime kits used in class.

After completing the hands-on activities where students learned the fundamentals of robotics and programming, all students were invited to complete a questionnaire. The survey presented five different educational robots, each with distinct external features and morphological categories (Figure 4) and asked students to evaluate their willingness and enthusiasm for having the opportunity to program each of the robots.

Figure 4: Robots presented to students

The five robots were carefully selected to represent a range of design types commonly found in educational settings: humanoid, animaloid, drone, car, and rover. Each robot was also chosen based on its suitability for children aged 10–14 and its ability to be programmed using a block-based environment rather than textual coding.

For each robot, students were asked two questions:

1. "**Would you like to program this robot?**" (Response options Yes/No)
2. "**If yes, how much would you enjoy programming this robot?**" (5-point Likert scale from 1 "Not at all" to 5 "Very much")
3.

This approach allowed us to assess both initial interest and enthusiasm linked to robot appearance, and whether these preferences showed any gender-specific patterns. It is worth noting the students had no prior access to or interaction with the robots; each robot was presented through a single image, shown one after another in the questionnaire. The distribution of preferences for each robot is illustrated in Figure 5.

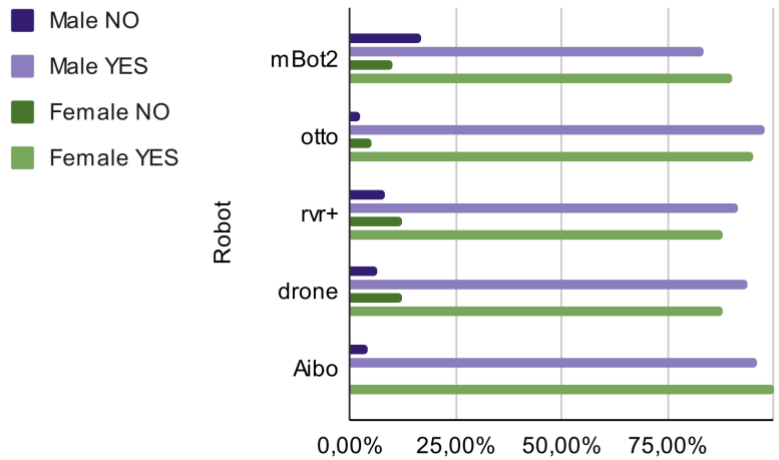

***Figure 5**: Robot preferences given by students*

Among the five presented, Otto (humanoid) and Aibo (animaloid) emerged as the most appreciated, with over 95% of interested students showing a preference for them (Figure 5). Although the level of interest was high for both genders, some subtle differences emerged. Males exhibited a slightly stronger preference for drones and rovers. Notably, all "No" responses for Aibo came from male students, possibly indicating a greater appeal of the animaloid robot among girls.

The analysis of average ratings by gender (Figure 6) confirmed these tendencies. Males showed marginally higher enthusiasm for programming drones (4.76 vs. 4.58) and rovers (4.72 vs. 4.29). This suggests that they might be more inclined toward robots with functional and dynamic characteristics. In contrast, both genders reported similarly high enthusiasm for Otto and Aibo, with average ratings exceeding 4.4. In this case, the presence of features resembling living beings may play an important role in stimulating interest and emotional engagement, especially for students less drawn to technical aspects.

In summary, despite these small variations, our findings suggest that enthusiasm for programming robots is generally comparable across genders. However, the observed trends imply that robot morphology may play a subtle role in shaping engagement, especially when comparing technical, mobile designs with more anthropomorphic or animal-like robots. These findings reinforce the idea that robot design should be considered a pedagogical factor in promoting inclusive robotics education.

