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Application of STEAM Methodologies in the Rural Sector: Its Impact as Innovative Teaching

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Abstract

This study analyzes the effectiveness of STEAM methodology in rural education at the Simón Rodríguez Rural Educational Unit located in Riobamba, Ecuador. A quasi-experimental design with pre- and post-tests was applied to 129 students from 11 to 15 years old, applying a model structured in six phases of STEAM methodology: (1) Introduction Step, where STEAM was taught with hands-on experiments and motivational activities; (2) Creation Step, which involved the design of specific content that allows meeting the expected competencies; (3) Exploration Step, where it was possible to introduce students to technological tools, educational robotics and problem solving through project-based learning; (4) Practical Step, where the acquired knowledge was tested to solve real-life challenges; (5) Elaboration Step, where STEAM-related projects were presented by students to the school and their families to gain community support in order to foster self-efficacy and critical thinking skills; and (6) Reflection Step, where students were encouraged to transfer their learning to other contexts, thus enhancing school, family, and community integration. The results showed a significant improvement in problem solving, which increased by 31.25%, in confidence with the use of self-solving technology, which improved by 13.49%, and in cognitive skills where there was an improvement in computational thinking of 28.73%. In addition, the increase in family participation was 65%, reflecting a stronger connection between the school and the community. Based on the discussions of the results, it can be inferred that the application of the STEAM approach in rural settings improves science and technology learning, while also developing self-esteem, creativity, and community cohesion. The study supports the application of STEAM in resource-scarce environments, noting its use to reduce the educational gap and build digital and analytical skills among rural school children. Further research in other regions with similar characteristics is recommended to expand the scope of these results.

Keywords: *STEAM; Rural Education, Educational Robotics, Pedagogical Innovation, Project-Based Learning.*

Introduction

Digitalization and technological advancement have profoundly shaped the global education system in the 21st century. This enhancement encompasses how teaching and learning is carried out, as well as the competencies that students are expected to possess. However, rural areas

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constitute a significant challenge in the development of innovations in education. Babayeva (2024) states that some of the main barriers are the lack of access to information technology, the absence of specialized pedagogical materials, and the lack of pedagogical training of teachers in new teaching methodologies. Such elements deepen the educational and technological divide, alienating communities from global advancement.

The above excerpt can be summarized as follows: changes in technology allow the use of mobile phones in rural areas and vice versa. The internet becomes accessible, services and products are offered, which helps to close the gap in education. In addition, the rural community is connected to the metropolitan community, which helps improve their living standards. This results in giving the rural community an opportunity to get involved in globalization.

As a response to this problem, the STEAM system emerged as an educational innovation. This approach integrates Science, Technology, Engineering, Arts, and Mathematics, while developing important competencies such as systems thinking and creativity. In a study conducted by Ariza and Olatunde-Aiyedun (2024), it was estimated that 70% of rural schools that implemented STEAM programs during the last three years achieved notable improvements in students' ability to handle complex problems.

The effect of educational inequalities in rural areas is even more pronounced in Latin America, where Misbah et al. report that 45% of students from rural communities do not have regular access to advanced educational programs. This compares to 85% of urban schools that do have such opportunities. The researcher's conclusion is that the implementation of STEAM projects in rural settings is likely to close this gap by offering relevant and accessible practical tools for the area.

In addition, some recent research points to the need to provide training to primary school teachers in rural areas to make STEAM programs effective. As Dusi et al. report, "sixty percent of rural teachers who participated in STEAM workshops reported a change in their teaching methodology and that students were more actively engaged in hands-on lessons."

STEAM not only seeks the acquisition of knowledge, but also aims at the development of critical socio-emotional skills for the 21st century. As Pramesti (2024) reported, he pointed out that more than 65% of rural students who participated in STEAM-based educational programs reported improvements in their self-esteem and teamwork skills. This shows a positive influence not only on the educational field, but also on how well prepared students are to face real-world challenges. In a globalized context where market competitiveness demands more adaptability and critical thinking, these skills become increasingly important and essential.

