Promoting Gender Inclusion in Computing: An Experience Report on a National Web Development School for Girls

Thaís Lauriano
thaislauriano@usp.br
Institute of Mathematics and Computer Science (ICMC)
São Carlos, São Paulo

Brena Marques
brena.marques@usp.br
Institute of Mathematics and Computer Science (ICMC)
São Carlos, São Paulo

Lina Garcés
linagarces@usp.br
Institute of Mathematics and Computer Science (ICMC)
São Carlos, São Paulo

ABSTRACT

Female representation remains low in undergraduate programs and research related to STEM fields, with women accounting for only an estimated 15% of the sector in Brazil as of 2022. Nevertheless, one factor contributing to the increased participation of women in STEM programs has been the implementation of strategies focused on strengthening girls' mathematical and scientific foundations during childhood and adolescence. Therefore, aiming to overcome the economic and societal barriers that school-age girls face in accessing this kind of knowledge, the Web Development School for Girls course was developed to promote interest, skills development, and self-confidence among participants, encouraging them to pursue careers in STEM. The initiative was national and conducted fully online, featuring weekly lessons and assessment activities, daily mentoring sessions, and the application of project-based learning, which placed students at the center of the learning process. This program was explicitly aligned with the Sustainable Development Goals (SDGs 4, 5, and 10). The program demonstrated the effectiveness of the PBL methodology through the quality and complexity of the final web projects delivered by the students. While successful in its pedagogical goals, the initiative encountered key limitations, including a high dropout rate of 53.6%. It is concluded that strengthening engagement strategies, such as integrating more frequent live or face-to-face sessions, and refining administrative processes are essential for improving retention in future editions of the school.

KEYWORDS

Gender equality, Web development, education in computing, reduced inequalities.

1 INTRODUCTION

The Brazilian Institute of Geography and Statistics (*IBGE*) [7] reported, in 2022, that women accounted for only 15% of graduates in Computer Science and Information and Communication Technologies (*ICT*) in Brazil. Compared to the last decade, when women's participation was 17.5% in 2012 (see Figure 1), this suggests that, despite advances in other STEM[1] fields, women's participation in technology remains not only limited but is also declining.

[1]Science, Technology, Engineering, and Mathematics

In: IV WebMedia for Everyone (W4E 2025) (W4E 2025). Anais Estendidos do XXXI Simpósio Brasileiro de Sistemas Multimídia e Web (W4E'2025). Rio de Janeiro/RJ, Brasil. Porto Alegre: Brazilian Computer Society, 2025.

ISSN 2596-1683

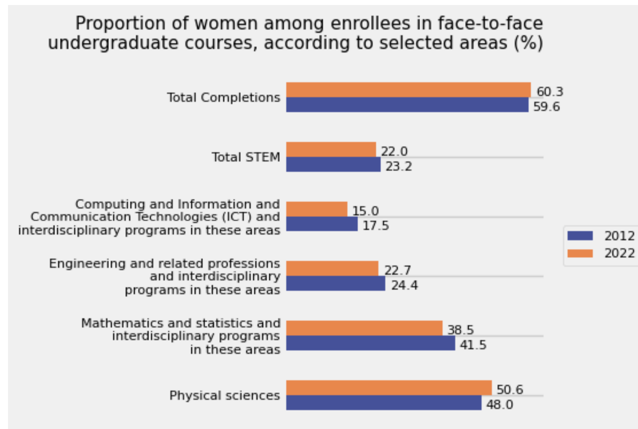

Figura 1: Proportion of women among enrollees in face-to-face undergraduate courses, according to selected areas(%)

Simultaneously, projections from the Brazilian Association of Information and Communication Technology Companies (*Brasscom*) estimate that by 2025, the country will require approximately 797,000 new technology professionals. When compared to the current graduation rate of women, this gap highlights a structural barrier that limits both diversity and the possibility of meeting market demand.

This projection remains highly relevant as it indicates the continuing structural need for professional training, especially for underrepresented groups in the field.

Bridging this gap is not only a matter of equity but also of economic and innovation potential. Research from consulting firms such as Accenture [1] and McKinsey & Company [8] underscores the link between diversity and business performance. Accenture reports that workplaces with low diversity often exhibit reduced innovation capacity and a lower propensity for taking calculated risks. Similarly, McKinsey & Company found that companies with greater diversity can achieve up to a 15% increase in profitability. These findings reinforce the relevance of Sustainable Development Goal 5 (SDG 5), which aims to achieve gender equality and empower all women and girls.

