A Model for the Development of Programming Courses to Promote the Participation of Young Women in STEM

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ABSTRACT

There is a gender gap in science, technology, engineering, and mathematics (STEM), and this is a global problem that affects society. However, it is worth pointing out that the gap is not uniform in all STEM fields. Women's underrepresentation is more marked in physics, engineering, and computer science fields. Nowadays, the labor market is becoming more competitive, technology-based and demands a diverse workforce. Therefore, it is important to continue promoting the participation of women in STEM, and the universities play a leading role in it. Previous research has shown that early learning experiences in STEM can show female students that they can succeed in this fields. This paper describes a model for developing programming courses for pre-university students to promote the participation of young women in STEM programs. The course was developed in one week, 25 students (16 girls and 9 boys) participated. The instructors of the course were four female professors. The programming language was Python, and the methodology used case-based learning. Both instructors and students gave positive comments on their experience in the course. The proposed model, including instruments, learning resources, and methodology, can be replicated and adapted to be used even in other learning fields.

CCS CONCEPTS

• **Social and professional topics → K-12 education**; **Computing literacy**.

KEYWORDS

Programming course, Women in STEM, Python

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1 INTRODUCTION

It is well known that there is a gender gap in science, technology, engineering, and mathematics (STEM) globally. However, the gap is not uniform across STEM fields. According to the American Physical Society, in the United States, biological sciences, chemistry, mathematics, and statistics are close to gender parity, whereas engineering, physics, and computer science are highly male-dominated. A recent report by UNESCO shows the same pattern globally [13]. The causes and consequences of the low participation of women in STEM fields have been studied extensively, with the purpose of identifying strategies to reduce the gender gap.

Cheryan et al. analyzed the reasons of the differences in women participation across STEM fields and proposed a model with three factors to explain the larger gender gaps in engineering, physics and computer science: (1) masculine culture, (2) insufficient early experience, and (3) gender gap in self-efficacy [1]. Masculine culture includes stereotypes of people in these fields, negative stereotypes of women abilities, and lack of female role models. Insufficient early experience refers to few course offerings that provide girls a sense of belonging in them, and freedom to choose courses, and opt-out of STEM classes. Finally, gender gap in self-efficacy refers to the differences between men's and women's estimations of their own abilities in STEM.

Maine and Schimpf examined the causes of the underrepresentation of women in computing fields across life stages [6]. They found that from preschool to middle school, four factors affect the access of girls to computers: (1) psychological, (2) material, (3) skills, and (3) usage. Psychological access refers to the difference in interest to use computers and video games between boys and girls. Boys tend to spend more time playing video games while girls spend more time using communication media and listening to music. Material access is explained by the difference in the number of boys and girls that own a video game system, as boys are more likely to own these systems. Skills access refers to the difference in computer skills between boys and girls, as boys tend to participate more in programming tasks than girls. Finally, usage access refers that boys use programming platforms such as Scratch more frequently than girls do. Concerning the high school age, several studies have shown that, on average, boys gain more computing experience compared to girls [6].

Labor markets opportunities influence major choices, and in the last years, specially after the onset of the COVID-19 pandemic, the labor markets are changing due to the need of adoption of new technologies. In a study conducted during 2019 and 2020, the World Economic Forum (WEF) and the LinkedIn Economic Graph Team identified eight jobs clusters that are growing in demand in the world: engineering, data and artificial intelligence (AI), cloud computing, product development, sales, marketing, people and culture, and content production. The 2021 Global Gender Gap report showed that only two of these emerging job clusters have gender parity. Women are underrepresented in most of the "future jobs." The lowest female representation in the workforce can be seen in cloud computing (14%), engineering (20%) and data and AI (32%), which are fields that require disruptive technical skills [2]. These results suggest that the gender gap in engineering and computer science will persist in the future because of the occupation segregation in emerging jobs [2].

With respect to Colombia, in 2020 it was estimated a deficit of 75 thousand systems engineers [12]. This need increased with the pandemic as it led all organizations to migrate their processes to more digital environments. At the same time, there is a limited offer of programs in systems engineering and computing, according to the National Information System for Higher Education in Colombia.

It has been shown that one way to encourage more girls to chose STEM majors is by offering courses to high school girls to provide a context in which they can increase their self-esteem and self-confidence about their STEM skills. Previous studies have shown successful experiences in the development of short programming courses for high school girls based on Java [8], and Ruby programming languages [7]. Another study proposed a prototype of a virtual reality (VR) system to teach the basics of programming that was evaluated with students of different ages [10]. It has been shown that improving skills related to logic in female high school students through programming courses, and promoting female role models supports the development of new ways of thinking related to the generation of enthusiasm towards STEM and creativity. Thus young women can see themselves pursuing a STEM career.

