ISBN: 978-628-96613-1-6. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2025.1.1.2027

Closing the Gender Gap in STEM: Impact of Challenge-Based Training on Girls in Cartagena de Indias.

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Abstract*– This study analyzes the impact of a challenge-based training program with an emphasis on robotics and programming on the development of STEM skills in girls from Cartagena de Indias. The methodology was based on Challenge-Based Learning (ABR), addressing real problems through the practical application of knowledge in 15 training sessions. The results showed an increase in participants' confidence and interest in STEM areas. In addition, the study reflected advances in the perception of gender equality, although stereotypes persist that limit female participation in these disciplines. The findings highlight the importance of implementing educational strategies that foster the inclusion and empowerment of girls in STEM, ensuring their access to opportunities in an increasingly technological labor market.

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R*esumen – Este estudio analiza el impacto de un programa de capacitación basado en retos, con énfasis en robótica y programación, sobre el desarrollo de habilidades STEM en niñas de Cartagena de Indias. La metodología se basó en el Aprendizaje Basado en Retos (ABR), abordando problemas reales mediante la aplicación práctica del conocimiento en 15 sesiones de formación. Los resultados mostraron un aumento en la confianza e interés de las participantes en las áreas STEM. Además, el estudio reflejó avances en la percepción sobre la igualdad de género, aunque persisten estereotipos que limitan la participación femenina en estas disciplinas. Los hallazgos resaltan la importancia de implementar estrategias educativas que fomenten la inclusión y el empoderamiento de las niñas en STEM, garantizando su acceso a oportunidades en un mercado laboral cada vez más tecnológico.*

Palabras clave – Educación STEM, brecha de género, robótica educativa, aprendizaje basado en retos, orientación vocacional.

I. Introduction

According to the World Economic Forum's 2024 Global Gender Gap Report, Latin America and the Caribbean have made significant progress towards gender parity since 2006, reducing the overall gap by 8.3% [1]. Nonetheless, achieving full gender equality remains a considerable challenge, especially in areas such as education and future skills. In STEM (science, technology, engineering, and mathematics), closing the gender gap remains a distant goal, even in countries with high equity levels.

This situation is worrying since, according to the World Economic Forum's 2025 Future of Jobs Report, the professions with the most significant growth projection belong precisely to STEM areas. Disciplines such as artificial intelligence, big data, renewable energies, and software development lead to global labor market trends. Although the report indicates that social skills such as leadership, resilience, and social influence are also on the rise, it continues to highlight the importance of technological literacy and knowledge in artificial intelligence and big data, which will be key to competitiveness in the labor market. The combination of technical and socio-emotional skills will be essential to adapt to the changes driven by digital transformation and automation [2].

However, there are concerns that women continue to be underrepresented in STEM (science, technology, engineering, and mathematics) areas, limiting their access to these high-demand job opportunities and perpetuating the gender gap in key sectors for technological and economic development. Today, they continue to face low participation as students and teachers, researchers, and workers in these fields [3].

On the other hand, the analysis of the results of the 2024 Saber 11 tests taken by students in the last grade of school reveals that the city of Cartagena de Indias faces significant challenges in improving the quality of education. The town presents significant gaps compared to the national average and other capitals and shows marked differences between Official Educational Institutions (IEOs) and private ones [3]. Despite some progress, Cartagena continues to be below the national average in educational performance. The quality of public education in Cartagena continues to lag: the average of IEOs in Cartagena de Indias was 61.4 points, the lowest among the main capitals of Colombia and significantly lower than the national average of 68.1 [4].

Against this backdrop, and to train new generations to be competitive in the global market, strengthening education in STEM areas is essential. Without solid training in these disciplines, young people in Cartagena risk being left behind in the labor market, limiting their ability to contribute to the socioeconomic development of the region and reduce global inequalities. This situation further affects women, who have historically had low participation in STEM, which further widens the gender gap in these fields.

This context underscores the urgency of implementing sustained strategies that strengthen the city's education quality and reduce existing gaps. Promoting equitable and inclusive training is crucial, as it guarantees the new generation (especially women) the necessary tools to face future challenges and take advantage of the opportunities of the knowledge economy [5].

