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From Pilot to Practice: Expanding Remote STEM Education Across Remote Communities (Evaluation)

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I am a former Associate Professor in the Science and Mathematics Department at Columbia College Chicago, with over 25 years of experience promoting STEM education in communities worldwide. Beyond my teaching responsibilities, I have actively worked to expand STEM learning opportunities in underprivileged communities.

My efforts include developing and implementing various community engagement programs, such as:

1. Scientists for Tomorrow – Co-Principal Investigator (Co-PI) of this NSF-ISE-funded initiative, aimed at integrating STEM learning into Out-of-School Time programs at community centers.

2. Junior Research Scientists Program – A program funded by After School Matters to support high school students in Chicago in conducting STEM research.

3. STEAM Learning Collaboration – Partnered with CCAS-NEIU to enhance STEM learning in the Upward Bound Math & Science program.

Additionally, I co-founded and co-chair the student-led STEAM Conference and established ManifiestoSTEAM, a collaborative initiative promoting STEM education in Spanish-speaking, underprivileged communities across Latin America. I also collaborate with international organizations such as the OEA and Virtual Educa.

Currently, I am developing a blended learning strategy to bring high-quality STEM education to remote and rural communities. This initiative aims to spark students' interest in STEM subjects and careers, fostering local talent and opportunities.

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Abstract

Following the success of an initial pilot project aimed at addressing educational inequities in rural areas through a blended remote learning approach, this paper presents the outcomes of its second and expanded implementation across 11 remote schools in Latin America, and the third implementation with 23 schools including 12 rural school under the Consejo Nacional de Fomento Educativo (CONAFE) Mexico. The pilot focused on enhancing STEM education by providing remote instruction, access to learning management systems, and hybrid learning models, combining expert urban teachers with local educators. The success of the pilot motivated a larger-scale implementation, which this paper details.

In this phase, the educational methodology from the pilot process (described in a previous paper) [1] was applied in a second implementation across 11 schools. Students explored key concepts on energy, sustainability, and microgrid construction for community use. The study highlights how hands-on projects and remote collaboration engaged students despite infrastructure challenges. Data collection included pre- and post-tests, student attitude surveys toward STEM, and participation in synchronous and asynchronous learning activities.

A third implementation was designed to assess the feasibility of remote learning in underprivileged areas with limited resources, focusing on schools supported by the Consejo Nacional de Fomento de la Educación (CONAFE). Additionally, other schools that voluntarily chose to participate were also included in the project.

The paper will present the results, which show significant improvements in students' understanding of STEM concepts and increased interest in STEM careers. Additionally, hands-on projects demonstrated the potential for rural communities to independently generate and manage electrical energy. This study examines key factors, challenges, and lessons learned, providing a replicable model for remote STEM education in underprivileged regions.

1. Introduction

The growing need for sustainable energy in rural and underserved areas has sparked global interest in educational programs that address both the technical and social challenges of energy access. At the same time, rural schools face significant challenges compared to their urban counterparts, especially in access to quality STEM education. To help close this gap, a hybrid learning model was developed to promote topics like Energy, Electricity, and Sustainability in rural and urban communities. To test this model's tools and feasibility, a pilot project called Microgrid V1.0 was launched in four Latin American schools. The goal was to provide students and teachers in underprivileged rural schools with the skills to design and build renewable energy systems, specifically microgrids. The project combined hands-on learning via the implementation of Project Based Learning (PBL) approach with remote instruction, offering a blended approach that integrated key STEM concepts such as energy transformation, sustainability, and electricity generation through remote learning and blended strategies.

2. Theoretical frameworks

As mentioned previously, the educational model developed to provide remote quality education in STEM in remote or rural locations is based on several pilar, that includes Project Based Learning and Remote Learning. Following is a summary of their characteristics:

2.1 Project-Based Learning (PBL)

PBL is a student-centered approach grounded in constructivist principles, emphasizing active engagement with real-world problems [2]. By participating in meaningful projects, students acquire knowledge and develop critical skills, including problem-solving, collaboration, and creativity [3].

Key Attributes of PBL:

1. **Student-Centric Learning:** Students actively direct their learning process, enhancing autonomy and relevance [4].
2. **Skill Development:** PBL promotes 21st-century competencies—critical thinking, collaboration, communication, and creativity [5].
3. **Interdisciplinary Approach:** Projects integrate multiple disciplines, fostering a holistic understanding of complex issues [6].

4. **Collaboration:** Group work enhances social skills and knowledge retention through peer interaction [7].
5. **Authentic Assessment:** Evaluation focuses on tangible outcomes and reflective processes, encouraging metacognitive skills [8].

Challenges in PBL Implementation: Despite its benefits, PBL presents several challenges:

- **Planning Complexity:** Teachers need to design projects that align with learning objectives and remain feasible within available resources [4].
- **Resource Constraints:** Limited access to materials and technology can hinder project execution, particularly in under-resourced rural areas [8].
- **Teacher Training:** Effective facilitation requires training in fostering autonomous and collaborative learning environments [4].

2.2 Remote Education

Remote education, often confused with distance learning, emerged predominantly as a response to emergencies, including the COVID-19 pandemic [9]. Unlike the structured and pre-planned nature of distance education [10], remote education was implemented rapidly to address mobility restrictions. This distinction underscores the adaptability and immediate applicability of remote education in times of crisis.

Hybrid Education: Remote education has evolved into hybrid models that combine synchronous and asynchronous methods. This shift provides flexibility, enabling students in remote regions to access quality educational materials and real-time interactions with instructors. Platforms like Moodle and Zoom have been instrumental in facilitating these models, enhancing collaboration and personalized learning [11]. However, challenges such as the digital divide persist, particularly in rural areas where access to devices and stable internet is inconsistent [12].

To counter these challenges, strategic interventions include:

- Provision of affordable devices and internet connectivity.
- Asynchronous learning modules that reduce dependency on real-time internet access [13].
- Continuous professional development for teachers to adapt to digital tools and hybrid methodologies [14].

2.3 Promoting STEM Education in Rural Areas

In this project, integrating remote education with PBL provides a robust framework for addressing STEM education disparities. By leveraging technology and active learning methodologies, students in rural regions gain exposure to practical and theoretical STEM applications. Specific focus areas include:

1. **Energy and Sustainability Projects:** These topics resonate with rural students who often experience limited access to electricity. For example, designing sustainable microgrids serves both educational and community needs.
2. **Interdisciplinary STEM Modules:** PBL enables integration across science, technology, engineering, and mathematics, fostering holistic problem-solving skills.
3. **Local Instructor Support:** Collaboration with local educators ensures cultural relevance and facilitates ongoing mentorship.
4. **Community Engagement:** Projects are designed to address real-world challenges, increasing student motivation and community impact (Lucas Education Research, 2020).

In the first phase – pilot plan -, detailed in the initial paper of the author [1], the project demonstrated that students from rural areas, often lacking access to advanced technological resources and specialized teachers, could successfully construct functional microgrid systems within their schools, and at the same time, to acquire the academic knowledge needed. This pilot provided valuable insights into the potential for such programs to foster both academic learning and community empowerment by involving students directly in solving local energy issues. The successful implementation across the four schools revealed not only the educational benefits but also the social impact of students becoming key contributors to their communities' access to electricity through renewable energy.

Building on the lessons learned from the pilot, this second phase expands the Microgrid project to twelve schools, broadening its geographical scope and deepening its impact. The goal of this second phase is twofold: 1) to scale the project and 2) to refine the instructional methodology based on the feedback and challenges encountered during the pilot. In this paper, we will explore the implementation process in these twelve schools, focusing on the logistical adjustments made to accommodate the larger number of participants and the diverse conditions across different regions. The project's educational framework continues to leverage remote instructors who collaborate with local teachers, ensuring that students in even the most isolated regions can access high-quality STEM education.

