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Bridging Informal and Classroom-Based STEM Engagement: A Multi-Context Outreach Model

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Abstract*– STEM education continues to face challenges associated with limited exposure to experimental methodologies and predominantly lecture-centered practices, particularly in Latin American contexts. This study presents the design, implementation, and evaluation of Ciencia para Todos (Science for All), an integrated university-led outreach model centered on three main lines: Science in Public Spaces, Science in Museums, and Science in the Classroom. This work promotes and articulates experiential public activities, mediation by university students, structured teacher training, and digital dissemination within a unified operational structure. Evaluation was conducted using quantitative and qualitative perception indicators collected from public participants, undergraduate facilitators, and secondary school teachers across multiple implementation contexts. Results indicate high reported levels of satisfaction and perceived usefulness in informal environments, strong perceived applicability of active methodologies among teachers, and consistent formative reflections from participating students. Since the evaluation relied primarily on perception-based measures, rather than controlled learning instruments, the findings should be interpreted as indicators of perceived reception and transferability. The proposed framework provides a basis for future longitudinal evaluations of university-led STEM outreach initiatives.

***Keywords*-- Experiential learning, Science communication, University engagement, Informal learning, STEM outreach.**

I. Introduction

Science, Technology, Engineering, and Mathematics (STEM) education is fundamental to the development of innovation-driven economies, as it offers solutions to societal problems that require scientific development and technological competence. However, a disparity persists between the scientific knowledge received by a significant portion of society, particularly children, adolescents, and non-specialist audiences, who have limited direct exposure to experiential or inquiry-based learning environments. In several Latin American contexts, structural constraints such as limited access to laboratory infrastructure, misconceptions about STEM career paths, and teaching practices predominantly centered on lectures have led to lower participation and declining interest in STEM pathways [1]. These factors collectively contribute to a perception of science as complicated, abstract, or inaccessible, especially in the early stages of education.

Therefore, informal and non-formal science initiatives have been examined as complements to traditional classroom education. Previous research has shown that experiential activities, public demonstrations, and active participatory learning can not only improve positive perceptions of science but also increase curiosity about STEM disciplines by reducing the cognitive and emotional barriers associated with traditional education [2]–[4]. In particular, environments in which students voluntarily participate and are directly involved in hands-on experiments have been shown to attract diverse audiences. Most of these reported efforts have been isolated or short-lived, and therefore, there has been little documentation examining integrative efforts that articulate multiple outreach channels along with systematic evaluation strategies capable of assessing their development and impact [3], [5].

In our previous research on STEM motivation among high school students [6], we reported how pedagogical practices and limited exposure to interactive methods had a significant impact on students' academic perceptions. These findings indicated that successful active learning methods should not only target students but also be applied to pedagogical aspects and techniques used in the classroom. In this context, Science for All was developed as a university-led STEM outreach model built on three interconnected lines: Science in Public Spaces, Science in Museums, and Science in the Classroom.

The model integrates experiential activities, undergraduate student mediation, teacher training in active learning methodologies, and digital dissemination within a unified operational framework. It involves multiple stakeholder groups, including members of the public (children, adolescents, and families), undergraduate students from the Escuela Politécnica Nacional (EPN) acting as facilitators, and secondary school teachers participating in training programs. Activities are designed and coordinated by faculty members, with undergraduate students contributing to the preparation and implementation of experimental stations and communication strategies. This structure allows the model to simultaneously address science outreach, student learning experiences, and teacher professional development.

This study describes the design, implementation, and evaluation of the proposed outreach model. Quantitative and qualitative perception indicators collected from different stakeholder groups are analyzed to characterize their reach and reception. By documenting its structure and results, this work contributes to current discussions on integrative STEM outreach strategies in higher education contexts, particularly in Latin America [7].

The remainder of this document is structured as follows. Section II describes the application model for outreach, highlighting its principles and lines of action. The results obtained are presented and discussed in Section III. Finally, Section IV concludes with a summary of the findings and future work.

II. The "Ciencia para Todos" Outreach Model

Organized as an integrated STEM outreach model, the Science for All initiative seeks to promote inclusive and interactive approaches to engage students with science in diverse educational settings. The operational structure of the model is summarized in Figure 1. The proposed framework articulates three lines of support that target different audiences, while maintaining shared pedagogical characteristics and providing feedback to one another.