One strategy that has proven results is using technologies such as Arduino and its components. A study done with teachers from schools in Latin America, with greater participation from teachers from Chile and Colombia, found that integrating Arduino in teaching allows the development of projects applicable to real contexts, which increases students' interest and strengthens their connection with STEM learning. In addition, the results indicated increased creativity, attitude, and motivation levels of the students who participated in the workshops, favoring critical thinking and a more experimental way of learning [6].

II. Methodology

A. STEM skills training

We developed the training over 15 sessions, each lasting 4 hours, in which 12 groups of boys and girls from four (4) IEOs in Cartagena de Indias learned fundamental concepts about robotics and programming using Arduino boards, sensors, and actuators as well as servo motors. During the sessions, participants acquired practical knowledge to program in C++ to solve specific challenges designed for each meeting. Four (4) of the twelve (12) groups were made up exclusively of girls. We made up groups of varied school grades. They can have students from fourth grade to tenth grade of secondary school.

The methodology used was Challenge-Based Learning (ABR). This pedagogical strategy promotes the resolution of real problems through the practical application of knowledge. This strategy encourages students to be interested in providing solutions in the context in which they interact. It is a methodology applicable to the context and strengthens collaborative learning [7]. In STEM areas, ABR has proven to be an effective strategy in improving academic performance and promoting essential skills for the 21st century. [8]

Each four-hour session presented a new challenge, such as programming smart traffic lights or developing proximity, noise, or smoke detectors. At the end of each session, the students met the challenge posed, demonstrating their advances in technical skills and creative problem-solving.

In training sessions 14 and 15, the students participated in creating an integrative project that would consolidate the knowledge acquired during the training program. This final project required the application of all the tools and concepts learned to design practical solutions to problems of everyday life.

The final project for the four all-girls groups focused on designing a security system to protect women in residential and community settings. This integration of a gender perspective in the program seeks to reduce stereotypes and develop a sense of belonging to STEM areas in both boys and girls. This challenge not only fostered technical skills but also empowered girls to participate in solving problems in their environment by developing technological solutions.

The system designed by the girls uses a combination of sound sensors and lights to detect and respond to loud or unusual sounds in the environment. When activated, the system generates a visual and audible alert that serves a dual function:

- Deter potential intruders by drawing immediate attention to the area.
- Facilitate rapid visibility and community response, activating a neighborhood support network.

At the same time, the four groups made up exclusively of girls were offered talks about pioneering Colombian women in STEM areas to inspire and motivate them.

B. Qualitative assessment

This phase of the project was framed in a qualitative approach with a phenomenological design. Focus groups were used as the main information collection technique to explore the participants' perceptions and experiences regarding the impact of the STEM skills training program [9]. This qualitative technique fosters dialogue among participants on a main topic, exploring diverse perspectives and conceptions expressed through language.

The focus groups were developed following a methodology structured in several key stages: planning, creating an environment of trust, developing the discussion, feedback, and closure. During the sessions, we used strategically designed open-ended questions to explore various relevant topics, such as vocational and academic interests, gender equality and roles in STEM, innovation and creativity in technology, and the practical application of knowledge in everyday life. These questions allowed for a reflective and participatory dialogue among the students.

We grouped the questions into the following five categories:

Category 1: Vocational and Academic Interests

- What would you like to do or study after finishing school? What attracts you to this option?
- After this training, how do you see careers in science, technology, engineering, or mathematics?
- What skills would you like to develop to work in engineering or technology areas?

Category 2: Gender Equality and Roles in STEM

- Do you think girls can do the same activities as boys? Why?
- What kind of person shows interest in technology and math, and why?
- Less than 30% of researchers in STEM (Science, Technology, Engineering, and Mathematics) areas are women (UNESCO, SF). Is there anything that should change about this data?
- How would you encourage a friend to learn more about science, technology, engineering, or math?
- What do you think of women studying engineering or working in science and technology?

Category 3: Innovation and creativity in technology

- What do you think about the idea of creating things to solve problems? Would you like to participate in activities of this type?
- What do you think about learning how devices work (speakers, smart lights, smart watches, among others related to the internet) or creating one of these devices at some point?
- What kind of internet-connected device would you like to invent or improve? How would it work, and what would it do?

Category 4: Practical Application of Knowledge

- Have you applied what you learned in this program in other contexts, such as at home or with friends?