This phase also introduces new educational tools and resources, including enhanced use of digital platforms, asynchronous assignments, and expanded hands-on activities. By doing so, the project aims to not only improve students' understanding of renewable energy technologies but also to foster an interest in STEM careers among youth in remote areas. The expansion to twelve schools offers an opportunity to evaluate the scalability of the Microgrid project, with the intention of developing a replicable model that can be applied in other regions facing similar educational and energy challenges.

The paper will begin by providing a brief overview of the outcomes from the first phase of the project and the key lessons learned. It will then describe the strategies and modifications employed to scale the project, followed by an in-depth analysis of the educational and technical outcomes from the twelve participating schools. Finally, the challenges of scaling such an initiative and the implications for future STEM education programs in rural areas will be discussed.

3. Summary of the implementation of Microgrid V1.0

The project "Remote Learning: A Means to Advance Educational Equity in Isolated or Rural Regions" explores an innovative approach to addressing the educational disparities between urban and rural regions, particularly in Latin America. The initiative seeks to tackle the educational challenges faced by rural schools, which often lack access to qualified teachers and educational resources, by using remote learning as a tool to bridge the gap. This pilot project involves the development of a blended learning model combining synchronous remote teaching with asynchronous local support, focusing on topics such as energy, electricity and sustainability.

3.1 Main Problem

Rural regions face significant educational inequities compared to their urban counterparts. Rural students, particularly at the high school level, are more likely to drop out due to a lack of subject-specific teachers and limited access to resources. While urban schools enjoy better infrastructure, rural schools are left with fewer qualified instructors and limited exposure to technology. The goal of the project is to ensure that students in these areas can have access to quality education on STEM subjects, preparing them for future careers and providing their communities with practical benefits.

3.2 Project Objectives

The primary aim of the pilot project is to equip rural students and their teachers with knowledge and practical skills in electricity and renewable energy. Students are expected to learn about energy, electricity and sustainability, and by the end of the course, construct a microgrid to ensure their school has a stable supply of electrical energy. The project also has a larger goal of encouraging students in rural areas to pursue STEM careers, providing them with both theoretical knowledge and hands-on experience.

3.3 Methodology

The project is based on a blended learning model, where urban teachers, referred to as "remote instructors", deliver lessons through video conferencing to students in rural areas, supported by local teachers who facilitate classroom logistics and assist with the learning process. This method allows students to access quality education remotely while still benefiting from the in-person support of a local instructor.

The learning process consists of eight synchronous weekly sessions led by remote instructor, supported by asynchronous activities managed by local teachers. The final two sessions focus on hands-on projects, such as building a solar charger for mobile phones and designing a model microgrid that can power a classroom.

3.4 Curriculum Design

The course, structured around the principles of project-based learning (PBL) with a strong STEM focus, covers topics such as:

1. **Energy and Electricity**: Students explore renewable and non-renewable energy sources, basic electrical concepts like voltage and current, and practical applications of electricity.
2. **Solar Energy and Photovoltaic Cells**: Students learn how solar panels work, their parameters, and how to convert solar energy into electricity.
3. **Microgrid Development**: Participants build a functional microgrid, gaining practical

experience in energy storage, the conversion of direct current (DC) to alternating current (AC), and the use of inverters.

The course emphasizes hands-on learning through practical projects and demonstrations, such as constructing solar chargers and model microgrids. Students engage with real-world challenges, developing creative solutions and working collaboratively to apply theoretical concepts to practical tasks.

3.5 Evaluation

The project includes several evaluation mechanisms to measure both the academic outcomes and students' attitudes toward STEM careers. Students take pre- and post-tests to assess their knowledge gain in topics related to solar energy and electricity. Additionally, a STEM attitude survey gauges any changes in students' perceptions of STEM fields and their interest in pursuing careers in these areas and a myriad of formative assessments and questionnaires to improve the development of the educational model for futures implementations. The validation of the instruments was implemented before the pilot plan and the validation procedure is presented in detail in the initial paper of the author [1].

3.6 Key Findings

The results from the pilot project implemented in four schools in Latin America (two in Argentina, one in Colombia and one in Mexico) indicate that the blended learning model significantly improves students' content knowledge. The use of both remote and local instructors helps bridge the gap in educational resources, providing rural students with a richer learning experience. The hands-on projects have proven to be highly engaging, with students demonstrating an understanding of the practical applications of the knowledge they acquire.

3.7 Challenges

Despite the project's successes, several challenges emerged during implementation. Connectivity issues in rural areas, weather conditions affecting school access, and logistical conflicts within the local schools occasionally disrupted synchronous sessions. Moreover, students were sometimes unfamiliar with technology, such as Learning Management Systems (LMS), which required additional support from local instructors.

3.8 Improvements for Future Implementation

Based on feedback from students and instructors, several improvements have been identified for the next iteration of the project, MicroGrid V 2.0:

1. **Enhanced Interaction**: More interactive sessions, with greater involvement from local instructors, are needed to maintain student engagement and ensure active participation during both synchronous and asynchronous activities.
2. **Pre-Project Training**: Local instructors should receive more extensive training on the course content and the use of LMS platforms before the start of the project to ensure smoother implementation.
3. **Increased Hands-On Learning**: Students have expressed a desire for more practical activities and real-world applications, so future versions of the course will include additional experiments and interactive tasks.
4. **Improved Connectivity Solutions**: As connectivity remains a significant obstacle, strategies to address internet limitations in rural areas must be prioritized, such as the use of offline resources or improved infrastructure.

The project has demonstrated that remote learning, combined with hands-on STEM education, can be a powerful tool for promoting educational equity in rural areas. The pilot program has shown that, with the right support, rural students can achieve a level of education comparable to their urban peers, particularly in areas like energy and sustainability. The project also highlights the potential of remote learning to not only fill the gap left by the shortage of qualified teachers in rural areas but also to foster a deeper interest in STEM careers among students in these communities.

Moving forward, the next phase of the project, Microgrid V 2.0, will build on the lessons learned from the pilot, incorporating feedback from participants to refine the curriculum and improve the overall learning experience. The goal is to create a scalable and replicable model that can be implemented in other rural communities, providing students across Latin America with greater access to quality education and the opportunity to engage with STEM fields in a meaningful way. Following is the description of the development and implementation of the scale up project Microgrid V2.0

4. Implementation of the Project Microgrid V2.0

Following the feedback from the students and local instructors, before starting the process of identifying a set of new schools, the project implemented modifications in the LMS, in the evaluation tools, and in the preparation of the local instructors.
In this second version of the implementation of the project, the administration of the project procured to develop two important aspects to facilitate the scale up of the project: 1) a strategy to decentralize the logistics of the project and include more local institutions in the management of the daily activities of the project and 2) a program of professional development for the local instructors.

4.1 Strategy to decentralize the logistics of the project.

In the version Microgrid V1.0, the author was running ALL the aspect of the project, from contacting and organizing the project in the different educational institutions, finding financial support for the materials needed for the project, dealing with the organization of the logistics of the project, and all the little details that are appearing during the implementation.

For the scale up of the project in the Microgrid V2.0, the first step is to find and include larger educational institutions, which ones have access to rural and non-privileged schools, that will take upon themselves the responsibility of the organization and follow up of the development of the project in their network of schools. In this implementation, four institutions assume this role: Universidad del Norte, in Barraquilla, Colombia, Computadoras para Educar , from the ministry of Education of Colombia, The Universidad Autonoma de San Luis de Potosi, Mexico, the Beneditina Universidad Autonoma de Puebla and and several independent school that decided to join the project.