This paper proposes a model for developing and assessing programming courses for high school students with emphasis on girls that is based on the approach by Laguna-Sanchez et al. for women's leadership education programs [5]. The model is relevant and timely because it promotes the attraction of women to computing and could be replicated in universities or companies that bet on gender equality in STEM. In fact, nowadays, more companies add to offering training or short courses for various interest groups in the development of their corporate social responsibility and in the promotion of diversity in data science and related fields [9].

2 MATERIALS AND METHODS

One of the objectives of the W-STEM project [3] is the attraction of women to STEM programs. In 2020, the institutions that belong to the project consortium developed attraction campaigns for high school girls to increase the number of female applicants to STEM programs. Due to the public health measures in response to the COVID-19 pandemic, several hands-on activities that were planned had to be adapted to a virtual modality. With the purpose of developing technological skills in young girls, Universidad Tecnológica de Bolívar (within the W-STEM project framework) proposed an online summer course in programming.

The course offered practical experience in computer programming through basic exercises in the use of the Python programming language. The course took place for a week in July 2020. It was offered free of charge to high school students of the city of Cartagena de Indias during the summer break. More than 60 10th and 11th-grade students registered for the course, and 25 (16 girls and 9 boys) attended and completed the activities.

This section describes relevant aspects of the proposed course, such as the learning objectives, topics, technological tools, methodology, assessment, and students' achievements, among other details.

2.1 Course goals

The course was designed to address the following learning goals:

- To learn the principles of computer programming.
- To develop computational logic skills.
- To use variables and control structures to solve basic engineering problems through the implementation of algorithms and the use of a high-level language (Python).

2.2 Course design

The programming workshop is a practical course designed for teenagers interested in developing or improving their programming skills. It presents the fundamentals of computer programming educationally and funnily.

The course is based on the Python programming language, which is an open-source language widely used in the development of web applications and video games, in data science and artificial intelligence. During the course, the students solved practical problems using control instructions to get started in the world of programming.

The course is divided into five modules and each one was carried out in a session of one hour and a half:

(1) Fundamentals of programming.
(2) Input and output data.
(3) Use of variables and data types.
(4) Selection control structures.
(5) Iterative control structures.

2.3 Methodology

Each session began with the presentation of the contents to be discussed, and a review of the topics addressed in the previous session. Then, the topics of the module were developed. Students were instructed to intervene and ask questions at any time when needed.

The learning guide was focused on solving a particular engineering problem and oriented the students step by step to achieve a satisfactory solution. These steps can be summarized as follows:

(1) Statement analysis to identify input and output variables.

(2) Definition of the data structure: students should identify other data involved in the solution and how they should be defined.
(3) Functional requirements analysis: in this step, the students define the instructions to solve the problem and determine the order in which they should be written.
(4) Tests to validate the proper functioning of the program.

The course was administrated via Google Classroom. Classroom is a platform designed to manage learning activities mediated by technologies. This tool is free to use for teachers and students who have access to a Google account. Within the platform, it is possible to share educational resources, establish communication through messages and notifications, and even assign activities to students and give them feedback. Within Classroom, the information was organized into four sections:

- Virtual meetings, where the links to the recordings of each virtual session were published. The classes were developed using Google Meet video conferencing.
- Support resources, where the presentations of each session, the case studies, and some tutorials for the use of technological tools were shared.
- Assignments, where the students submitted their assignments.
- Others, where two surveys were posted (one to be filled at the beginning of the course, and another at the end).

In the initial survey, the students reported their access to technological tools for the course (personal computer, laptop, smart phone, internet connection) and their previous programming experience. In the closing survey, the aim was to inquire about the students' experience in the course and receive their opinions and perceptions in aspects such as contents, methodology, technological tools and general quality of the course.

Another tool that was fundamental in the development of this course was Colab (https://colab.research.google.com/). This programming environment allows writing and running Python code in the web browser easily, for free, and without the need for installing software or configuring the system.

Each session included an assignment for the students. The first assignment was to complete the initial survey. The second assignment was a set of exercises to practice the Python language syntax and get used to the Colab environment. Starting the third session, a study case was proposed for the students to solve using computational algorithms in Python. Table 1 shows the assignments for each session and the number of students that successfully completed each assignment by gender.