A. Guiding Principles

The four fundamental pillars on which this model is founded are:

(1) experiential learning through hands-on experimentation,

(2) implementation in informal and non-traditional environments,

(3) inclusive and accessible design, and

(4) active involvement of undergraduate STEM students as science mediators.

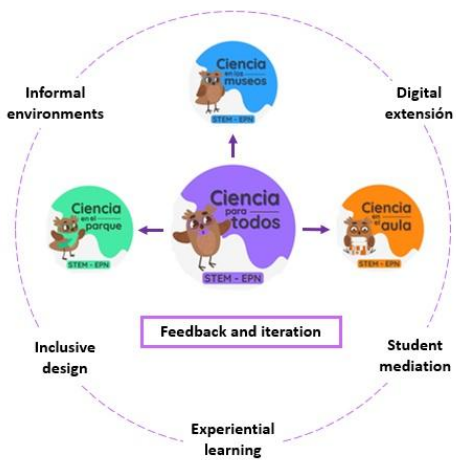

Fig. 1 Fig. 1. Operational structure of the Science for All outreach model, with its three transversal lines of work and feedback loops for continuous improvement.

These principles provide structural coherence across implementation contexts, but have also been adapted to specific audiences and institutional contexts. In practice, experiential learning is implemented through low-cost experimental systems that prioritize conceptual clarity and the applicability of science to everyday life over technological complexity. The focus on informal settings seeks to reduce barriers to access and encourage voluntary participation. Inclusive considerations will influence the choice of language and the organization of the activity's structure, promoting the use of different senses for experiencing the experiment. The active participation of young undergraduate students, on the one hand, increases participants' engagement with the activities and, on the other hand, helps them connect their professional knowledge with accessible communication practices.

B. Outreach Lines

1) Science in Public Spaces

This outreach strategy is implemented in open and accessible spaces, such as urban parks and public science events. Interactions are facilitated through modular experimental stations for quick (not too long) interactions and spontaneous participation. This format is suitable for diverse audiences, especially families and school-age groups. Activities are designed by faculty and student teams and implemented through voluntary participation of undergraduate students acting as science mediators.

2) Science in Museums

Outreach activities are integrated into the programming of museums that collaborate on the project, such as the Interactive Science Museum (MIC) and the Gustavo Orcés V. Natural History Museum (MHNGOV). For these reasons, museum implementations allow for longer interaction times and a more organized and potentially more participatory mediation model compared to interventions in public spaces. Activities are co-developed in collaboration with partner institutions and facilitated by trained undergraduate students under faculty supervision.

3) Science in the Classroom

This approach broadens the initiative and makes it relevant to both formal and semi-formal educational settings. This will include teacher training programs and the development of a digital educational platform. Emphasis is placed on transferring active and experiential methodologies to secondary education, with the aim of promoting sustainable implementation in the classroom. Training courses are designed and delivered by faculty members, with support from the project team in the development of materials and digital resources.

C. Student Mediation and Iterative Improvement

Undergraduate students actively participate as facilitators and contributors to the design of activities across all of the project's outreach initiatives. Their involvement includes designing and preparing experimental materials, creating scripts tailored to the target audience, direct interaction with participants, and facilitating post-activity reflection sessions. Feedback gathered from participants and student facilitators is incorporated into subsequent implementations.

This iterative process allows for the progressive refinement of activities and facilitates the scalability of the model. Science for All functions as a structured framework for university outreach, rather than a collection of independent events, by integrating citizen participation, institutional collaboration, and interventions with high school teachers.

III. Results and Discussion

A. Outreach Scope Across the Three Project Lines

The Science for All model was implemented through three related outreach initiatives (Science in Public Spaces, Science in Museums, and Science in the Classroom). These initiatives, together, facilitated the participation of different age groups in informal, semi-formal, and teacher-centered contexts.

Table I presents the approximate number of people reached in each outreach initiative, as well as the total number reached over the 18 months of the project. It is important to note that, given that a large number of activities, particularly in parks and at public events, were open to the public, the number of participants was estimated based on institutional data (museums) and the collection of photographic and audiovisual information (parks), rather than on registration data from individual participants.

The largest direct beneficiaries were those of Science in Public Spaces. Nearly 1,400 people attended more than fifteen sessions held in urban parks and at open science events. The intervention was based on modular experimental stations, a minimum of four stations per session, which allowed for short-term interactions, often with families.