The role of these large institutions is to be the administrative side of the program in their participating school, in this way the project needs to deal with a concentrate number of representatives instead with the multiple schools, in one hand, and in the other hand, these larger institutions will provide guidance to their schools and the resources needed for the implementation of the project. Following is the list of schools participating in the project Microgrid

V2.0

Table 1. Participating schools in the project Microgrid V2.0

School Name	Organization	Country
Antonia Santos	Computadoras para Educar	Colombia
Jorge Arrieta	Computadoras para Educar	Colombia
IET Chivata	Computadoras para Educar	Colombia
Colegio Biffi	Universidad del Norte	Colombia
Colegio Real	Universidad del Norte	Colombia
Instituto La Salle	Universidad del Norte	Colombia
Santa Cruz CONAFE	Buap	Mexico
UASLP Huasteca Sur	UASLP	Mexico
Bachillerato Matlapa	UASLP	Mexico
Bachillerato Xlitla	UASLP	Mexico
IED Adolfo León Gómez	Independent	Colombia
Jerárquicos	Independent	Argentina
Sargento Cabral	Independent	Argentina
Liceo Lazaro	Independent	Rep Dominicana

Each organization had a coordinator that arranged the logistical issues with the rural school administrations, ensuring that the project had the needed institutional support from the local schools. The main points of these logistics arrangements was to ensure that the project was took seriously by the local school, integrating the curriculum of the project in the local curricula, ensuring that the local instructor will be dedicated to the project, and other administrative issues needed to solved before the program can run in a given school such as the classroom with the resources needed to the synchronous meetings, access to internet for the students to have access to the LMS canvas platform, etc.

As a note, although the details mentioned above look simply to achieve, it took approximately two months to complete and ensure that the participating school will be ready to start the implementation of the project. This process started on January 2024 and the implementation of the project started on March 18th, 2024. In this period the project had two meetings with all the collaborators (via videoconference) and two sessions of professional development for the local instructors

4.2 Professional Development for the Local Instructors

Once the logistics of the project were organized and resolved, as was suggested in the feedback received from the implementation of the Pilot – Microgrid V1.0, the project developed a session of professional development for the local instructors. The agenda of the Professional Development Can be found in the Appendix 1.

Professional development was offered on two different days to ensure the maximum of local instructions participation. Despite the efforts to convocated and motivate the local instructors, less than 50% of the instructors participated in the professional development. This caused the researcher to spend many extra hours ensuring that the local instructors were ready to work with their students in synchronous and asynchronous meetings. From this experience is clear that in the next version of the project professional development will be mandatory.

4.3 Implementation of the project in schools

When finalizing the logistics arrangements, the project divides the rural and urban schools in four cluster for the synchronous meetings, according to the days and times the school selected for the meeting. All the synchronous meetings were provided by the author

Mondays 11-13 CST (Arg 13-15) (Colombia 11-13) (México 10-12)
Tuesdays 8-10 CST (Arg. 10-12) (Colombia 8--10) (México 7-9)
Tuesdays 12-14 CST (Arg. 14-15) (Colombia 12-14) (México 11-13)
Fridays 10-12 CST (Arg. 12-14) (Colombia 10-12) (México 9-11)

The program started on the Week of Monday March 18th and finished on the week of Monday May 13th, being the last synchronous meeting on Friday May 17. All the sites have at least seven synchronous meetings.

During the period of the project some schools have unexpected (or undeclared at the time of the organization) holidays or special activities days at the schools. To solve this problem, all the synchronous meetings were recorded and placed on the platform LMS Canvas, allowing the local teachers and their classes that missed one synchronous meeting to see the video of the meeting previous the next synchronous meeting. Anecdotic data showed that many local instructors watched the videos with their students.

In the week called week #0 – before the start of the program, all the participants needed to be enrolled in the platform and complete the Content Knowledge pretest and the Attitude Survey towards STEM subjects and careers.

Between the week #1 and week #8, the participants participated in the synchronous meetings leaded by the remote instructor and complemented with the asynchronous learning leaded by the local instructor

On the last week – week #8, students from the different communities of the program, presented their projects to their peers from different countries. The different teams from the schools produced a presentation and shared their experience with their peers. Following are some pictures extracted from their presentations

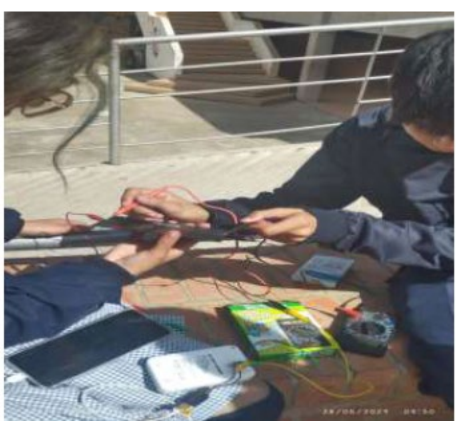

Figure 1. Students testing solar panels on different communities

The last activity of the students regarding the project was to complete the Content Knowledge posttest, the attitude towards STEM subjects and careers, and an exit survey. These instruments were accessible via the platform canvas from May 20 to May 30th, 2024.

4.4 Data analysis of the results of the implementation of the project Microgrid V2.0

4.4.1 Analysis of the Content Knowledge changes during the project

To start the analysis, it is needed to clarify that of ALL the schools that participated in the project only 11 schools completed valid pre and post instruments. From these 11 schools N=146 students completed the Content Knowledge pre and posttest as shown below

Table 2. Participating schools in the project Microgrid V2.0 – Number of Students per School that completed the pre and post test

School

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Antonio Santos	20	13.7	13.7	13.7
	Bachillerato Mtlapa	19	13.0	13.0	26.7
	Bachillerato Xitlila	4	2.7	2.7	29.5
	Colegio Biffi	9	6.2	6.2	35.6
	IED Adolfo Gomez	17	11.6	11.6	47.3
	Instituto Lasalle	8	5.5	5.5	52.7
	Jerarquicos	24	16.4	16.4	69.2
	Jorge Arrieta	16	11.0	11.0	80.1
	Royal School	13	8.9	8.9	89.0
	Sargento Cabral	7	4.8	4.8	93.8
	UASLP Huasteca Sur	9	6.2	6.2	100.0
	Total	146	100.0	100.0	

4.4.1.1 At the beginning of the project

Of the 14 schools committed to participate in the project, 301 students enrolled in the platform Canvas. From them 276 students completed the pretest with a mean of 8.98 of 20 points. In this version, the pre and posttest were embedded in the LMS, to ensure that each student can do the test only once in each timeframe.

4.4.1.2 At the end of the project

The posttest was available after the last synchronous session of May 17th and remained open until May 30th. The posttest was completed by 155 students from 11 schools. Although there were send multiple reminders to the local instructors, the number of students that completed the posttest was 56% of the students that completed the pretest. Anecdotic data shows that: 1) some of the local instructors have changed positions during the project,2) the ages of the students were smaller that the project requested, and 3) that some classes were “optional” and not embedded in the curriculum as requested by the project. This last factor causes that in groups with large number of students, only a few performed the post test. The institutions that sponsored these schools did not do a good job preparing and managing their sites.

Table 3. Demographic information of the participants that completed the posttest

Number of Students per School

	Number of students
Antonia Santos	23
Bachilleraro Matlapa	19
Bachillerato Xitlila	5
Colegio Biffi	12
IED Adolfo Gomez	17
Instituto Lasalle	9
Jerarquicos	24
Jorge Arrieta	16
Royal School	13
Sargento Cabral	8
UASLP Huasteca Sur	9
Total	155

Age

		Number of Students
	Younger than 14	3
	14.00	24
	15.00	37
	16.00	51
	17.00	24
	18.00	5
	Older than 18	10
	Total	154
Missing	System	1
Total		155

Gender

		Number os Students
	Female	77
	Male	72
	I prefer not to say	4
	Total	153
Missing	System	2
Total		155

4.4.2 Assessment of the changes in Content Knowledge of the participants that have valid pre and posttest

To assess if the intervention had a significant impact on the participants, a paired T-test was implemented on the 146 students with a valid pre and posttest. The results of the Content Knowledge test before the intervention were $M1 = 8.59$ ($SD = 3.35$), and after the intervention, they were $M2 = 12.04$ ($SD = 4.09$).

The paired t-test revealed a significant difference between the conditions, $t(145) = 9.632$, $p < 0.001$.

Therefore, we reject the null hypothesis and conclude that the intervention had a significant impact on improving participants' content knowledge.