In parallel, when considering cognitive skills of children and young people to be successful in the digital era, developing computational thinking becomes essential for the new generation [14]. Computational thinking refers to the set of skills involved in understanding and constructing solutions to problems across various domains through algorithm design and the application of core computing principles, as defined by the Brazilian National Common Curricular Base (BNCC), complement for Computing [13]. Promoting computational thinking prepares students for a technological future and broadens their opportunities across multiple areas of knowledge.

Active learning methodologies have been successfully applied for teaching computer science topics [5]. Specifically, Project-Based Learning (PBL) has been widely adopted to enhance engagement and knowledge retention. PBL guides the learning process through the construction of practical projects developed throughout the course [2], fostering a collaborative environment that allows students to acquire knowledge more meaningfully by integrating theory and practice [15].

This situation motivated the creation of an online web development school specifically designed for girls aged 14 to 19. The school is organized into two levels: beginner and intermediate. The initiative aims to equip participants with technical skills and inspire them to pursue careers in technology, thereby contributing to increased female representation in the sector.

This work reports on the experience of conceiving and executing this course, detailing the dissemination strategies, logistical and pedagogical organization, and the main challenges encountered, along with the solutions adopted.

The paper is organized as follows: Section 1 provides the context and motivation; Section 2 reviews related work; Section 3 outlines the instructional design and structure; Section 4 reports the results achieved; Section 5 discusses lessons learned and improvement opportunities; and Section 6 offers final considerations and future directions.

2 RELATED WORK

The under-representation of women in computing in Brazil is influenced not only by gender but also by social and racial factors, which affect access to quality education. According to the Brazilian Ministry of Women (Observatório Nacional) , while 63% of postdoctoral fellowships granted by CNPq go to white women, only 0.2% are awarded to indigenous women and 1.4% to Black women. These disparities highlight the need for inclusive educational strategies that can mitigate social inequalities [10].

The absence of girls' early exposure to STEM education often reinforces gender stereotypes and restricts future opportunities for women in technology. Research highlights that the early years are particularly decisive in shaping girls' interest and aptitude in this field [18].

In response to this challenge, universities and companies worldwide have developed initiatives aimed at fostering gender equity in technology, including technical training programs, mentorship opportunities, and hiring events:

- International Initiatives: Organizations like Girls Who Code [6] and the Technovation Challenge [16] have developed large-scale, structured programs aimed at girls in middle and high school. These programs typically focus on skills development, mentorship, and the application of computing skills to solve real-world problems.
- National Programs: In Brazil, similar university-led extension initiatives, such as "Gurias na Computação"[3], "Macuxi digital"[17], and many other programs [9, 11].

While such efforts mark important progress, significant gaps remain to achieve equity throughout the educational and professional trajectories of women. The challenge is even greater in the context of public schools, where inadequate infrastructure and the scarcity of specialized technology teachers contribute not only to gender disparities but also to broader social inequalities.

3 COURSE DESIGN

The Web Development School for Girls is an online course, offered at no cost to school-aged girls from schools in Brazil. The school took place during the second semester of 2024, spanning from August 2024 to January 2025.

3.1 Registration and Selection Process

Registration was conducted using a Google Form, which was disseminated through various media outlets. These outlets included the organizing extension group's social media profiles on Instagram and LinkedIn, the educational institution's website to which this group belongs, and a local television channel. The latter aired a report with the organizers to publicize the course. An informed consent form was obtained from the legal guardians of all selected minors, authorizing their participation in the course.

A total of 215 applications were submitted, from which 104 candidates were selected, with eligibility based on their educational background (specifically, being enrolled in high school). The selection process prioritized balance—both between students from public and private schools and across different states of origin to extend opportunities to those with more limited access to such initiatives. Ultimately, the final cohort represented 18 Brazilian states, with 60% of participants coming from public schools and 40% from private schools.

The students were divided into two groups: one comprised of those with previous experience in programming, designated as the intermediate class with 24 students, and another consisting of those with no prior experience, defined as the beginner class with 80 students.