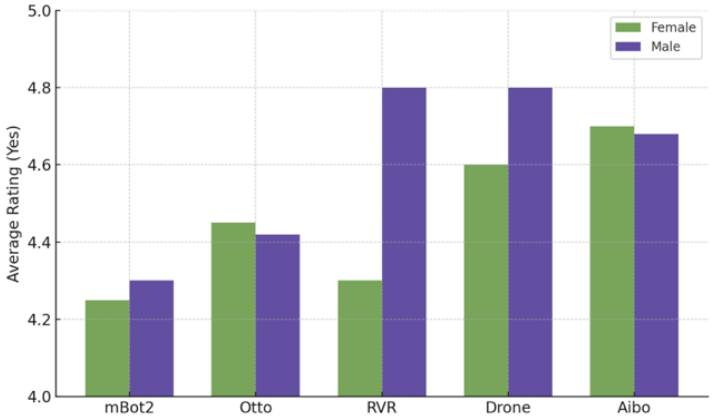

***Figure 6**: Robot design and inclusive practices: a pilot study on gender equity in STEM*

5 Activities Evaluation

Over one week, students participated in ten hours of classroom-based robotics activities, organized into daily two-hour sessions. After pair formation and an initial team-building phase, students engaged in constructing and programming robots, progressively exploring core concepts such as movement, sensing, and interaction, through hands-on activities. These practical tasks served not only to engage students but also to introduce and explain foundational topics of coding and robotics, starting from basic robot movements and progressively incorporating sensor-based programming.

To make learning more engaging, the lesson plan included a sequence of mini-tasks framed within real-world scenarios and increasing in complexity. These tasks were delivered on physical cards, given to each student pair one at a time. As students completed each objective, they received the next task. This format encouraged autonomy, intrinsic motivation, and active engagement, allowing students to progress at their own pace.

At the end of the program, students completed a questionnaire to reflect on their experience. Using a 5-point Likert scale, they rated:

- Their enjoyment of programming the robot;
- How easy or difficult they found the activity;
- Whether they considered the experience boring or interesting;
- Whether they perceived the activity as tiring or fun.

Additionally, students were asked to compare what they experienced to their initial expectations about robotics. They were given four options:

— I think robotics is not interesting, and I thought so before;
— I discovered that robotics is less interesting than I thought;
— I still think robotics is interesting;

— I think robotics is more interesting than I thought.

These questions aimed to assess the overall experience of the robotics program, evaluating enjoyment, perceived difficulty, and engagement. Furthermore, the comparison between expectations and the real experience helped to explore if the activities reinforced or changed their perceptions and attitudes toward robotics as a result of their experience.

	disliked - liked		hard - easy		boring - interesting		difficult - fun	
gender	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
F	4.77	0.43	3.38	0.95	4.58	0.68	4.41	0.81
M	4.71	0.74	3.37	1.04	4.29	1.06	4.11	1.18

Figure 7:*Experience evaluation*

The results (Figure 7) showed that both male and female students strongly enjoyed the activity, with average enjoyment ratings close to 5. Analysis of the evaluations of various aspects of the robotics activity, disaggregated by gender, revealed that:

- Both genders significantly enjoyed the activity, with ratings close to 5, reflecting overall positive experiences;
- Female students rated the activity as slightly easier than male students;
- On the "Boring–Interesting" scale, both genders rated the activity closer to "Interesting," with slightly higher scores among females;
- On the "Tiring–Fun" scale, female students again rated the experience as slightly more fun than males.

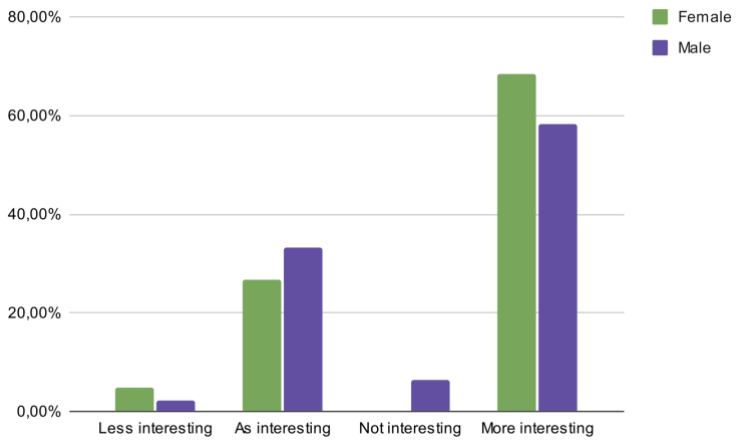

Figure 8*: Interest compared to expectation*

Figure 8 illustrates how male and female students compared their interest in robotics before and after the course.