Table 4 Paired T test results of all students that completed valid pre and post test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	8.5890	146	3.35831	.27794
	Posttest	12.0479	146	4.09092	.33857

Paired Samples Test

		Paired Differences					t	df	Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			One-Sided p	Two-Sided p
Pair 1	Pretest - Posttest	-3.45890	4.33928	.35912	-4.16869	-2.74912	-9.632	145	<.001	<.001

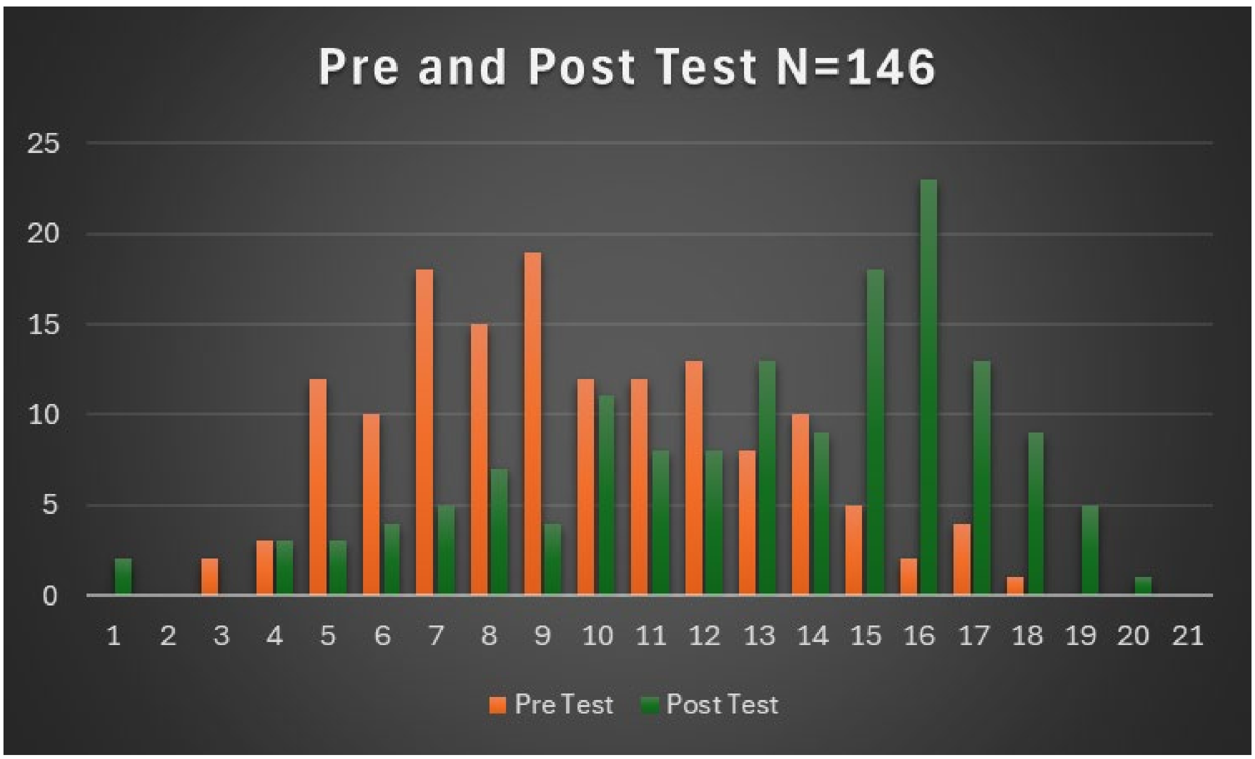

Figure 2: Visual Comparison of pre and post test results. The horizontal axis represents the score of the test and the vertical axis its frequency.

From figure 2 it is possible to see the positive shift of the results of the posttest in comparison with the pretest. This figure helps to corroborate the results of the Paired T-Test, that shows a significant impact of the intervention on the large population (N=146).

A deeper analysis of a T-Test per school show that in many schools the project was successful, but in certain schools the project did not have a significative impact in the population involved as shown in the next table

Table 5: Paired T test results of all students that completed valid pre and posttest per school

Paired Samples Test

	Paired Differences				Significance	
Escuela	Mean	Std. Deviation	t	df	One-Sided p	Two-Sided p
Antonio Santos	-4.20000	3.87434	-4.848	19	<.001	<.001
Bachillerato Matlapa	-.42105	4.32455	-.424	18	.338	.676
Bachillerato Xitlila	3.00000	5.88784	1.019	3	.192	.383
Colegio Biffi	-4.62500	3.46152	-3.779	7	.003	.007
IED Adolfo Gomez	-5.35294	3.99908	-5.519	16	<.001	<.001
Instituto Lasalle	-2.12500	4.01559	-1.497	7	.089	.178
Jerarquicos	-6.16667	3.77252	-8.008	23	<.001	<.001
Jorge Arrieta	-4.87500	2.27669	-8.565	15	<.001	<.001
Royal School	-1.15385	4.05886	-1.025	12	.163	.326
Sargento Cabral	-1.85714	5.27347	-.932	6	.194	.387
UASLP Huasteca Sur	-2.44444	2.18581	-3.355	8	.005	.010

Making a further analysis of the schools it is possible to see that:

- At the schools Bachillerato Matlapa , and Bachillerato Xitlita students did not participate in all the synchronous meetings, neither completed any asynchronous activities, neither presented a final project to the community.
- Institute Lasalle and Royal school, both private and urban schools, placed the class as an optional and the local instructor did not use the grade of the class to give a grade to his/her students. Although many students from these schools completed the pre and posttest, students knew that the results of the posttest will have no impact on their grade.
- It is possible to see that the rest of the schools, with the exception of Sargento Cabral school, showed a significant change in their content knowledge of the subject.

4.4.3 Analysis of the impact of the asynchronous activities in the content knowledge gain of the participants.

One point that is interesting to explore is the impact of the asynchronous activities in the results of the posttest and in the gain of content knowledge by the students. Common sense dictates that if students are investing more time in the preparation of the activities of the course, then it is expected that their proficiency in the content will increase. But on the other hand, the amount of time that students participate in asynchronous activities can be a function of the involvement of the local instructor. It is important to remember that the local instructor is responsible for the implementation of the asynchronous learning time.

Below is a graph that shows the relationship between the number of asynchronous activities submitted to the platform Canvas, and the difference between the pre and posttest per student