TABLE I
Outreach Scope Across the Three Project Lines

Project line	Outreach context	Number of interventions	Estimated direct participants
Science in Public Spaces	Urban parks and open science events	>15 sessions	≈ 1,400
Science in Museums	MIC and MHNGOV museums	Multiple weekends	≈ 570
Science in the Classroom	Teacher training programs and virtual platform	2 structured training courses + ongoing platform	79 teachers
Total			≈ 2000

Science in Museums was implemented in collaboration with the MIC and MHNGOV. Most of the activities took place during the summer to take advantage of school holidays and the increased attendance at these spaces. The guided demonstrations and interactive stations integrated into the museum's programming reached approximately 578 participants over several weekends.

The Science in the Classroom program was aimed at formal and semi-formal teaching environments through teacher training and the design of a virtual learning environment. 79 secondary school teachers participated in training organized around robotics, experimental physics, and active learning methodologies.

Overall, these three outreach initiatives reached approximately 2,000 direct beneficiaries in public, institutional, and educational settings. While these figures are estimates at the event level and are not derived from individual participant records, they represent a general estimate of the operational scope and contextual diversity of the implemented activities. The composition of participants across the different engagement types also reflects the structural nature of the model's design, which is intended to function in multiple interaction environments.

B. Public Perception in Informal Learning Environments

Participant perceptions were measured using voluntary questionnaires at outreach activities in parks and museums. Since these interventions were available through open access, responses were analyzed descriptively and presented as percentages to facilitate comparisons between populations in different settings. The survey instruments were based on Likert-type scales, and responses were aggregated into percentage indicators to allow comparison across different outreach contexts.

As depicted in Figure 2, high satisfaction and perceived usefulness were observed across all contexts. For the park activities (n = 85), the mean satisfaction score was 4.89/5, or 97.8% when normalized. 98.8% of respondents indicated that they found the activities useful and would recommend them to others. The average number of participants accompanying each respondent to the intervention was 2.95, indicating that these interventions were primarily implemented in small family groups.

For the Interactive Science Museum activities (n = 38), the average satisfaction score was 4.8/5 (96.0% normalized). All respondents reported the activities as useful, and 97.4% were willing to recommend the event. The hands-on demonstrations were particularly well-received, with 90% of participants rating them "Very Good."

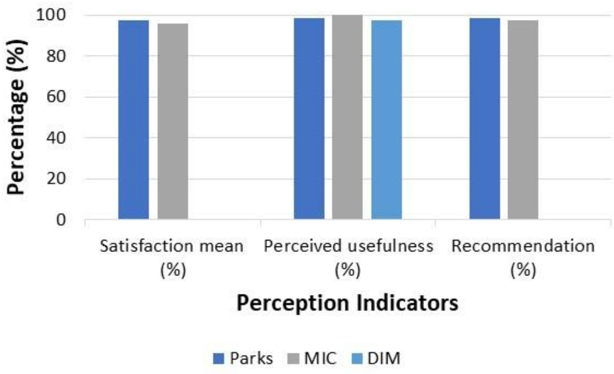

Fig.2 Perception indicators in three informal outreach contexts. Mean satisfaction scores (Parks and MIC) were normalized to a percentage scale (mean/5 × 100). DIM data were only available for perceived usefulness. Percentages correspond to voluntary survey responses collected during each event (Parks: n = 85; MIC: n = 38; DIM: n = 79).

For International Museum Day (n = 79), 97.7% of respondents found the information provided to be both useful and novel. While an average satisfaction score was not reported for this event, 78.6% of respondents gave it the highest possible satisfaction score (5/5).

Across all settings, qualitative feedback, gathered through open-ended survey responses and informal interactions during the activities, consistently highlighted the clarity of the explanations, the accessibility of the experiments, and the participation of the attendees. While survey participation was voluntary and not all attendees responded, the consistency of these observations across separate events suggests that the experiential approach implemented is well-received in different informal contexts. Although not comparable to controlled learning measurements, these perceptual findings provide information about the public's reception of the activities and the relevance of this type of experiential learning.

C. *Undergraduate Student Engagement as Science Mediators*

All outreach activities included undergraduate students as facilitators and collaborators in the design, preparation, and presentation of the activities. Participation records show that 49 students from different majors participated in outreach activities as shown in Figure 3.

The highest percentage of students was from the Electronics and Automation (40.8%) and Physics (38.8%) majors, followed by Telecommunications (10.2%). Participation in Applied Mathematics, Economics, and Information Technology represented smaller proportions. This distribution demonstrates that, as a multidisciplinary project focused on all STEM areas, students from diverse backgrounds are drawn to collaborate and support the project.