2.4 Evaluation instruments

Two evaluation instruments were developed to collect opinions and perceptions of instructors and students. They were carried out through online questionnaires. The instructors' questionnaire had two parts. The first part was about the trainer's personal information: gender, age, and education. The second part included open questions about the program. For example: What do you highlight about the execution of the workshop in terms of participants, contents, and methodology? What were the main difficulties? How would you rate your experience as a trainer in the workshop? How do you think this program contributes to reducing gender inequalities in STEM? Some of the students' questionnaire questions were: Was this workshop your first virtual training experience in programming? How would you rate the quality of the contents, your learning, the technological tools, and the activities developed? What was the most important learning?

2.5 Conceptual model

According to the TPACK (Technological Pedagogical Content Knowledge) model, an e-learning system must intertwine three fundamental components: technology, pedagogy and content [4]. However, other authors have emphasized the importance of the human component in the development of a technology-mediated learning system. This is how other models have been specified that highlight People, Technology and Pedagogy as their three main elements [11]. The model for the development of this programming course was based on the last mentioned approach, as shown in Figure 1. It has three components:

(1) Human component. The instructors of the course were female professors of systems engineering to have female role models for the students. The course was open for boys and girls, but the promotion materials showed images of girls using computers, to encourage girls to participate.
(2) Technological component. The technological resources and programming environment were chosen because they can be used free of charge. Python was chosen as programming language because is used widely for software development and AI applications, and it is under an open source license.
(3) Pedagogical component. We used case-based learning as one of the educational strategies of the course. Thus, it was possible to pose real engineering problems and propose their analysis and discussion to reach a satisfactory solution. In addition, for each session, digital resources were developed to support the learning process. At the end of each module, a homework activity was proposed to consolidate knowledge and evaluate the performance and progress of the students.

3 RESULTS AND DISCUSSION

3.1 Students' performance

As seen in Figure 2, most of the girls (75%) and half of the boys reported having no previous training experience in programming. However, their performance in the course was good. Figure 3 shows the percentage of boys and girls that completed the assignments of the course. It can be seen that most of the students could complete the activities of the first three sessions. However, they had more difficulties with the fourth assignment, as it was the first time they learned about control structures. The results of the last assessment were better.

3.2 Students' perceptions

The results show not only a positive impact on the acquisition of programming skills by the students, but also an increase of their self-confidence. This can be seen in the results of the final survey. The survey was completed by 20 students, aged 13 to 17 years, 12 girls and 8 boys. The survey included questions to evaluate the quality of

Table 1: Assignments proposed in each session. A total of 16 girls and 9 boys attended the course.

Session	Assignment name	Assignment type	Girls' submissions	Boys' submissions
1	Presentation	Initial survey	10	4
2	Knowing Colab	Basic exercises	13	7
3	Pythagoras	Python case study	14	6
4	Conditionals: Quadratic equation	Python case study	6	0
5	Cycles: Angry birds	Python case study	9	6

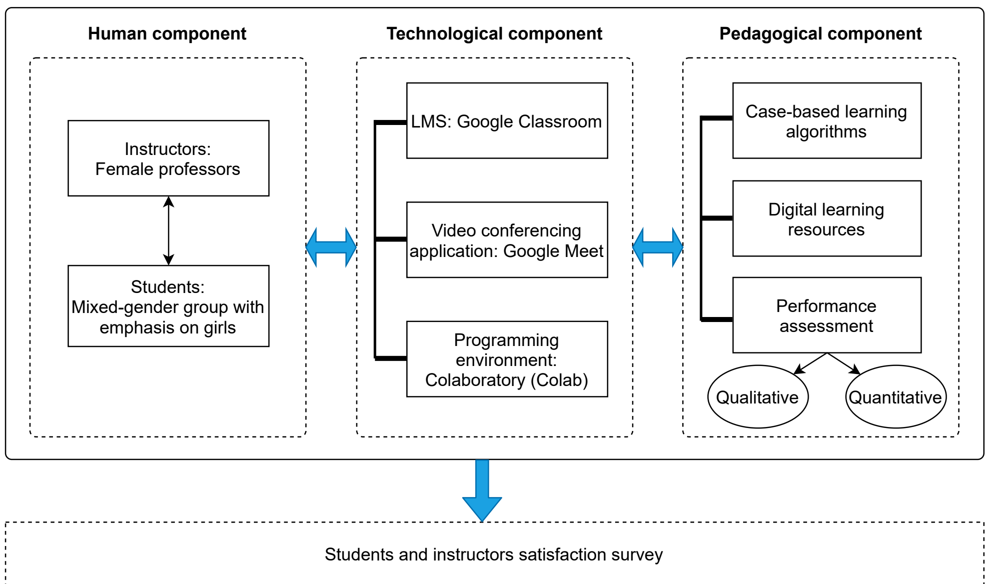

Figure 1: Conceptual model for the development of programming courses to promote the participation of young women in STEM.