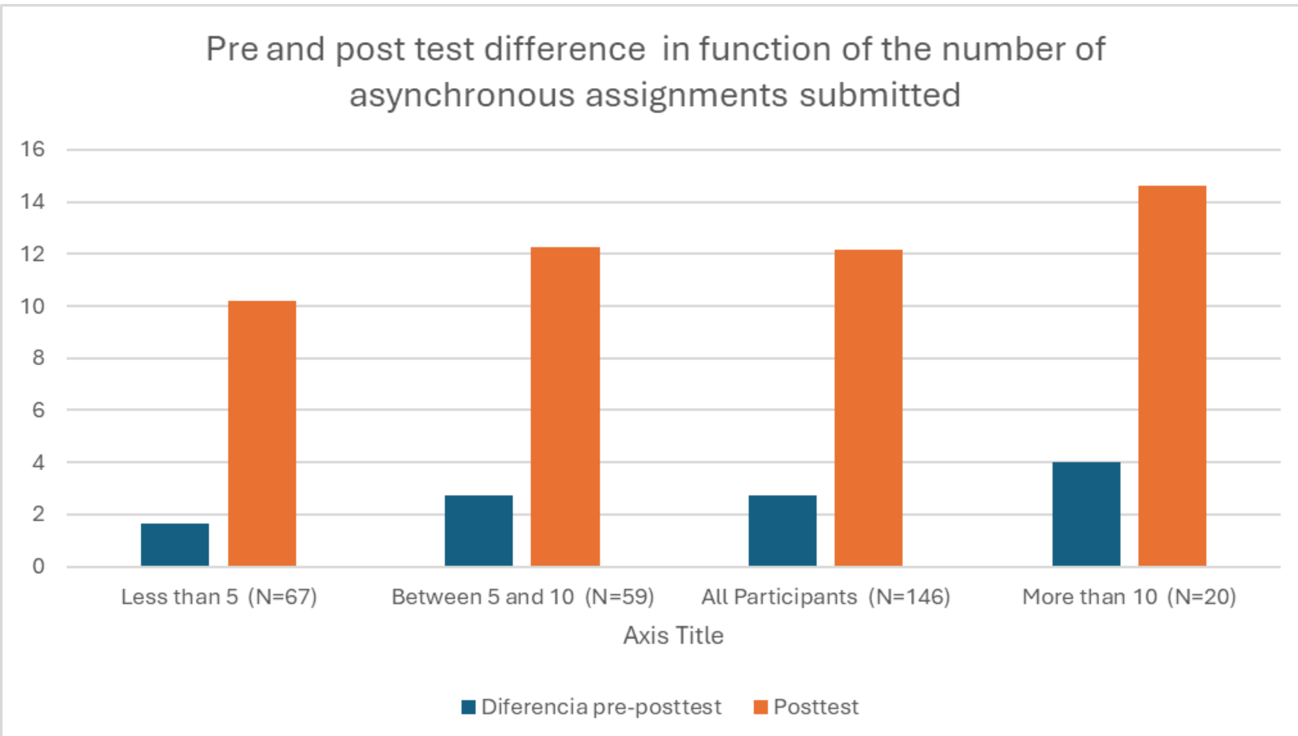

Figure 3: The impact of asynchronous learning in the change of the difference between the pre and posttest.

From Figure 3, it is possible to see that the students that submitted more asynchronous assignments, have the larger increase on the difference between their pre and posttest, as well as the larger mean of the posttest from all the groups. It indicates that the asynchronous assignments have an impact on the results of the posttest and on the knowledge gain of the students.

As indicated before, the time and efforts to motivate students to complete the asynchronous assignments is the prevue of the local instructor.

4.5 Conclusion of the Implementation Project MicroGrid V2.0

It is possible to see that the project has a significative impact on the content knowledge of students in many schools. Students that not only participated in the synchronous classes but also were active on the asynchronous activities had a larger change on the posttest score that those students that did not engage in asynchronous work. One of the potential reasons could be that the local instructor did not complain with the requirement to have at least one hour a week where students can access to the platform and work on their asynchronous assignments.

The implementation of the second project (Microgrid V2.0) has shown considerable progress in promoting STEM education in rural, underprivileged schools across Latin America. The project's main achievements include a significant improvement in students' content knowledge on renewable energy and electricity concepts, as demonstrated by a statistically significant increase in posttest scores. Moreover, students who actively engaged in both synchronous and asynchronous activities showed a more substantial improvement in their understanding of the subject matter.

One of the key takeaways from the project is the importance of hands-on learning in reinforcing theoretical concepts. The students' involvement in building functional microgrids and working on other renewable energy projects fostered not only academic learning but also practical skills that have the potential to benefit their communities directly. This integration of real-world applications into the learning process has been a vital factor in engaging students and increasing their interest in STEM fields.

However, several challenges were identified during this phase, most notably related to logistical constraints, including connectivity issues, holidays, and the inconsistent participation of local instructors in professional development sessions as well as leading the asynchronous learning. These challenges were more prominent in certain schools, which affected the overall success of the program in those schools. The level of involvement of local instructors in asynchronous activities played a critical role in student outcomes, suggesting that more emphasis should be placed on ensuring that local teachers are adequately trained and motivated to lead these sessions.

Despite these challenges, the Microgrid V2.0 project has demonstrated the viability of scaling STEM education in remote areas through a blended learning approach. The results affirm the project's potential for further expansion, with the caveat that improvements in teacher training, connectivity solutions, and institutional support are necessary for sustained success. Future iterations of the program should focus on addressing these gaps, making professional development mandatory, and ensuring that all participating schools integrate the program fully into their curriculum.

The Microgrid V2.0 project has not only advanced educational equity in rural communities but has also laid the groundwork for a replicable model of STEM education that can be applied in other underserved regions and can be developed with different contents. By combining remote learning with hands-on projects, the initiative has empowered students to become active contributors to solving local energy issues, which could inspire a new generation of innovators in the field of renewable energy.

5. Implementation of the project Microgrid V3.0

Following the results of the expansion of the project in the Microgrid V2.0, some institutions contacted the author and expressed their willingness to implement the project on a larger scale. These institutions included the Consejo Nacional de Fomento Educativo (CONAFE) from Mexico, Universidad del Norte from Colombia, Red de Institutos Técnicos Comunitarios (ITC) y UNESCO-Honduras, and the University of Peques in Chile. Several schools connected with the project also declared their interest to join to the next implementation. The larger number of schools (twelve) were affiliated with the organization CONAFE, from Mexico. This institution works precisely with the type of school the project was designed to serve.

5.1 The National Council for the Promotion of Education (CONAFE)

The CONAFE is a decentralized organization of Mexico's Ministry of Public Education, focused on providing basic education to children and adolescents in highly marginalized areas. Its innovative Community Education for Well-being Model centers on a tutoring relationship—a personalized, one-on-one interaction emphasizing dialogue, collaboration, and respect for learners' individual rhythms and interests. This constructivist, humanistic approach aims to foster lifelong learning skills and a passion for knowledge.

CONAFE's model goes beyond traditional education by involving community members of all ages in learning processes, creating learning communities where everyone teaches, learns, and collaborates. The Community Educator, a trained individual from the local area, facilitates learning management skills and shares in-depth knowledge on topics of community interest.

Curriculum development is non-traditional and revolves around community priorities, integrating content through tutoring relationships and formative fields. Families play an active role, ensuring that learning is rooted in local knowledge and culture.

This model prioritizes collaborative work among students of different ages and knowledge levels, fostering inclusivity and mutual growth. The tutoring relationship not only helps learners acquire knowledge but also encourages them to reflect on and share their learning, creating a ripple effect of educational empowerment throughout the community.

Unique Attributes of the CONAFE Model

- Tutoring Relationship: Personalized, respectful, and learner-centered interaction.
- Constructivist Approach: Focuses on learning how to learn through dialogue and collaboration.
- Learning Communities: Inclusive spaces where all members teach, learn, and coexist.
- Community Involvement: Education enriched by local knowledge and culture.
- Community Educators: Local figures trained to manage learning and facilitate education.
- Non-Traditional Curriculum: Prioritizes community interests over standardized content.
- Intergenerational Learning: Engages learners of all ages in collaborative education.

- Focus on Marginalized Areas: Addresses educational inequities in underserved regions.

5.1 Participant schools and students

In this third implementation participated initially 23 schools from four countries, thirteen schools from Mexico, six schools from Colombia, three schools from Honduras and one school from Chile. Before starting the program 285 students registered to the Learning Managing System (LMS) Canvas with the following demographic: 53% female, 46% and 1% prefer not to declare. Regarding the ages of the participants, it is presented in the following figure

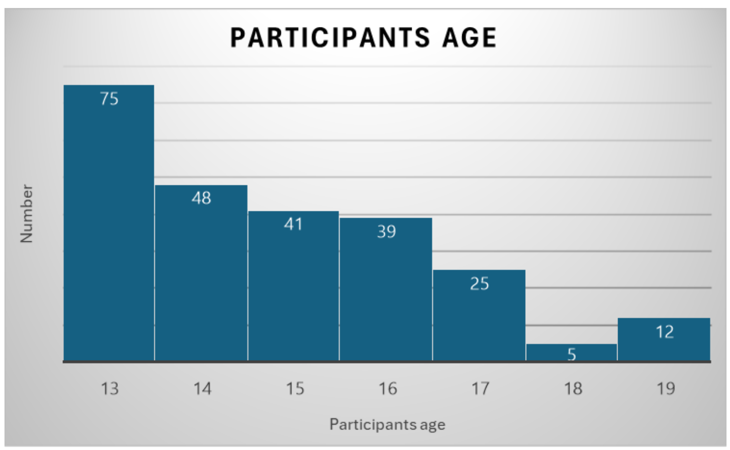

Figure 5. Number of Students participants per age group

Before starting the intervention, students completed a Content Pretest and a questionnaire about their attitudes toward STEM and careers in those fields. The instruments used were designed and tested during the MicroGrid V1.0 pilot plan and subsequently revised and retested during the implementation of the MicroGrid V2.0 project.