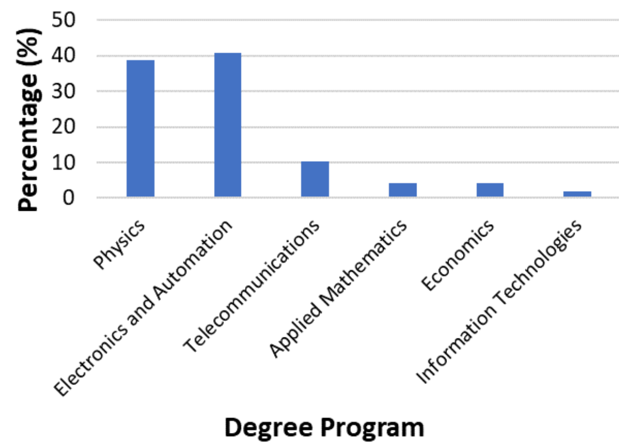

Fig. 3 Distribution of undergraduate student participation by degree program. Percentages are calculated based on consolidated attendance records of 49 students who participated in outreach activities.

Reflection sessions with participating students showed signs of improvement in their communication skills and public speaking confidence. Several reported that, at the beginning of their participation, the main difficulty was translating technical concepts into something understandable for the general public. However, it could be said that exposure to a variety of topics and people gradually developed their adapted communication strategies.

These findings indicate that participating in the formal process of scientific mediation can foster the acquisition of transversal skills in undergraduate students, especially in communication and adapting disciplinary knowledge to diverse audiences. While this study did not use standardized tools to measure these advances, the convergence of results and opinions among the students points to an improvement in their soft skills, particularly in empathy and public speaking.

D. *Impact of Teacher Training and Digital Outreach*

Our previous study on motivation in STEM [6] found that teaching activities based exclusively on lectures were associated with less interest in scientific topics. Based on these results and observations, the outreach model was complemented with structured teacher training activities to engage teachers in more active and experimental learning methodologies. The main objective was to convey that sophisticated resources or well-equipped laboratories are not necessary to teach science interactively and experimentally.

Two training courses were conducted within the Science in the Classroom program: one on educational robotics (n = 34) and the other on teaching experimental physics and active learning (n = 32). For comparative purposes, three benchmark indicators were examined in both courses: overall satisfaction, clarity of objectives, and classroom applicability. Responses for the two highest Likert categories were aggregated and presented as percentages.

Very high scores were obtained: 97.1% for overall satisfaction, 100% for clarity of objectives, and 97.1% for applicability in the robotics course. All three measures reached 100% in the experimental physics and active learning course. As illustrated in the results in Figure 4, responses were mainly concentrated around the most demanding evaluation criteria, suggesting that the methods employed are perceived as transferable. The teachers highlighted that the hands-on experiences, based on accessible materials and robotic interventions, could be adopted in their classrooms. In addition to face-to-face training, a digital component was included to ensure the continuity of individual sessions.

This work included the creation of an online educational platform and the compilation of experimental guides with low-cost resources and materials. Dissemination on social media was well documented, with a total of more than 730,000 views, reflecting its reach beyond geographical boundaries. While these are not immediate measurements of the impact on learning, digital engagement metrics indicate the degree of reach of the initiative beyond the planned intervention spaces. The digital component now serves to complement this secondary dissemination layer, enabling ongoing participation and access to educational materials beyond the classroom.

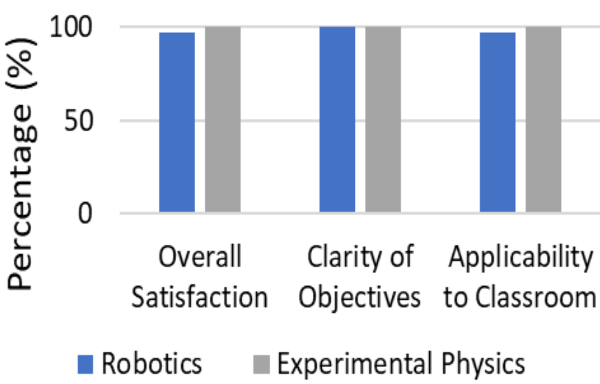

Fig.4 Teacher training evaluation indicators for robotics (n = 34) and experimental physics (n = 32) courses. Percentages correspond to the aggregation of "Very Satisfactory" and "Completely Satisfactory" responses for overall satisfaction, clarity of objectives, and applicability to classroom practice.