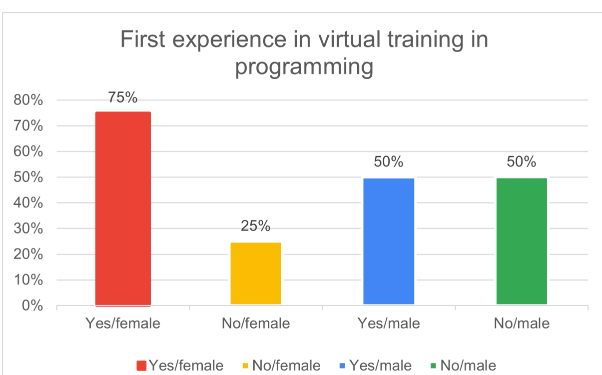

Figure 2: Percentage of students for whom this course was their first training in programming.

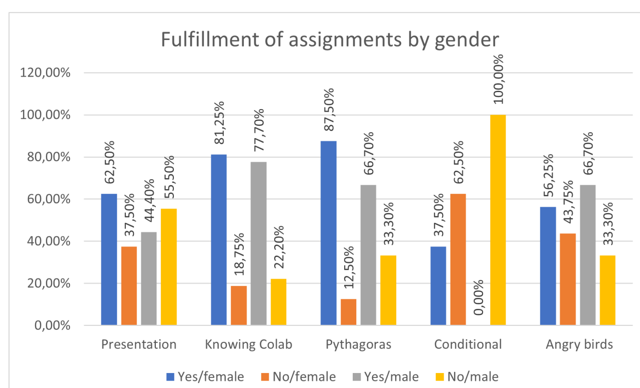

Figure 3: Percentage of students by gender that completed the proposed assignments of the course.

the contents, learning experience, technological tools and activities. Figure 5 shows the results of the evaluation of the modules by gender. Additionally, two open questions were included to collect general comments about the importance of the topics covered and their learning experience. The students provided positive comments about the course. Figure 4 and Table 2 shows some of them.

Table 2: Students' perceptions

Experience	Contents	Methodology	Other
"beautiful experience" "very fun experience" "good experience" (Stud. 4; Stud. 14; Stud. 18 and Stud 19) "I was surprised, and I would repeat it again" (Stud. 10)	"even though it is basic, it is the basis for more advanced knowledge" (Stud. 17)	"excellent methodology" (Stud. 1) "there is a lot of interaction with the students" (Stud. 14) "quite practical the way of explaining" (Stud. 19) "attentive to any questions that we could present" (Stud. 19)	"it will serve me a lot in everyday life, especially in the career I want to study." "it will serve me a lot in the future" "this technological knowledge will be very valuable from now on." "it will serve at some point in our lives" (Stud. 8; Stud. 5; Stud. 2 and Stud. 1)

Figure 4: Feedback comments made by the students.

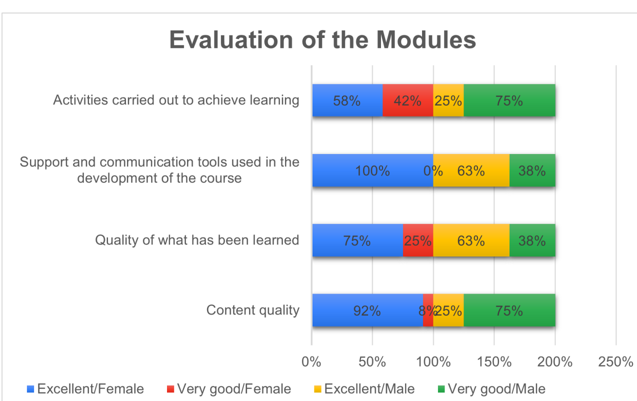

Figure 5: Evaluation of the course made by the students.