A difference to the other implementations, this time the remote instructor only presented the synchronous meeting ***once for ALL the 23 participating schools***. The remote teacher implemented the intervention through synchronous meetings (eight in total, one two-hour session per week—Tuesdays from 10 AM to 12 PM Central Standard Time, USA—between

September 10 and October 29). During this period, local teachers were responsible for ensuring that students had access to the educational platform to complete asynchronous tasks.

At the end of the intervention, a two-week period (from October 29, 2024, to November 15, 2024) was provided for local teachers and their students to complete the Content Posttest, the questionnaire on attitudes toward STEM and careers in those fields, and an exit survey for the students.

5.2 Analysis of the results of the implementation of Microgrid V3.0

Twenty-three schools initiated the project. Of the 285 students enrolled, 248 completed the Pretest (87%), achieving an average score of 7.92 out of 20, with a standard deviation of 4.39. A histogram is presented below to illustrate the distribution of Pretest scores.

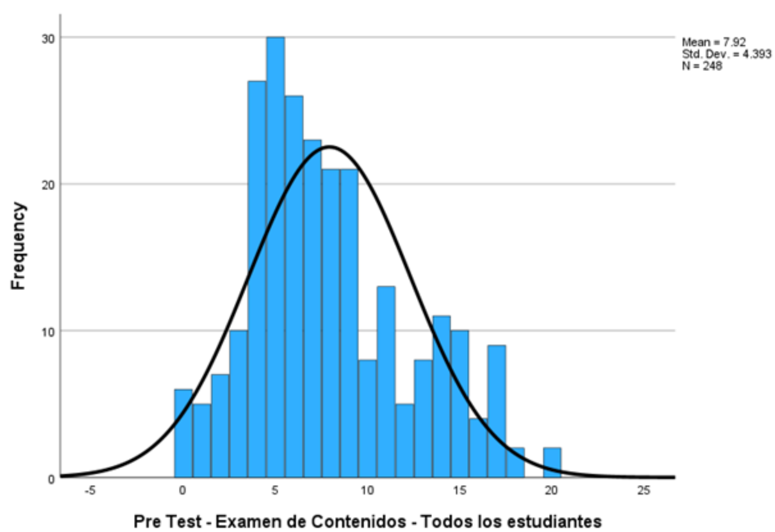

Figure 6. Distribution of the Pretest scores – all the pretest

Of the 285 students initially enrolled in the project, 176 completed the Posttest (61.8%), with an average score of 12.34 out of 20 and a standard deviation of 4.94. A histogram is presented below to illustrate the distribution of the Posttest scores.

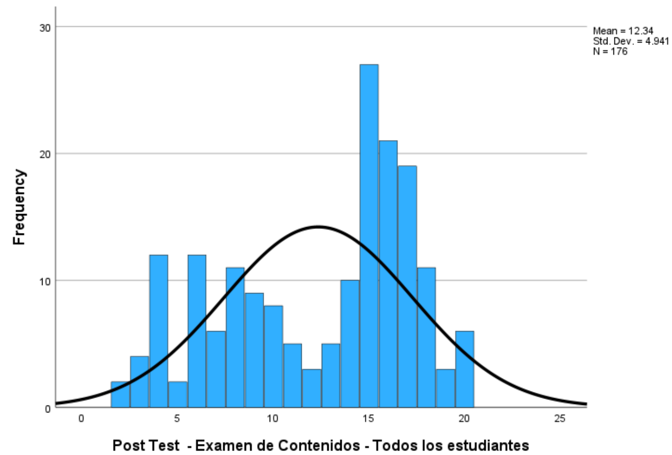

Figure 7. Distribution of the Postest scores – all the posttest

5.2.1 Comparison Between Pretest and Posttest Results for Students Who Completed Both Exams

To assess whether the intervention had a significant impact on students, the results of the Posttest and Pretest will be compared for those students who completed both exams. For this purpose, a Paired T-Test statistical analysis is applied to the entire group. This test compares the means of two related measurements (Pretest and Posttest, taken before and after an intervention) to determine whether there is a statistically significant difference between them.

A table is presented below showing the schools and the number of students with valid Pretest and Posttest scores. Following the intervention, 165 students were identified as having completed both the Pretest and the Posttest.

Table 6: Schools that completed pre and posttest

School	Valid pre and postte	Mean Prete	S.D	Mean Postes	S.D.	T Value Paired T Test	P Valua Paired T Test	Significative Chang
Actipan	13	5.08	2.72	10.77	3.52	3.92	0.001	Yes
Biffi Lasalle	19	12.74	4.25	15	1.66	2.02	0.029	Yes
Carranza	11	5.55	2.43	6.18	2.71	0.571	0.29	No
Cienaga	7	5.57	1.134	6.43	2.15	0.859	0.2	No
Coyotera	7	4.71	1.98	6.71	1.87	1.7	0.07	No
El Pajar	4	5.5	3.1	6.75	1.89	1	0.196	No
Guarita (Hon)	17	6.71	2.9	13.76	2.95	7.904	0.001	Yes
Hincada	3	7.33	0.577	7.33	1.52	0	0.5	No
IED Gomez	16	6	5.17	15.25	2.29	7.63	0.001	Yes
Instituto Lasalle	11	14.91	1.57	17.64	0.924	4.038	0.001	Yes
La Huerta	9	7	2.55	15.33	1.118	8.22	0.001	Yes
Pastoria	5	5.8	1.643	4.6	0.6	-1.395	0.118	No
Royal School	1	16		15				NA
S.I. Chiapas	7	7	1.732	5.43	2.5	-1.416	0.1	No
San Jose (HON)	3	8.33	2.309	11.67	3.333	1.147	0.185	No
Santa Cruz	2	6.5	3.5	7.5	2.21	1	0.25	No
U de Peques	14	7.93	4.215	14.14	3.394	6.013	0.001	Yes
Virreyes	16	5.63	1.857	17.06	3.785	12.72	0.001	Yes

For all the group of students that complete valid pre and posttest (N=165)

Table 7: Paired T test results of all students that completed valid pre and posttest per school

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Postest	12.37	165	4.929	.384
	Pretest	7.61	165	4.288	.334

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Postest - Pretest	4.764	5.328	.415	3.945	5.583	11.484	164	<.001	<.001

Paired Samples Effect Sizes

			Standardizer[a]	Point Estimate	95% Confidence Interval Lower	Upper
Pair 1	Postest - Pretest	Cohen's d	5.328	.894	.712	1.074
		Hedges' correction	5.353	.890	.709	1.069

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

A Paired T-Test was conducted to compare the results of the Pretest and Posttest taken before and after the intervention. The results revealed a significant difference between the pre-intervention means ($M = 7.61$, $SD = 4.28$) and post-intervention means ($M = 12.37$, $SD = 4.93$; $t(164) = 11.484$, $p < 0.001$). This result allows for rejecting the null hypothesis, indicating that the intervention had a significant effect on students' Posttest scores. The effect size, calculated using Cohen's d coefficient, was 0.894, which corresponds to a large effect according to conventional standards. This suggests that the intervention had a statistically significant impact on the participants' outcomes.

In other words, this test demonstrates that the intervention had an impact on the entire group.

5.2.2 Comparison Between Students' Pretest and Posttest Scores by School

In this section, we explore the Pretest and Posttest results of students, with the unit of analysis being the school. Table 6 summarizes the results of the Paired T-Test conducted to compare the Pretest and Posttest scores of students within each school.

The table presented shows the results of the Paired T-Test by school for students who completed both the Pretest and Posttest. It can be observed that 115 out of 149 students enrolled in the educational platform across eight schools showed a significant impact through the implementation of the project, while 49 out of 94 students enrolled in the platform across nine schools did not report a significant impact. The table also reflects that in certain cases, the Posttest scores were lower than the Pretest scores.