Category 5: Robotics and specific technologies

- What do we know about a robot?
- What are sensors used for in a robot?
- What is the function of sensors in a robot?
- What do sensors do in a robot, and why are they important?
- What are the parts that make up a robot?
- What are the types of robots, and what are they for?
- Tell me, what things make a robot move?

We developed each focus group in one of the four (4) Official Educational Institutions (IEOs), where audio was recorded, and detailed annotations were taken for later analysis. To ensure a balanced perspective and an atmosphere of trust, we led the groups by two psychology professionals, a man and a woman, who facilitated the discussions and promoted active and respectful participation.

Each session lasted approximately two hours, during which time the students were able to express themselves freely without fear of judgment or reprisals. A safe and inclusive environment was prioritized, where participants felt comfortable sharing their experiences, opinions, and expectations around the topics addressed.

The sample, as a result of the four focus groups, included 38 students, of which 61% were girls (23) and 39% were boys (15). The ages of the participants ranged from 9 to 14 years, as detailed in Table I.

TABLE I
FOCUS GROUP DISTRIBUTION

		Man	female	Total
IEO - 1	F	3	7	10
	%	30%	70%	100%
	Age Range	Between 9 and 14 years old		
IEO - 2	F	1	7	8
	%	13%	88%	100%
	Age Range	Between 11 and 14 years old		
IEO - 3	F	6	5	11
	%	55%	45%	100%
	Age Range	Between 9 and 11 years old.		
IEO - 4	F	5	4	9
	%	56%	44%	100%
	Age Range	Between 11 and 14 years old		

For the data analysis, we used the Atlas.ti software. It allowed axial coding and identifying patterns and recurring themes in the participants' narratives. It also made it possible to establish connections between different fragments of information and group them into categories based on shared characteristics within the children's stories. This analytical process allowed for a deeper understanding of the meaning participants gave to their experience, providing key elements for evaluating the program's impact [10].

III. Results and Discussion

The qualitative results are presented in two main stages. First, we identified the definitive descriptive macro-categories and categories by coding the participants' responses, as shown in Table II. Subsequently, we carried out a hermeneutical analysis of the narratives, complementing the information presented in the content matrix of the table above.

TABLE II
MACRO CATEGORY IDENTIFICATION

Macro category	Descriptive Categories	Total Frequency
1. Vocational Orientation and Interest Selection	Motivations behind vocational choice	16
	Vocational indecision	4
	Attraction to STEM fields	14
	Knowledge about vocational choice	7
	Lack of knowledge about vocational choice	2
	Misconceptions about vocational choice	2
	Vocational change due to the program	7
	Vocational orientation modeling	7
	Program as a second vocational option	4
2. Gender Equality and Associated Roles	Perception of gender equality in skills	15
	Gender stereotypes perceived by boys	17
	Critical perspective on gender gaps	10
	Strategies to reduce gender gaps	5
	Traditional gender roles in the household	3
3. STEM Skills and Knowledge	Key skills for STEM	13
	Specific knowledge in robotics	65
	Confidence in STEM skills	2
	Importance of studying robotics	2
4. Perception of the Training Program	Positive opinions about the program	6
	Negative opinions about the program	5
	Practical application of knowledge	14
	Lack of family support	1

Analyzing the narratives of macro category 1 (Vocational guidance and choice of interests), it is evident that the frequency of "Motivations behind vocational choice" and "Attraction to STEM fields" is the highest, with a total frequency of 16 and 14, respectively (Fig. 1). This indicates that the training program had a significant impact on students' vocational orientation, helping to consolidate interest in STEM areas.

Likewise, the participants' reports show the program's impact on the choice or redefinition of their vocational orientation. An example of this is the testimony of a student who expressed how her perspective changed from her experience in the program: "Well, before the program, I wanted to be a psychologist because I saw that it was about helping people. But when the TRASO program started, they told me, 'Let's go to math' and so on... I was interested in being an industrial engineer." This testimony reflects how exposure to new areas of knowledge can influence children's career aspirations, broadening their horizons and sparking interest in STEM disciplines.