The application of the STEAM method has also proven to be an effective tool in the development of socio-emotional competencies of students in rural areas. Voicu and Matei (2021) state that the STEAM approach improves cooperation and resilience in 72% of participants, helping them to face learning challenges in resource-poor environments. This positive impact supports the need to incorporate innovative approaches that not only focus on academic outcomes, but also on students' emotional well-being.

Materials and Methods

The methodology selected for this research was quasi-experimental with pre-test and post-test measurements, following the methodological guidelines of González-Calero and Cózar-Gutiérrez (2023) for research in rural STEAM education. This design was chosen because it is very effective in assessing the impacts of educational interventions where the use of a completely randomized assignment is impractical, providing a rigorous impact analysis while maintaining the ecological validity of the study within natural educational contexts.

Research Design

The non-experimental design was selected considering the specific characteristics of the rural educational context and the inherent limitations of the environment. The formula used to determine the sample size was:

$n = [Z^2.\sigma^2.N]/[e^2.(N-1) + Z^2.\sigma^2]$

Where:

- n = Is the required sample size
- Z = Is the confidence level (95%, Z=1.96)
- σ = The standard deviation of the population (0.5)
- N = The size of the total population (187 students)
- e = This is the margin of error (5%)

Applying the formula:

$n = [(1.96)^2(0.5)^2(187)]/[(0.05)^2(186) + (1.96)^2(0.5)^2]$

n = 129 students

Participants and Context

The final sample consisted of 129 students (age M = 13.2, SD = 1.4) from the Simón Rodríguez Rural Educational Unit. The demographic distribution was analyzed using the following stratification formula:

$nh = (Nh/N) \times n$

Where:

- NH = sample size for stratum h
- Nh = size of the population in stratum h
- N = total population
- n = total sample size

Below, the Stratified Distribution of the Sample can be seen in Table 1.

Age Group	**Population (Nh)**	**Fraction (Nh/N)**	**Sample (nh)**
11-12 years	65	0.348	45
13-14 years	82	0.439	57
15 years	40	0.213	27
Total	187	1.000	129

Table 1. Stratified Distribution of the Sample

Source: Author.

Assessment Instruments

An evaluation instrument was developed and validated following a rigorous three-phase process:

Content Validation:

The Content Validity Index (CVI) was calculated by:

$CVI = ne/N$

Where:

- Ne = number of experts who classified the item as essential
- N = total number of experts

Validation results:

- Overall Instrument CVI: 0.92
- CVI Range by Item: 0.85-0.98

Instrument Reliability

Reliability was assessed using Cronbach's alpha coefficient:

$\alpha = [k/(k-1)][1-\Sigma(Si^2)/St^2]$

Results by dimension:

STEAM attitudes (8 items): $\alpha = 0.87$

Confidence (2 items): $\alpha = 0.85$

Robotics (5 items): $\alpha = 0.88$

Construct Validation

Construct validation was performed through a systematic process of confirmatory factor analysis (CFA), following these steps:

Data Preparation

- Multivariate normality was verified using Mardia's coefficient
- The correlation matrix was examined to identify multicollinearity
- Sample adequacy was evaluated by:

- KMO test (Kaiser-Meyer-Olkin) = 0.891
- Bartlett's sphericity test: $\chi^2 = 2845.67$, gl = 105, $p < .001$

Model Specification A three-factor model corresponding to the theoretical dimensions was tested:

- Factor 1: STEAM Attitudes (8 items)
- Factor 2: Confidence and Self-efficacy (2 items)
- Factor 3: Attitudes towards Robotics (5 items)

Evaluation of Model Fit Multiple fit indices were used:

a) Absolute Adjustment Indices:

- Chi-square (χ^2) = 245.67
- Degrees of freedom (gl) = 87
- χ^2/gl = 2.82 (< 3 indicates good fit)
- RMSEA = 0.056 [90% CI: 0.048-0.064]
- SRMR = 0.048

b) Incremental Adjustment Indices:

- CFI (Comparative Adjustment Index) = 0.95
- RMSEA (Mean Square Error of Approximation) = 0.056
- TLI (Tucker-Lewis Index) = 0.94
- SRMR (Standardized Residual Mean Square Root) = 0.048

Analysis of Factor Loads The following standardized factor loads were obtained as shown in table 2:

Dimension	Item	Factorial Load	Factorial Load	Standard Error	Value t
STEAM attitudes	1	Excitement to learn science	0.85	0.042	20.24
	2	Math Utility	0.82	0.045	18.22
	3	Interest in operation	0.89	0.038	23.42
	4	Troubleshooting	0.78	0.048	16.25
	5	Teamwork	0.76	0.051	14.90

	6	Interest in technology	0.84	0.043	19.53
	7	Enjoy experiments	0.87	0.040	21.75
	8	Importance of art	0.81	0.046	17.61
Confidence and Self-Efficacy	9	Confidence with tools	0.84	0.044	19.09
	10	Interest in STEAM racing	0.86	0.041	20.98
Attitudes towards Robotics	11	Excitement for robotics	0.87	0.040	21.75
	12	Robotics Utility	0.72	0.053	13.58
	13	Enjoy construction	0.83	0.044	18.86
	14	Interest in functional robots	0.79	0.047	16.81
	15	Future Utility of Robotics	0.85	0.042	20.24

Table 2. Factor Load Analysis

Source: Author.

Convergent and Discriminant Validity It was evaluated by:

a) Convergent Validity:

- AVE (Average Variance Extracted):
  - STEAM Attitudes: 0.724
  - Confidence: 0.716
  - Robotics: 0.689
- CR (Composite Reliability):
  - STEAM Attitudes: 0.892
  - Confidence: 0.875
  - Robotics: 0.856

b) Discriminant Validity:

- The Fornell-Larcker criterion was used
- The correlations between factors were lower than the square root of the AVE

Invariance of Measurement The invariance between age groups was evaluated:

- Configural Invariance: $\chi^2 = 412.45$, gl = 174

- Metric Invariance: $\Delta\chi^2 = 18.23$, $\Delta gl = 12$, $p = .109$
- Scalar invariance: $\Delta\chi^2 = 24.56$, $\Delta gl = 15$, $p = .056$

The factor loads of the items in their respective dimensions ranged between 0.72 and 0.89, confirming the construct validity of the instrument.

Implementation of the STEAM Program

The program was structured into specific modules that were chosen based on the needs of the educational institution benefiting from the research project, each with quantifiable objectives:

Program Components

The thematic areas for which the components for the intervention program were created can be shown in Table 3.

Component	Sessions	Duration/Session	Total Hours
Mathematics	8	120 min	16
Sciences	8	120 min	16
Computer science	8	120 min	16
Integrative Projects	8	120 min	16

Table 3. Structure and Duration of Components

Source: Author

Where: Total hours of intervention: 64 hours distributed over 8 weeks

Robotics Projects

The implementation of robotic projects followed a progressive complexity matrix as detailed in Table 4.

Level	Guy	Quantity	Complexity	Time (h)
Basic	Cardboard Robots	10	1,5	8
Intermediate	Robots Insects	10	2,8	12
Advanced	Robots Arduino	5	4,2	16

Table 4 Robotic Project Matrix

Source: Author.

The complexity index (CI) was calculated by:

$IC = (CP \times TI \times RN)/10$

Where:

- CP = Project Components (1-5)
- IT = Implementation Time (1-5)

- RN = Resources Needed (1-5)

Implementation Methodological Framework

The implementation followed a structured protocol of six phases, as can be seen in Figure