Schools marked in black did not complete any Posttests.

All schools participated in the intervention under the same conditions. During the intervention, there were factors under the control of the research team and others that were the responsibility of the local teachers. From the research team's side, synchronous classes were offered weekly, and all scheduled sessions were delivered. Local teachers were responsible for working with students during asynchronous activities, ensuring that assigned tasks were completed *before* the next synchronous meeting. This part was not under the direct control of the research team.

5.3 Success indicators

During the study, additional indicators were collected to relate student outcomes to their effort and the involvement of the local teacher. These indicators include:

1. **Average number of tasks submitted per school:** This indicator reflects the work completed during asynchronous activities, which were under the responsibility of local teachers and students. A total of 19 tasks were assigned.
2. **Students' impressions of the course:** In the exit survey, students answered the question: *On a scale of 0 to 10, where 0 is "terrible" and 10 is "excellent," how would you rate the course overall?* This indicator reflects students' overall perception of the course.
3. **Tasks reviewed by the Local Teacher (as reported by the local teacher):** This indicator represents the feedback provided by local teachers to their students during the course.
4. **Desire to be a remote teacher in the future:** In the exit survey, local teachers were asked: *On a scale of 0 to 10, how interested are you in being a local instructor for a similar project in the future?* This indicator measures the feasibility and interest of teachers in participating as local instructors.

5. **Decision to be a local teacher in the project:** This indicator shows whether the local teacher voluntarily chose to join the project or was assigned by the school administration.

Below, a table is presented showing these success indicators and their corresponding schools. The "Significant Change" column indicates which schools experienced a significant change in Pretest and Posttest results and which did not.

Table 8: Summary of the success indicators per school

School	Significative Change	d de Cohen	Mean tasks submitted	Mean impressions of the students	Participation in synchronous meetings	Rating of checking homework by the instructors	Desire to be a local instructor again	Self selected
Actipan	Yes	1.088	10.46	6.41	7	4	10	Yes
Biffi Lasalle	Yes	0.464	9.79	8.13	5	3	10	Yes
Carranza	No	0.172	6.27	8.18	8	2	9	Yes
Cienaga	No	0.328	2.56	NA	8	3	9	Yes
Coyotera	No	0.643	13.57	7	8	1	5	No
El Pajar	No	0.585	4	7.6	8	2	8	No
Guarita (Hon)	Yes	1.095	10.1	7.4	7	3	10	Yes
Hincada	No	0	3.6	NA	7	3	10	NA
IED Gomez	Yes	1.061	11.8	8.5	7	4	10	Yes
Instituto Lasalle	Yes	1.217	10.9	9.3	8	3	10	Yes
La Huerta	Yes	1.257	2.1	8	8	4	10	No
Pastoria	No	-1.565	0	7.16	8	1	9	No
Royal School	NA		14	9	NA	NA	NA	NA
S.I. Chiapas	No	-1.314	0	6.15	8	NA	NA	NA
San Jose (HON)	No	0.662	0.6	7.89	6	1	2	Yes
Santa Cruz	No	0.707	7	NA	8	1	NA	NA
U de Peques	Yes	1.607	7.78	8.81	8	2	10	Yes
Virreyes	Yes	3.181	18.9	8	8	2	5	No

Note: In the column *Rating of checking homework by the instructors (self-reported)*, the following scale was used: 4 – All Tasks, 3 – Most Tasks, 2 – Some Tasks, 1 – None.

The data presented in Table 8 suggests the following ideas to explain the differences between schools:

1. **Differences in Tasks Submitted:**
   A significant difference exists in the number of tasks submitted between schools with significant change and those without. Possible reasons include:
   a. **Access limitations** (e.g., connectivity issues, lack of access to computers).
   b. **Time limitations** for asynchronous activities (organized by the local teacher).
   c. **Limitations in the local teacher's role as a tutor.**

2. **Students' Impressions:**
   Although there is a difference in students' impressions of the project between the two groups of schools, both groups viewed the project as valuable. However, students from schools with significant change had a slightly more positive impression.

3. **Tasks Corrected by the Local Teacher:**
   A stark difference exists in the number of tasks corrected by the local teacher between the two groups. Schools with significant change received more feedback and completed more tasks. This difference likely affected students in the following ways:
   a. **Teacher Feedback:** By correcting tasks, teachers convey that the work is important and encourage further engagement.
   b. **Positive Reinforcement:** Receiving positive grades motivates students to stay engaged and deepen their learning.

4. **Desire to Be a Remote Instructor Again:**
   In schools with significant impact, all but one instructor expressed a strong desire (scoring 10) to be a local teacher again, with only one scoring 5. This indicates that teachers in this group internalized the project's goals. In contrast, only five out of nine teachers in schools with no significant change expressed interest in being a remote instructor, and two teachers did not respond despite multiple reminders.

5. **Teacher Selection for Participation:**

   In schools with significant impact, six out of eight instructors stated that participating in the project was their decision, while two mentioned it was mandated by their administration. In schools with no significant change, only three out of nine stated it was their choice to join the project.

5.3.1 Summary of the Indicator Analysis

From the data comparing results of the two groups of schools—those with significant change and those without—it can be inferred that the local teacher plays a critical role in the success or failure of the group within the project.

- **Role in Asynchronous Activities:** Local teachers are responsible for ensuring students complete asynchronous tasks. These tasks are aligned to help students internalize the material before progressing in the course.
- **Providing Feedback:** By offering feedback, teachers signal the importance of the tasks and motivate students to complete more activities, aiming for better grades.
- **Reduced Posttest Participation:** In schools with no significant change, the lower number of Posttest completions suggests that local teachers did not integrate the project into the curriculum or use its results as part of the students' semester grades.
- **Teacher Commitment:** In schools without significant change, teachers participated under institutional direction rather than by choice, which limited their commitment to the project.

5.4 Final thoughts on the analysis by schools

The local teacher is a cornerstone of success in the remote education model. Their commitment determines student outcomes. Their role includes ensuring the completion of asynchronous activities that reinforce learning and providing feedback that motivates students to improve.

In schools with minimal progress, it can be assumed that teachers did not integrate the project into the curriculum or consider its grades in semester evaluations, reflecting a lack of ownership of the project. Additionally, teachers' participation, mandated by their institution, reduced their engagement.

In contrast, committed teachers ensured the project's relevance, fostering a positive impact on learning outcomes.

6. Lessons Learned from the Implementation of the MicroGrid Project

6.1 Introduction to Comparative Analysis

The three implementation phases of the MicroGrid project (V1.0, V2.0, and V3.0) provide a valuable opportunity to analyze and learn how to bring the remote education model to rural communities, ensuring equitable access to quality STEM-focused education.

Each phase was developed in diverse contexts, incorporating specific adjustments aimed at optimizing results and addressing limitations identified in previous stages. This section cross-analyzes the experiences of each implementation to identify lessons learned and how these insights can enrich future initiatives.

6.2 Insights into Organization and Logistics

6.2.1 What worked:

- In **V1.0**, proximity to schools and direct relationships with local teachers resulted in efficient logistics, albeit limited to a small group of institutions.
- Decentralization in **V2.0**, where larger institutions assumed coordination roles, significantly expanded the project's reach and reduced the central team's operational load.
- **V3.0** consolidated logistical planning through clear schedules and greater systematization, improving communication among stakeholders.

6.2.2 Opportunities for improvement:

- Initial preparation was a constant challenge. In **V1.0** and **V2.0**, insufficient training for local coordinators delayed key activities.
- In **V2.0**, some coordinating institutions failed to ensure consistent commitment from participating schools, highlighting the need for stricter guidelines.
- Despite notable systematization in **V3.0**, technological inequalities between rural and urban schools remain an obstacle to address.

6.3 Impact of the Local Teacher's Role

6.3.1 What worked:

- Committed local teachers proved fundamental to success across all phases, acting as key facilitators between students and the content.
- In **V3.0**, the positive impact of active teacher feedback was more evident, reflected in better Posttest results and higher student satisfaction.