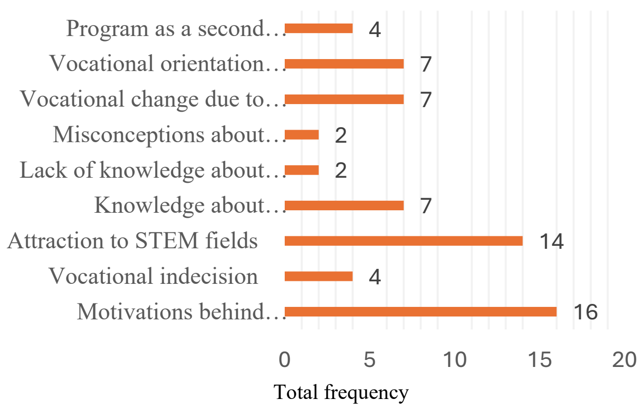

Fig. 1 Analysis of macro category 1 narratives

When analyzing vocational preferences (Fig. 2), we observed that STEM careers were the most frequent. Since most of the focus group participants were women, this result demonstrates the impact of the training program in reducing gender stereotypes and promoting equality in these areas.

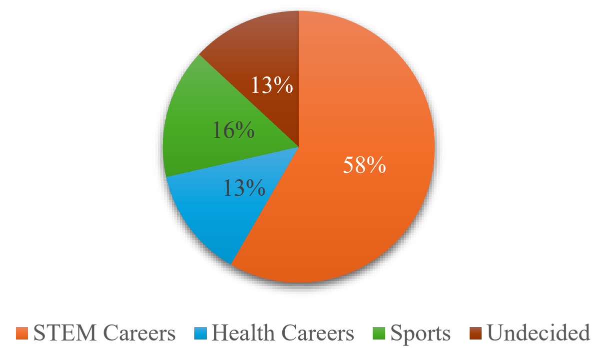

Fig. 2 Vocational preferences

Regarding macro category 2 (Gender equality and associated roles), we identified that many students recognize the presence of gender stereotypes (Fig. 3), this being the category with the highest frequency of mentions (17). Some students describe these stereotypes appropriately, for example, in the following testimony: "Because in industrial engineering, many people say that those who have to work are male engineers, not women. So there are more men than women."

Some participants reproduce them in their speeches, while others show a high perception of equity in terms of individual abilities (15 mentions), attributing this change in their vision to the program's impact.

In addition, we evidenced a critical stance in the face of structural inequalities, which suggests that the training contributed to raising awareness about this problem. However, despite these advances, entrenched gender stereotypes persist in their narratives. Expressions such as "Women are a complement to make men smarter" reflect this duality between the recognition of equality and the permanence of traditional ideas.

When analyzing macro category 3 (Fig. 4), the Development of skills and knowledge in STEM, it is evident that the program led to significant progress in acquiring skills and expertise in these areas, with a particular emphasis on robotics. The category "Specific knowledge of robotics" was the most outstanding (65 mentions), reflecting mastery of technical language by students in key aspects of the program, such as exploration of the environment, movement systems, electrical components, connections, and classification of robots.

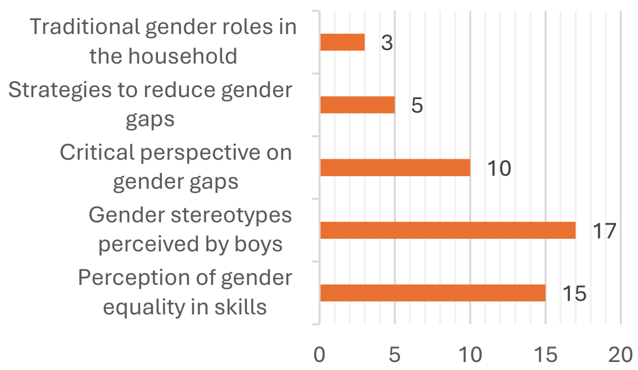

Fig. 3 Analysis of macro category 2 narratives

In addition, participants recognized the importance of essential skills in STEM, such as logic, programming, creativity, and critical thinking: "You need skills like logic, programming, robotics, imagination, and creativity" and "If we have good discipline, we can develop these skills."

Beyond technical learning, the initiative encouraged students to envision a practical and relevant application of STEM knowledge in their academic and professional future.