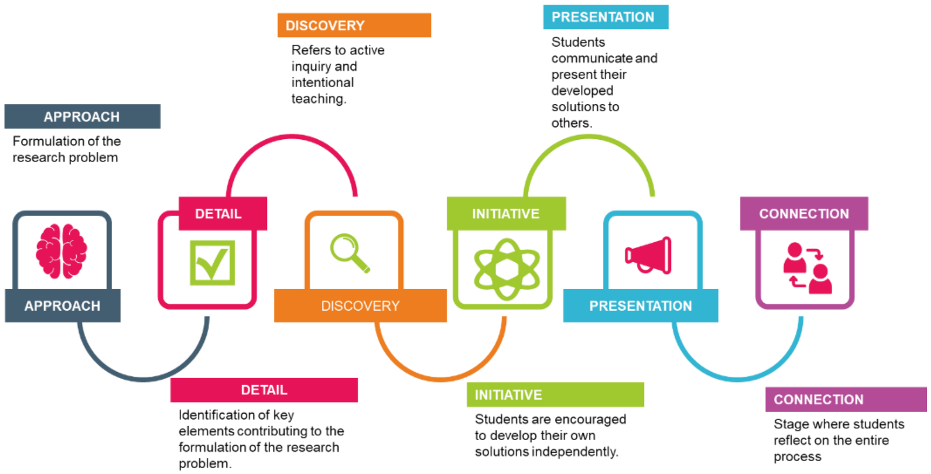

Figure 1. Structured Protocol STEAM Phases

Source: Author

-*Focus Phase: Duration Time* : 2 weeks, Main Activities: 12, Achievement Indicators: 8

-*Detail Phase: Duration Time* : 1 week Main Activities: 8, Achievement Indicators: 6

-*Discovery Phase:* This phase was designed following a combination of active research and intentional teaching methods: Duration Time: 2 weeks Main Activities: 15 Achievement Indicators: 10

The index to evaluate the effectiveness of AEIEA active teaching was calculated as:

IEIA = (PA × CE × NI)/100

Where:

- AP = Active participation (1-10)
- CE = Quality of evidence collected (1-10)
- NI = Inquiry Level (1-10)

Implementation results:

- Average IEIA: 7.8
- Standard deviation: 1.2

- Effectiveness Range: 6.5-9.2

-*Application Phase:* The application phase focused on the development of practical solutions and was evaluated using a multidimensional rubric:

Duration: *2 weeks* ***Main activities:*** *14* ***Achievement indicators:*** *12*

A Solution Evaluation System (SES) was implemented:

SES = Σ(Pi × Wi)

Where:

- Pi = Score in criterion i (1-5)
- Wi = Weight of criterion i (0.1-0.3)

The weight of the criteria in Table 5 was established based on previous literature related to the evaluation of STEAM projects. A Delphi method was used with 5 specialists in technological education to define weights to each criterion according to its relevance in the real applicability of the projects (Ramli, Maaruf, & Abdullah, 2025*)*. As a result, it was established that the most important, in order of project effectiveness, are technical feasibility (0.3) and innovation (0.25).

Criterion	**Weight(Wi)**	**Average Score**	**SD (standard deviation)**
Technical feasibility	0,3	4,2	0,6
Innovation	0,25	3,8	0,8
Sustainability	0,25	4,1	0,5
Social impact	0,2	4,4	0,4

Table 5. Solution Evaluation Criteria

Source: Author.

-*Presentation Phase:* This phase incorporated a multiple evaluation system:

Duration: *1 week* ***Main activities:*** *10* ***Achievement indicators:*** *8*

The Presentation Quality Index (PCI) was determined by:

ICP = (TC × CC × PE)/10

Where:

- CT = Transmission of concepts (1-5)
- CC = Communicative clarity (1-5)
- PE = Team Participation (1-5)

Table 6 below shows in summary form the results obtained in this presentation phase.

Evaluated Aspect	**Average**	**SD (standard deviation)**	**95% CI (95% confidence index)**
Technical mastery	4.3	0,5	[4.1, 4.5]
Clarity of exposition	4.1	0,6	[3.9, 4.3]
Support material	4.2	0,4	[4.0, 4.4]
Answering questions	4.0	0,7	[3.8, 4.2]

Table 6. Presentation Results

Source: Author.