6.3.2 Opportunities for improvement:

- In **V1.0** and **V2.0**, some local teachers did not integrate the project as part of their curriculum, which affected student engagement.
- Participation in the training sessions offered was limited in **V2.0**, indicating that such sessions should be mandatory and tailored to teachers' actual needs.

6.4 Student Participation and Learning

6.4.1 What worked:

- Practical activities and final projects introduced in **V2.0** and **V3.0** increased motivation and understanding of STEM concepts, particularly in rural schools.
- The combination of synchronous and asynchronous sessions worked well across all three cycles, providing flexibility for students.

6.4.2 Opportunities for improvement:

- Urban schools presented specific challenges, such as the perception that the course was optional, which reduced participation.
- Practical projects need to be tailored to reflect local contexts, increasing their perceived relevance for students.

6.5 Evaluations and Project Impact

6.5.1 What worked:

- All three phases demonstrated a significant impact on students' STEM knowledge, with statistically significant improvements between Pretest and Posttest results.
- In **V3.0**, more robust measurement of results was achieved through the integration of advanced statistical analyses.

6.5.2 Opportunities for improvement:

- Across phases, the importance of including qualitative indicators to evaluate soft skills and the community impact of the project has been underestimated.
- Incorporating focus groups and interviews with students could provide deeper insights into the intervention's effects.

6.6 Considerations for Future Implementations

From the analysis, several key considerations emerge for the continuity and expansion of the MicroGrid project:

- **Scalability:** Decentralization, as seen in **V2.0** and **V3.0**, is effective but requires a clear regulatory framework to ensure minimum implementation standards.
- **Personalization:** Pedagogical and logistical strategies must be adapted to the specific contexts of rural and urban schools, particularly regarding access to technological resources.

- **Teacher Commitment:** Establishing incentives for local teachers and making their training mandatory could increase project ownership.
- **Sustainability:** Partnering with community organizations and local stakeholders is essential to ensure the long-term continuity of the project, especially in rural communities.

A table presented below shows a comparison between the three implementations of the Microgrid Project

Table 9: Comparison of the Implementations of the Microgrid Project V1.0, V2.0 and V3.0

Aspect	Microgrid 1.0	Microgrid V2.0	Microgrid V3.0
Number of participating schools	4 (All 4 completed the evaluations)	14 (11 completed the evaluations)	23 (17 completed the evaluations)
Number of registered students	97	301	285
Completion rate (pre and post-test completed)	0.773	56%	61.8%
Initial mean (pre-test)	8.21	8.59	7.61
Final mean (post-test)	13.69	12.04	12.37
Statistical significance (improvement in knowledge)	Yes ($p < 0.001$)	Yes ($p < 0.001$)	Yes ($p < 0.001$)
Schools reporting significant change	3	7	8
Effect size (Cohen's d)	0.96 (large effect)	0.797 (large effect)	0.894 (large effect)
Participating teachers	8	16	21
Teacher participation in training sessions	No specific training provided	Less than 50%	57%
Reported logistical issues	Connectivity and weather disruptions	Connectivity issues, incomplete curriculum integration	Unequal access to LMS, insufficient technological resources
Implementation duration	7 September - 25 November 2023	18 March - 17 May 2024	10 September - 29 October 2024
Course impressions (students)	8.89 out of 10 (N=79)	8.47 out of 10 (N=144)	7.8 out of 10 (N=162)
Teachers: Interest in repeating the role of local instructor	9.5 out of 10 (N=8)	9.43 out of 10 (N=17)	7.14 out of 10 (N=21)

7. Conclusions

The Microgrid Project represents a pioneering effort in bridging the gap in STEM education for rural and underserved communities. Through its three phases — Microgrid V1.0 (pilot project), V2.0, and V3.0 — the project has demonstrated the potential of integrating remote and project-based learning to foster academic growth and community empowerment. The results consistently highlight significant improvements in students' understanding of renewable energy and electricity concepts, as evidenced by measurable gains in Pretest and Posttest scores. These outcomes underscore the success of combining theoretical instruction with practical, hands-on activities, enabling students to apply their knowledge in meaningful ways.

One of the project's key achievements lies in its ability to empower students by equipping them with practical skills through real-world applications. The process of designing and constructing functional microgrids not only enriched students' academic experiences but also allowed them to contribute directly to solving local energy challenges. This hands-on engagement instilled a sense of agency and motivation, inspiring students to pursue further exploration in STEM fields. The project's adaptability across diverse contexts, from small rural schools to larger networks like CONAFE in Mexico, highlights its scalability and relevance for various educational settings.

However, several challenges emerged during the implementation phases. The variability in the engagement and preparedness of local instructors significantly influenced the outcomes. Schools with highly committed teachers achieved better results, while those with limited participation in professional development or inconsistent leadership in asynchronous activities faced setbacks. Infrastructure and connectivity issues further exacerbated these challenges, particularly in remote areas where reliable internet access remained a persistent barrier. Additionally, in some cases, institutional support was insufficient, with schools failing to fully integrate the project into their curricula, reducing its perceived importance among students and teachers.

Despite these hurdles, the project offered valuable lessons for future implementations. The importance of mandatory and context-sensitive professional development for local instructors became evident, as well as the need for tailored strategies to address technological barriers. Ensuring institutional alignment and commitment will also be critical for sustained success. By embedding project activities into school curricula and providing clear incentives, both students and teachers can be more effectively engaged. Furthermore, decentralizing logistical responsibilities to larger educational organizations proved effective in scaling the initiative, though refinements in coordination and guidelines are necessary.

The project’s broader implications extend beyond education. By addressing community-specific energy challenges, the initiative has demonstrated how STEM education can directly contribute to sustainable development. Students not only learned about energy systems but also became active participants in solving pressing local issues, fostering a sense of responsibility and innovation. This dual focus on education and community impact aligns with global efforts to promote equitable development and sustainable practices.

As the Microgrid Project progresses, its success offers a replicable model for other underserved regions. The integration of remote learning with hands-on STEM projects provides a pathway for advancing educational equity while addressing real-world challenges. By refining its approach and addressing the lessons learned, the project is poised to make an even greater impact, empowering a new generation of students to become innovators and leaders in their communities. This initiative stands as a testament to the transformative potential of education when aligned with local needs and global aspirations for sustainable progress.

8. Acknowledgements

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Appendix #1

Microgrid V2.0 Professional Development Agenda

1. **Introduction of Participants**
   - Get to know each other.
2. **Student Requirements**
   - Students need: internet access, a computer, and an email account (preferably Gmail).
   - Make sure they know how to: use email, word processor, upload images, take screenshots.
   - Important: check emails daily; this is the project's main communication method.
3. **Navigating the Canvas Platform**
   - Explain the course structure.
   - Access Canvas and enroll students.
   - How to check grades.
4. **Teacher Strategy**
   - Roles of the Remote and Local Teachers.
   - Work outside of synchronous classes.
   - Local Teacher as the leader in asynchronous sessions.
5. **Synchronous Class Logistics**
   - Review the didactic agenda before each class.
   - Ensure the class is ready (connection and technical details).
   - Students should have their phone or a computer window open for Menti (communication app). If available, use the school internet to avoid using personal data.
   - Strategies to encourage active participation.
   - Hands-on activities during synchronous sessions.
6. **Asynchronous Class Logistics**
   - Set a dedicated time for students to access asynchronous tasks and ask questions.
   - The role of the Local Teacher in asynchronous activities.
   - Importance of completing the tasks.
7. **Projects**
   - Materials needed for the first project: solar phone charger.

- Materials for the MicroGrid demonstration in the classroom.
- Experiments students will conduct and how they will report them.
- Preparation of the final report and presentation.

8. **Assessments**
    - Content exam and attitude survey before Week 1.
    - Formative assessments during the project.
    - Final content exam and attitude survey at the end.
    - Exit surveys for students and local teachers.
9. **Project Dates**
    - Week 1 starts on Monday, March 18th 2024
    - Week 8: May 17th -project presentations.
    - May 20th to May 30th Final assessments