Results indicated that:

- A majority of both genders found the activity "More interesting" than they had expected, with this trend more pronounced among female students;
- A significant number of male students said the experience was "As interesting" as expected, while fewer females selected this option;
- Very few students, regardless of gender, rated the activity as "Less interesting" or "Not interesting."

Overall, the data suggest that the robotics experience was perceived as enjoyable, interesting, and fun across genders, but some differences emerged in their expectations and perceptions. Female students tended to rate the activities as easier and slightly more enjoyable, suggesting that the curriculum design effectively mitigated potential barriers to female participation. When comparing the experience to initial expectations, a larger proportion of female students found the activities more interesting than anticipated, whereas, among those who found the experience just as interesting as expected, male students were in the majority. The data underscore the significance of embedding robotics activities within the regular curriculum as instrumental in enabling female students to confront and overcome implicit gender biases and stereotypes that often associate robotics with a “boy thing”.

6 Suggestions for the design of inclusive educational robotics activities

Our findings highlight that integrating robotics activities into regular curricular hours, offering self-paced learning opportunities, and fostering peer-collaboration effectively promoted equal engagement among male and female students. Girls, in particular, showed increased participation and confidence when activities were framed outside of competitive environments. Indeed, educational robotics is often introduced as an after-school activity, typically aimed at preparing students for competitions [16]. These competitive contexts tend to attract boys more than girls, and girls are primarily participating when they already have a strong interest in technology [17]. This also because previous researches indicate that many girls are less motivated by competitive environments [18, 19]. Such environments may unintentionally reinforce existing gender disparities, highlighting the need for more inclusive approaches capable of engaging a broader range of learners. These results underscore the importance of moving beyond traditional competition-centered models to create more inclusive educational contexts.

Based on these insights, we propose the following key principles for designing inclusive educational robotics activities:

- to be self-paced, allowing learners to engage at their own rhythm;
- to be integrated into curricular hours, ensuring broader access and participation;

- to promote peer-supported learning over individual or group competitions;
- to incorporate inclusive robot design, offering diverse aesthetic and functional options that avoid reinforcing stereotypes and appeal to a wide range of interests.

A comprehensive approach that combines inclusive activity structures and thoughtful robot design is crucial for fostering equitable engagement in robotics and, more broadly, in STEM education.

7 Conclusions

This study investigated how the design of educational robots and the structure of classroom-based activities can influence student engagement, with a particular focus on gender-related dynamics. Conducted during regular school hours and involving the entire class, the intervention offered a curriculum-based, inclusive alternative to competitive robotics activities, addressing potential barriers to female participation and promoting equitable engagement across genders. While the sample size was limited, the results contribute to ongoing efforts aimed at building more equitable and engaging STEM education starting from the primary level.

The results suggest the importance of taking into account robot aesthetics and pedagogical context in shaping students' experiences and attitudes toward robotics. Girls in particular benefited from the inclusive design of both the robots and the activities, reporting higher levels of engagement and positive shifts in perception.

This pilot project demonstrates strong potential for broader application and refinement. Future studies should explore its longitudinal impact on students' future study choices, self-efficacy, and sustained interest in STEM disciplines. Additionally, the approach and findings presented here may offer valuable insights and inspiration to educators and researchers seeking to develop gender-sensitive and inclusive robotics programs within formal education systems.

To build on these findings, further research should involve larger and more diverse populations, assessing how inclusive educational robotics can influence students' long-term learning pathways and their self-perception in STEM fields. Ultimately, fostering inclusive and engaging robotics education is not just a matter of technology, but of equity, representation, and opportunity.

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