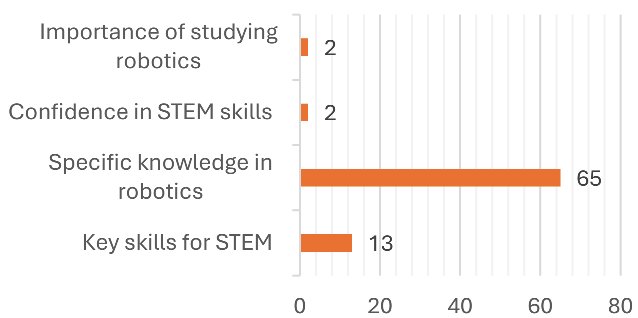

Fig. 4 Analysis of macro category 3 narratives

Finally, in macro category 4, the general perception of the program was mostly positive, highlighting its impact on students' personal and academic development. These students valued the knowledge acquired as an opportunity that complements their formal education. Although some don't see STEM as their first vocational choice, they recognized that the program broadened their perspectives and provided them with a career alternative.

In the same way, the students' reports reflect the practical application they have given to the knowledge acquired in the training program (14 mentions), which reaffirms the program's effectiveness in preparing students to face real challenges. This finding is key to validating the usefulness of the program in contexts beyond the classroom: "What I learned has also helped me with a friend of my father's. That he has been making a robot and had skipped a step. And I had to help him" and "... In my house my brothers are macho. They say we have always to be doing the job. They tell us that... So, sometimes I tell them, if women, that is if we can because you can't do the job."

However, we identified some negative perceptions related to the lack of family support and erroneous beliefs about training, which in some cases limited the participation of specific students.

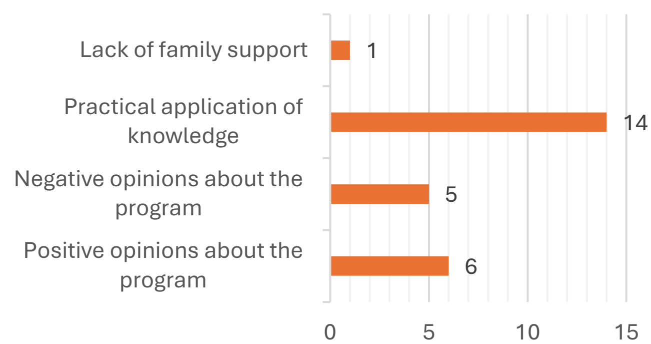

Fig. 5 Analysis of macro category 4 narratives

IV. Conclusions

The challenge-based training program, emphasizing robotics, positively impacted the development of STEM skills in impacted students. The category "Specific knowledge of robotics" was the most mentioned (65 mentions), reflecting a solid technical mastery in using components such as Arduino, sensors, actuators, and servomotors, as well as in programming in C++. In addition, participants identified essential skills such as logic, programming, and creativity, showing confidence in their ability to apply them through hands-on learning. These results confirm that the Challenge-Based Learning (ABR) methodology made it possible to strengthen technical skills and promote an applied vision of technology in everyday scenarios. We have evidenced this in developing innovative projects, such as safety systems for women in community environments.

Regarding gender equality, the program made progress by increasing girls' interest and participation in STEM disciplines. The girls participating in the focus groups, for the most part, expressed greater confidence in their abilities in these areas. However, gender stereotypes persist.

Regarding vocational guidance, the program broadened students' perspectives toward STEM careers. While some do not consider these areas their first career choice, they recognize that the training allowed them to explore new opportunities. Factors limiting full participation in these areas were identified, such as lack of family support and misconceptions about STEM careers, which highlights the importance of complementary strategies with the family and community to strengthen accompaniment in vocational decision-making.

These findings underscore the need to implement sustained strategies that combine technical education, gender equity, and greater community and family involvement in the training process. Strengthening access to STEM training from an early age and integrating other strategies, such as mentoring models that have proven to work, is recommended.

ACKNOWLEDGEMENT/RECOGNITION

Thanks to Liliana Puello and the organization she leads for their invaluable support in developing this project. Their commitment and dedication have been fundamental pillars for implementing this initiative, allowing more girls and boys in Cartagena de Indias to access innovative STEM training. Thanks to their support, we have managed to strengthen the interest and participation of new generations in key disciplines for the future.

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