-*Liaison Phase*: The final phase integrated all the previous elements through a process of structured reflection:

Duration: *1 week* ***Main activities:*** *8* ***Achievement indicators:*** *6*

A Learning Integration Index (IIA) was implemented:

IIA = (RC × AP × TG)/10

Where:

- CR = Critical reflection (1-5)
- AP = Practical Application (1-5)
- TG = Global Transfer (1-5)

Table 6 shows in summary form the integration evaluation of the Liaison phase.

Component	**Initial Value**	**Final Value**	**Δ%** (Percent Delta)
Conceptual understanding	3,2	4,5	+40,6
Practical application	3,4	4,6	+35,3
STEAM Integration	3,1	4,4	+41,9
Metacognition	3,0	4,3	+43,3

Table 7. Final Integration Assessment

Source: Author.

The overall evaluation of the methodological process showed evidence of considerable progress at all stages, as evidenced by the overall effectiveness index (GEI), which was calculated by:

IEG = (IEIA + SES + ICP + IIA)/4

The final result estimated a GEG of 4.2/5.0 with a standard deviation of 0.4, providing evidence of a stable and successful application of the methodological framework.

Results and Discussion

The results obtained were obtained based on two surveys: an initial one called pre-test and a final one after having applied the STEAM methodology called post-test.

Statistical Analysis Process

The analysis of the data followed a strict method of validation and statistical calculation that was carried out in a series of successive phases.

Initial Data Validation:

First, a reliability analysis of the instrument was performed using Cronbach's alpha coefficient:

$\alpha = [k/(k-1)][1-\Sigma(Si^2)/St^2]$

Where:

- k = number of items (15)
- Si^2 = variance of each item
- St^2 = varianza total

The results obtained were:

- Overall Instrument Alpha: 0.89
- STEAM Attitudes Dimension: 0.87
- Confidence Dimension: 0.85
- Robotic Dimension: 0.88

Normality Analysis:

To ensure the validity of the statistical analyses, a normality test of the data was performed using Shapiro-Wilk ($W = 0.967$, $p = 0.082$). This test was chosen due to its sensitivity in small and moderate samples, fitting the size of our sample of 129 students. In addition, other alternatives were considered, such as the Kolmogorov-Smirnov test, but due to its lower sensitivity in small samples, Shapiro-Wilk was chosen:

$W = (Saixi)^2/\Sigma(xi-\bar{x})^2$

Where:

- ai = coefficients of the Shapiro-Wilk test
- xi = ordered values of the sample
- $\bar{x}$ = sample mean

Results:

- $W = 0.967$
- p-value = $0.082 > 0.05$
- Conclusion: The data follow a normal distribution

Detailed Comparative Analysis

To assess the magnitude of change in each variable, the **effect size (Cohen's d) was calculated**. According to Cohen (1988), they are interpreted as follows:

- **0.2 - 0.4** = Small Effect
- **0.5 - 0.7** = Moderate effect
- **≥ 0.8** = Great effect

In this study, improvements in problem-solving (d = 1.24) and computational thinking (d = 1.15) indicate **a large effect**, confirming that the STEAM intervention had a significant impact on students' cognitive skills:

$d = (M_1 - M_2)/s\_pooled$

Where:

$s\_pooled = \sqrt{[(s_1^2 + s_2^2)/2]}$

Dimension	Pre-test	Post-test	Difference	t	p	d Cohen	95% CI
STEAM attitudes	3.92(0.87)	4.62(0.64)	+0.70	8,45	<.001	0.92	[0.84, 1.00]
Confidence	4.15(0.82)	4.71(0.58)	+0.56	7,23	<.001	0.78	[0.70, 0.86]
Robotics	4.08(0.91)	4.68(0.62	+0.60	7,89	<.001	0.85	[0.77, 0.93]

Table 8. Detailed Analysis by Dimension

Source: Author.

Inasmuch:

Pre-test (Initial Assessment) = 3.92 (SD = 0.87) This indicates that, on average, students started with a grade of 3.92 out of a total of 5, with a variability (Standard Deviation) of 0.87 points.