3.2 Mentoring team

We had a team of 19 volunteer teaching assistants who went through a rigorous selection process. After applying via a Google Form, candidates were required to submit a small Django-based project to demonstrate their proficiency with the framework. This ensured all mentors were qualified to provide technical support to the students. To prepare for the project, teaching assistants were encouraged to study using the course's official didactic materials. Those who did not submit a project were disqualified.

All selected candidates for the mentoring team were required to agree to and comply with the official regulations for the program, developed by the organizing extension group. The document outlined the main objective of the program, mentor responsibilities, and the requirements for their qualification and participation. It also detailed expected attitudes and behaviors, emphasizing the need to maintain a positive, respectful, and inclusive learning environment. Monitors who adhered to the rules and met the participation requirements were eligible for a certificate of 180 hours.

This process ensured that the mentoring team was not only technically proficient but also committed to the ethical and pedagogical guidelines of the program.

3.3 Teaching Materials and Syllabus

The teaching materials used consist of slides, exercises, and video lessons developed and recorded by members of the school organization. To keep the content engaging and accessible, video lessons were designed to be short, with a maximum duration of 30 minutes. The curriculum was structured around an active learning approach, with each module building upon the last to ensure a smooth transition from foundational concepts to more complex topics. This approach allowed students to acquire knowledge meaningfully by integrating theory and practice.

The ***beginner curriculum***, as depicted in Figure 2, began with basic computing fundamentals, including concepts such as computers, software, hardware, variables, and algorithms. Following this, students were gradually introduced to programming in Python, covering topics such as variables, conditionals, loops, data structures, functions, file handling, and input/output. Later modules covered web development fundamentals, including web protocols (e.g., HTTP, IP, TCP), web servers, web architectures, web browsers, IP addresses, hosting, markup languages such as HTML and CSS, the concepts of front-end and back-end development, and a brief introduction to the Django web framework. For the web development modules (Introduction, CSS, and HTML), the content was structured based on the comprehensive documentation from the Mozilla Developer Network (MDN).

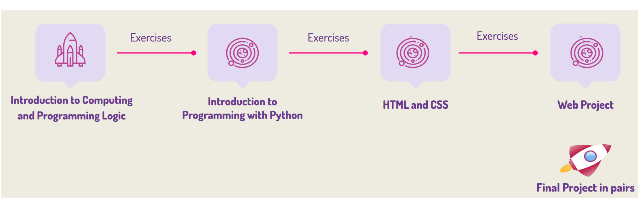

Figura 2: Beginner class course structure

The ***intermediate curriculum***, shown in Figure 3, followed a similar curriculum but skipped the introductory computing module, beginning directly with the Python programming content. This allowed them to move more quickly into applied web development with Python and Django. Moreover, the intermediate girls' group studied the database and the use of migrations in Django for connecting the front-end with the back-end.

Each group was tasked with completing weekly assignments in pairs, which consisted of theoretical or coding exercises based on the content of that week's module. The primary evaluation criteria for these assignments were the correctness of the logic and its alignment with the concepts taught.

The final phase of the course involved developing a web-based final project, also in pairs. The project topics were open for the students to choose, and their final project grade was a combination

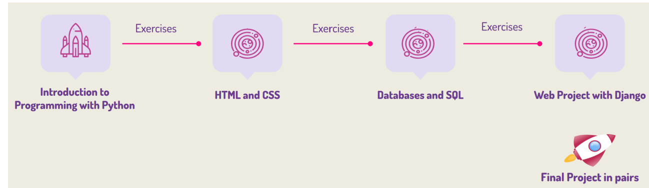

Figura 3: Intermediate class course structure.

of the developed code and a video presentation of the site. This method was used to verify their effective mastery of the work delivered. The final project consisted of a static website for beginner students and a dynamic website using the Django framework for intermediate students, and the girls had support from the teaching assistants throughout the whole development of the project during the tutoring sessions.

3.4 Platforms and Evaluation

The course adopted a hybrid asynchronous-synchronous format, where all lessons and activities were released weekly, every Monday, through separate Google Classroom environments for each group: beginners and intermediate. The submission and correction of the exercises and project were also made through Google Classroom.

Tutoring was organized so that at least four hours of support were available every day of the week, while each teaching assistant was committed to a maximum of four hours of mentoring per week. The mentors were also responsible for correcting the students' activities and projects.