3.3 Instructors' perceptions

The perceptions of the instructors were carried out through an online questionnaire. The average response time of the questionnaire was fifteen minutes. The conventional content analysis approach (inductive analysis) was applied with sixteen open-ended and multiple-choice questions. The sample was made up of four trainers, 100% are women, between 38 and 48 years old, have a master's degree in and participated in at least two of the four modules offered in the course.

The results showed a positive impact of the experience of the instructors of the program, 100% chose the rating "Excellent". They would participate in this program and other similar strategies in the future. Some of the results of the description of their experience in their own words: "enriching experience" "gratifying" (Inst. 1; Inst. 1 and Inst. 4) and the novelty of working with the audience coincides: "enriching to be able to reach students from secondary school" "excellent opportunity to interact with the youth population" "rewarding working with adolescents" (Inst. 1; Inst. 3; Inst. 4)

To find out how this course contributes to reducing gender inequalities in STEM in the words of the trainers: "it gives them confidence that they can study a STEM program" "every time you manage to connect a girl with the potential that is in her, you contribute to this objective" (Inst. 2 and Inst. 3). Lack of confidence has been one of the main reasons identified in the literature why girls are not attracted to study computer science and engineering programs [1]. Among the aspects that become opportunities for improvement: "being able to reach more students in the region and greater dissemination" (Inst. 1), "Internet connection" (Inst. 2) and "follow-up the participants" (Inst. 2).

3.4 Discussion

The proposed online course integrated three core elements, as presented in the conceptual model in Figure 1: the human component, the technological component, and the pedagogical component.

It should be noted that, within the human component of the model's structure, the female gender is emphasized. This is due to the course's main objective, which focuses on promoting the participation of female students in STEM areas.

Table 3: Instructors' perceptions

Participants	Contents	Methodology	Other
"the motivation they had" (Inst. 1). "they were active participating" "(Inst. 2). "they were very receptive" "good reception" (Inst. 3 and Inst. 1)	"according to age and level of prior knowledge" (Inst. 1). "basic content of fundamentals in programming" "basic but fundamental to get started in algorithmic thinking" (Inst. 4 and Inst. 1)	"practice" (Inst. 1). "good participation" (Inst. 1). "they kept the motivation until the end" (Inst. 1) "active" (Inst. 4)	"free tools" (Intr. 1). "use tools that had not used before for teaching" (Inst. 2)

Technology is the mediator between the course participants and the pedagogical strategies implemented in the proposed conceptual model. In other words, through this structure, the learner interacted with the learning resources and the assessment instruments through the use of the technological tools arranged for this purpose (Classroom tool, video conference tool, and programming environment). In short online courses, it is very important to have open-source tools that allow collaborative work in real-time. It is also essential to use intuitive tools that facilitate interaction and do not require further configuration, especially when learners do not have prior knowledge.

With respect to the pedagogical component, the implementation of the case-based learning strategy is emphasized, as it can be very effective in theoretical-practical courses. To complement the learning process, the students had supportive educational material given by the instructors, which was published in the virtual classroom. Finally, the students had to upload the developed cases to the virtual classroom. The instructors reviewed the exercises to assess the learning process, issued scores, and provided qualitative feedback on the observed performance. In this way, it was possible to move forward and clarify doubts.

At the end of the course, a survey was applied as a mechanism to validate the student's and instructors' levels of satisfaction during the summer course. 65% of the students indicated that the summer course was their first experience in virtual programming training. Therefore, these spaces are a great opportunity to encourage technology-mediated learning in young people and promote the incursion into STEM areas, especially in girls. According to the experience of the participants, the perception ranged between excellent and very good in terms of content, technological tools used, and learning achieved. This shows that the design proposed in the course model achieved a successful result.

As future work, other areas of knowledge that are part of STEM, such as robotics, and electronics, will be explored. In addition, an expansion of coverage is planned to promote the participation of a higher number of students from other regions of Colombia, taking advantage of the global situation that favors the massive implementation of technologies for education. Finally, it is planned to evaluate in three moments: before, during, and after the activities, incorporating more variables in the measurement, which will provide more information on the model's efficiency.

4 CONCLUSIONS

One strategy that has been proposed in the literature to attract women to STEM careers is the development of programming courses for adolescents. Recent studies have shown that girls are less exposed than boys to stimuli that motivate them to study STEM careers such as video games, STEM courses, programming courses, etc. This article proposes a model for the development of programming courses for high school girls and boys. The model consists of three components: human, technological and pedagogical, and is accompanied by assessment instruments that are applied to both students and instructors. The results of the first implementation of the course are positive and it is expected to continue replicating and adjusting this model in the future.

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