E. *Discussion and Limitations*

The results of the three outreach initiatives indicate a positive perception rate among participants from the general public, university students, and secondary school teachers. However, the interpretation of these results must be based on prior institutional experience and methodological limitations.

Our previous research conducted within the framework of the STEM motivation project for secondary school students [6] demonstrated that these students' lack of interest in science and technology careers was related to difficulties in understanding mathematics and physics, and limited exposure to interactive learning experiences. This study not only identified the direct role of teachers in students' demotivation in these areas but also the effect of traditional methodologies. This work inspired the subsequent development of Science for All, which has transcended methodological activities focused exclusively on students and now extends its reach to training sessions for secondary school teachers and greater participation from the general public.

As observed in this implementation, the perception data collected in parks and museums revealed high levels of satisfaction and usefulness, as participants interacted directly with the experiments. Children and young people showed particular interest in explaining everyday events in a simple way. The similar responses observed in the different contexts highlight that these hands-on, mediated experiments are attractive and interesting to a diverse group of people. However, participation in the survey was voluntary, and not all respondents answered. Therefore, the results represent self-selected samples, not a controlled sample. Furthermore, due to logistical limitations, a pre- and post-assessment of conceptual understanding was not conducted during the open public interventions. Given the open-access nature of the interventions, demographic variables, such as participant age, were not systematically collected in all contexts, which limited a more detailed analysis. For these reasons, the results presented should be interpreted as perception-based indicators rather than direct measures of learning progress.

Regarding undergraduate student attendance, it far exceeded the planned number (20 students). The participation of facilitators from different disciplines suggests that these outreach activities are appealing and are perceived as opportunities to have formative impacts on the development of their communication skills. These reflections, as well as the continuous improvement in each activity, were made possible by weekly follow-up meetings. Unfortunately, these findings are based on qualitative reflections rather than standardized assessment instruments, which limits the ability to quantitatively evaluate the development of transversal competencies.

Similarly, the teacher training showed a concentration of responses in the higher categories of the Likert scale, confirming the perceived validity of the proposed active learning methods. This observation is consistent with previous research [6] that showed that traditional lecture-centered approaches are a key factor in student demotivation from pursuing careers in science. Nevertheless, the surveys in this study largely reflected perceived training satisfaction and transferability rather than a measurable improvement in student performance.

Although the initiative aligns with the principles of inclusive and accessible participation in STEM disciplines, the present study did not include a gender-disaggregated analysis. This represents an additional limitation in the interpretation of participation patterns.

The combination of activities carried out in different contexts and with different target audiences, the mediation of undergraduate students, and the training of teachers by university professors within a single operational structure distinguish this model from existing isolated outreach activities. Analyzing and expressing these elements as part of a coherent model provides an opportunity to explore the interaction between its constitutive lines and achieve continuous improvement. The convergence in perception indicators suggests signs of contextual flexibility and operational coherence.

Future work will focus on incorporating longitudinal evaluation strategies, including monitoring teaching practices, structured assessment of student learning in controlled environments, and the use of validated instruments to measure the development of communication and transversal skills in participating undergraduate students. Moreover, future implementations will consider including indicators disaggregated by demographics and gender to allow for a more comprehensive analysis of participation and impact. These efforts will contribute to strengthening the empirical basis of STEM outreach initiatives led by universities in Latin American contexts.

IV. Conclusions

In this article, we present the development, implementation, and evaluation of Science for All, a STEM outreach model promoted by the university, framed within three interrelated lines: Science in Public Spaces, Science in Museums, and Science in the Classroom. The approach encompasses experimental activities involving public participation, student mediation, interventions focused on high school teachers, and digital dissemination, all under a single operational structure. Perception indicators collected in informal environments and teacher training contexts showed high reported levels of satisfaction and perceived applicability, while the participation of university students suggested possible formative effects on scientific communication. While the evaluation was based primarily on perception-based measurements and qualitative reflections, the results suggest that they should be interpreted as indicators of perceived reception and transferability, rather than as direct evidence of learning outcomes.

The evolution from a student-centered motivational project to a broader outreach framework that involves teacher capacity building and public engagement is a natural consequence of this practice. Future work includes establishing a diploma program for secondary school teachers in collaboration with digital educational platforms, as well as astronomical outreach activities, complemented by telescope infrastructure. Longitudinal and structured evaluations will be conducted to determine whether this integrated outreach model is sustainable and effective for education.

Acknowledgment

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