All communication throughout the course — including the tutoring sessions, interactions between students, teaching assistants, and the organizing team — was centralized in a dedicated Discord server. The server was structured with specific channels for the beginner and intermediate groups, private channels for the teaching team, and general-purpose channels open to all participants. This setup fostered both academic collaboration and a sense of community, as depicted in Figure 4.

To receive a certificate of completion, students were required to (i) attend at least one mentoring session per week for 70% of the course duration, and (ii) achieve a minimum score of 60/100, calculated as the weighted average of assignment grades and the final project evaluation. Furthermore, students with a final grade of 90 or above were recognized with a special certificate for outstanding achievement.

4 RESULTS

This section summarizes the main results of the web design course for girls, focusing on Brazilian region diversity, student and mentor engagement, students' performance in exercises and projects, and students' and mentors' feedback collected throughout the program.

4.1 Diversity

As described in Section 3, we received 215 applications and selected 104 students, comprising 80 beginners and 24 intermediate-level participants. The selected students represented 18 Brazilian states

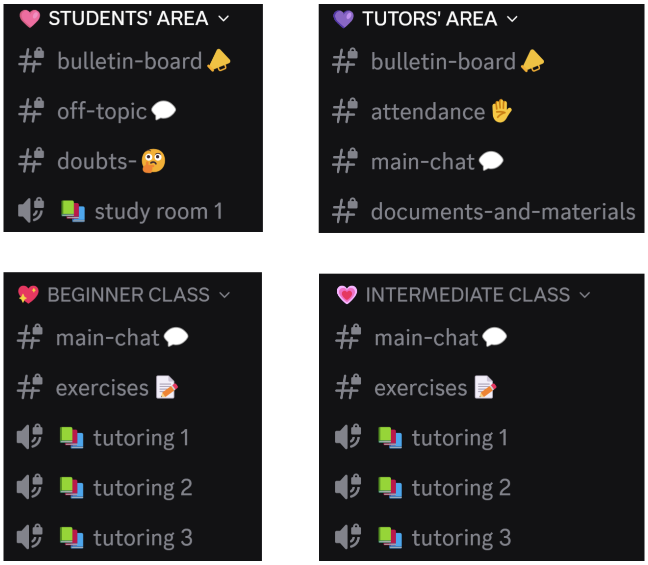

Figura 4: Channels structure in the school's Discord server

(see Figure 5), and 60% came from public schools, reflecting our commitment to democratizing access to knowledge.

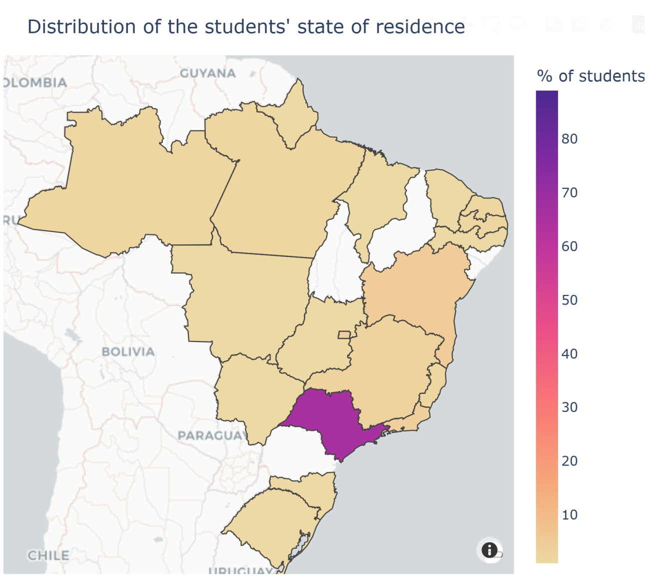

Figura 5: Students' states of residence in Brazil.

4.2 Enrollment and Retention

Of the selected students, 7 (seven) did not confirm their enrollment. Therefore, 97 students officially enrolled in the course (73 beginners and 24 intermediates). At the end of the course, the drop-out rate was calculated. Table 1 summarizes the participation and dropout rates.

While dropout rates were significant, especially among beginners (57.5%), the quality of the final projects demonstrated strong learning outcomes for those who completed the course.

4.2.1 Students' Projects. The final projects demonstrated the students' creativity and skill development, showcasing the effectiveness of the course's project-based learning methodology. A total of 26 projects were delivered by the beginner class, covering a wide range of topics. These included personal blogs on subjects like reading, news, recipes, and TV series; utility applications like a temperature converter and an expense calculator; and informational sites for specific themes, such as a virtual library or the 'Arcane' series. The projects showcased the students' ability to build static web pages using the knowledge acquired in HTML and CSS, and some even ventured into creating a database with Django, which was an optional component.

In the intermediate class, 10 projects were submitted, all of which utilized the Django framework to create dynamic websites. The topics were more complex and included a hotel reservation site, a mental health diary, and a site for reporting complaints and testimonials from women. Other notable projects were a reading blog, a site to check the weather, and a site with information about the Web Development School for Girls itself. The main features implemented across these projects were user registration and login, as well as the ability to create and manage posts, particularly in the blog-style projects.

Although the initial plan was for all students to work in pairs, the high dropout rate meant that many students were left without a partner and ended up completing their projects alone. The quality of the final projects, regardless of whether they were completed individually or in pairs, was exceptionally high, which attests to the strong learning outcomes achieved by the students who completed the course.

5 DISCUSSIONS

This section delves into the findings of the Web Development School for Girls, interpreting the results and providing a critical analysis of the program's design, challenges, and opportunities for future editions.

5.1 Management and Engagement Challenges

Managing two different classes simultaneously presented significant logistical challenges. With 97 students and 19 mentors supervised by only three organizing members, the workload required substantial effort from the core team. This included maintaining two separate environments on Google Classroom and Discord, as well as managing two distinct sets of activity and attendance spreadsheets. The team's capacity was a key factor, and a larger group of organizers could have streamlined these tasks.

Despite these challenges, the organization's approach to student engagement proved effective. The course adapted to the students' demanding schedules by providing materials weekly to prevent them from feeling overwhelmed. Attendance was tracked flexibly, requiring presence in only 70% of weekly sessions, and deadlines were extended, especially for the final project. This flexibility, which allowed students to complete their work during school holidays, was a critical strategy to improve retention, and without it, the

Tabela 1: Student enrollment and retention.

Group	Enrolled	Completed	Dropout Rate
Beginners	73	31	57.5%
Intermediate	24	14	41.7%
Total	97	45	53.6%

dropout rate might have been even higher. This highlights the importance of accommodating the real-life constraints of the target audience, many of whom were balancing work, school, and college entrance exam preparation.

The Discord server was a highly effective platform for communication, fostering a sense of community and providing a centralized space for students and mentors to interact. This structured environment facilitated quick and personalized support.

5.2 Data Organization and Analysis

The decentralized method for recording attendance and grades created a significant administrative burden on the organizing team. With attendance logged through weekly Google Forms and grades stored separately on Google Classroom, consolidating this information into a single spreadsheet was a time-consuming process, taking at least 30 minutes per week. This experience underscores the critical need for a more centralized data management system in future editions to streamline operations and allow the team to focus more on student support and course content.

5.3 Enhancing the Curriculum and Inclusion

One significant factor appears to be the overload experienced by many participants, who were managing multiple commitments. To address this, future editions should consider strengthening the program through partnerships with high schools. Formalizing student participation could provide institutional support, potentially reducing dropout rates by integrating the course more seamlessly into students' academic lives and making it more accessible to a wider audience.

The effectiveness of the project-based learning methodology was demonstrated by the quality of the projects completed by the students. However, the Django module highlights a key area for improvement. The content was perceived as too complex, and a more detailed, step-by-step approach with more practical examples would be beneficial. Creating supplementary material that guides students in how to apply Django principles to their final projects could significantly improve comprehension and reduce frustration.

Finally, the initiative's success in promoting interest in STEM must be viewed within the broader context of social inequality. While the course reached students across 18 Brazilian states and balanced participation between public and private schools, it is crucial to proactively implement strategies to reach more underrepresented groups, such as Black and Indigenous women. As highlighted by the Brazilian Ministry of Women data, these groups face significant barriers to accessing higher education in STEM. Future editions should focus on deliberate outreach to these communities to ensure the program effectively contributes to a more equitable and inclusive technology sector.

5.4 Drop-out Rate

The dropout rate in the course was high, with a total rate of 53.6%. This index is consistent with high rates observed in online, open-access courses. Studies on Massive Open Online Courses (MOOCs) often report dropout rates ranging from 75.0% to 95.0% of enrolled students [4, 12].

Several factors contributed to this outcome. Many students were in their final year of high school, balancing school, work, and preparation for university entrance exams, which limited the time available for the course. Similarly, the primary reasons for evasion identified in MOOC studies are related to a lack of time for dedication and family problems[12].

Another factor was the difficulty some students faced with self-directed learning. The Project-Based Learning (PBL) methodology also posed challenges for students who were not used to autonomous learning. Furthermore, group formation impacted retention: students who could not integrate into a team or whose teammates gave up on the course often struggled to stay motivated and complete assignments.

These observations suggest that prioritizing younger students (those in the last years of middle school and the first years of high school) could reduce dropout rates, as they generally have more time to engage with the course. Additionally, providing structured support, encouraging mentoring sessions, and facilitating team formation may help students who are learning independently and improve overall course retention.

5.5 Ethical Considerations

While the project was conceived with the primary goal of promoting gender inclusion, a key lesson for future editions concerns the formal ethical procedures required for academic reporting. The project obtained informed consent from the legal guardians of all minor participants, demonstrating a commitment to ethical practices. However, the data collected from participants, including grades and qualitative feedback, was not formally reviewed by an institutional research ethics committee (CEP). For this reason, this report does not present the direct results of that data. The experience underscores the critical importance of a formal ethical review process for any project involving data collection from human participants, particularly minors. This step is essential not only for compliance with academic publishing standards but also for ensuring the highest level of protection and transparency for all involved.

6 CONCLUSIONS

This paper presented an experience report on the Web Development School for Girls, an online initiative designed to address the under-representation of women in computer science by promoting interest, technical skills, and self-confidence in STEM among high school students. The results demonstrate the program's effectiveness, as evidenced by the high quality of the projects delivered by students who completed the course. Additionally, the data showed a significant increase in participants' self-confidence and interest in pursuing technology careers.

While the program successfully achieved its core objectives, it also highlighted key limitations, most notably the high 53.6% dropout rate. The online, asynchronous format, despite its flexibility, posed challenges in maintaining engagement, particularly for students managing multiple commitments. Nevertheless, this work contributes a valuable model for free, online STEM education, detailing critical lessons learned regarding pedagogical design, administrative management, and student engagement strategies.

For future editions, the findings suggest the need to implement additional strategies to improve student retention and engagement. Strengthening the sense of community through more frequent live sessions or face-to-face meetings could help build a stronger connection with participants. Enhancing the curriculum with more detailed, accessible content for complex topics like Django is also essential. By continuously refining its approach, the Web Development School for Girls can further its mission of contributing to a more equitable and inclusive technology sector in Brazil.

ACKNOWLEDGMENTS

The authors would like to thank CAPES (Coordination for the Improvement of Higher Education Personnel), REBECA: Brazilian Education Network for Engineering and Exact Sciences. For more diversity and inclusion in Science, Technology, Engineering and Mathematics, and CNPq Process: 440425/2024-7.

Also, the authors would like to thank the use of Artificial Intelligence tools for assisting in the translation and correction of this work.

REFERENCES

[1] Accenture. 2019. *Getting to Equal 2019: Creating a Culture That Drives Innovation*. Technical Report. Accenture. https://www.accenture.com/content/dam/accenture/final/a-com-migration/thought-leadership-assets/accenture-equality-equals-innovation-gender-equality-research-report-iwd-2019.pdf

[2] Marcos de Carvalho Borges, Silvana Gama Florencio Chachá, Silvana Maria Quintana, Luiz Carlos Conti de Freitas, and Maria de Lourdes Veronese Rodrigues. 2014. Aprendizado baseado em problemas. *Medicina (Ribeirão Preto)* 47, 3 (2014), 301–307.

[3] Isadora Ferrão, Aline de Mello, and Amanda Melo. 2017. Gurias na Computação: fortalecendo e incentivando a participação feminina no Ensino Superior. In *Anais do XI Women in Information Technology* (São Paulo). SBC, Porto Alegre, RS, Brasil, 1200–1203. https://doi.org/10.5753/wit.2017.3406

[4] Simone Claudino de Carvalho Flores, Marcelo Fassbinder, and Ellen Francine Barbosa. 2020. *Um estudo sobre Evasão nos MOOCs da Escola Virtual*. Master's thesis. Instituto de Ciências Matemáticas e de Computação (ICMC-USP), São Carlos, SP.

[5] Lina Garcés and Brauner Oliveira. 2024. Teaching Software Engineering with Project-Based Learning: A Four Years Experience Report. In *Anais do XXXVIII Simposio Brasileiro de Engenharia de Software* (Curitiba/PR). SBC, Porto Alegre, RS, Brasil, 476–486. https://doi.org/10.5753/sbes.2024.3530

[6] Girls Who Code. 2025. Girls Who Code: Programs, Impact, and Vision. https://girlswhocode.com/. Accessed: September 26, 2025.

[7] Instituto Brasileiro de Geografia e Estatística (IBGE). 2022. *Informativo - Mulheres nas Ciências Exatas e Tecnologia* (2nd. ed.). IBGE, New York, NY.

[8] McKinsey Company. 2015. *Why Diversity Matters*. Technical Report. McKinsey Company. https://www.mckinsey.com/capabilities/people-and-organizational-performance/our-insights/why-diversity-matters

[9] Aline Mello, Amanda Melo, and Isadora Ferrão. 2019. Uma análise sobre questões de gênero nos cursos de Computação do municıpio de Alegrete/RS. In *Women in Information Technology (WIT)*. SBC, 61–68.

[10] Ministério das Mulheres. 2025. *Relatório Anual Socioeconômico da Mulher (RASEAM) 2025*. Technical Report. Governo Federal do Brasil. https://www.gov.br/mulheres/pt-br/central-de-conteudos/noticias/2025/marco/ministerio-das-mulheres-lanca-o-relatorio-anual-socioeconomico-da-mulher-raseam-2025 Acesso em 15 de agosto de 2025.

[11] Maria Pimentel, Juliana Eusébio, Rudinei Goularte, Uthant Leite, and Helen Picoli. 2024. Cursos Curtos Online Síncronos para Meninas do Ensino Médio e Concluintes e para Professoras do Ensino Básico. In *Anais Estendidos do XXX Simposio Brasileiro de Sistemas Multimidia e Web* (Juiz de Fora/MG). SBC, Porto Alegre, RS, Brasil, 203–210. https://doi.org/10.5753/webmedia_estendido.2024.243755

[12] M. V. RODRIGUES, M. L. L.; MALTEMPI. 2022. Evasion in MOOC Courses: a Case Study. *EaD em Foco* 12, 1 (2022). https://doi.org/10.18264/eadf.v12i1.1644

[13] Sociedade Brasileira de Computacao. 2022. BNCC Computação: Proposta da Sociedade Brasileira de Computacao. https://www.gov.br/mec/pt-br/escolas-conectadas/BNCCComputaoCompletodiagramado.pdf. Accessed: 2025-08-18.

[14] Sociedade Brasileira de Computacao. 2025. *Grandes Desafios da Educação em Computacao 2025–2035 - Resumo Executivo*. Sociedade Brasileira de Computação (SBC), Porto Alegre.

[15] Samir Cristino Souza and Luis Dourado. 2015. Aprendizagem baseada em problemas (ABP): um método de aprendizagem inovador para o ensino educativo. (2015).

[16] Technovation. 2025. Technovation Challenge: Empowering Girls to Become Tech Entrepreneurs. https://technovationchallenge.org/. Accessed: September 26, 2025.

[17] Marcelle Alencar Urquiza, Marcelo Henrique Oliveira Henklain, Felipe Leite Lobo, Acauan Cardoso Ribeiro, Luciano Ferreira Silva, Thaís Oliveira Almeida, Yaritza Barreto, and Natália Ribeiro de Almada. 2024. Incentivo à inserção feminina na computação: um relato de experiência sobre o projeto Macuxi digital. *RENOTE* 22, 1 (jul. 2024), 227–236. https://doi.org/10.22456/1679-1916.141550

[18] Yushan Jiang Zhi Hong Wan and Ying Zhan. 2021. STEM Education in Early Childhood: A Review of Empirical Studies. *Early Education and Development* 32, 7 (2021), 940–962. https://doi.org/10.1080/10409289.2020.1814986 arXiv:https://doi.org/10.1080/10409289.2020.1814986