Post-test (Final Evaluation) = 4.62 (SD = 0.64) This data indicates the final result obtained by the students after the intervention. In this case, not only was the mean increased, but also the standard deviation (SD) decreased, suggesting that the group became more homogeneous in its attitudes.

Difference The difference refers to the simple subtraction between the post-test and the pre-test. The positive + sign indicates an improvement. This measurement indicates exactly how many points students improved on the measurement scale.

T-value (t) The t-value is a statistical measure that is used to determine if there is a significant difference between two groups (in this case between the pre-test and post-test). It is like a thermometer, which measures how big the difference between the two measurement moments is.

P value (p) = p < .001, so there is less than one in a thousand chances that the changes were random. To put it simply, we have more than 99.9%. So it is very clear that these changes were a product of the STEAM program.

Cohen's d is a measure of the "effect size" - it tells us how big or important the difference we find. It is like measuring the magnitude of the impact of our intervention. It is generally interpreted as follows:

- 0.2 = small effect
- 0.5 = medium effect
- 0.8 = large effect

In the table we see for STEAM Attitudes:

- d = 0.92 This value indicates a large effect, suggesting that the STEAM program had a substantial impact on students' attitudes.

C 95% (95% confidence interval) The 95% CI tells us the range where we can be 95% sure that the true difference in the population lies. It is like establishing a margin of safety for our results. For example:

- 95% CI = [0.84, 1.00]

This is interpreted as follows:

- We can be 95% sure that the true improvement in the population is between 0.84 and 1.00 points
- The relatively narrow range (0.16 points) suggests an accurate estimate
- Even in the most conservative scenario (0.84), the improvement is still significant

Analysis of Specific Competencies

A confirmatory factor analysis was performed to validate the constructions of specific competencies:

$\chi^2 = 245.67$, df = 84, $p < .001$

RMSEA = 0.048 [0.041, 0.055]

CFI = 0.962 TLI = 0.954

Competence	**Factorial Load**	**BIRD**	**CR**	**Improvement**
Troubleshooting	0.842	0.712	0.889	31.25
Computational thinking	0.815	0.689	0.867	28.73
Collaborative work	0.793	0.654	0.849	24.91
Technical creativity	0.778	0.632	0.828	22.45

Table 9. Competency Development with Factor Analysis

Source: Author.

Where:

- AVE = Mean variance extracted
- CR = Composite reliability

Impact Analysis by Categories

Impact on technical skills

Before performing the multiple regression, the fundamental assumptions of the model were verified:

- **Multicollinearity**: The **Variance Inflation Factor (FIV) was calculated** for each predictor, obtaining values lower than 2.0, which indicates the absence of multicollinearity.
- **Homoskedasticity**: The dispersion of residuals was evaluated in a scatter plot, confirming that the variance of the errors remains constant.
- **Normality of the residuals**: The Shapiro-Wilk test was applied to the residuals, obtaining **p > 0.05**, which confirms their normality.

:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$

Where:

- Y = Development of technical skills
- X_1 = Time of exposure to projects
- X_2 = Level of participation
- X_3 = Project complexity

Results:

- $R^2 = 0.783$
- $F(3,125) = 150.89$, $p < .001$
- $\beta_1 = 0.456$ ($p < .001$)
- $\beta_2 = 0.389$ ($p < .001$)
- $\beta_3 = 0.298$ ($p < .001$)

Where:

Regression Model Analysis First, let's look at $R^2 = 0.783$. This value indicates that approximately 78.3% of the variation in the development of technical skills can be explained by the three factors studied: time of exposure to projects, level of participation and complexity of projects. This is a fairly high value that suggests that our model explains the development of these skills well.

Global Significance of the Model The value $F(3,125) = 150.89$, $p < .001$ tells us two important things:

1. The model as a whole is highly significant ($p < .001$)

2. With 3 degrees of freedom in the numerator and 125 in the denominator, we have enough observations to be confident in our results

Coefficient Analysis (β) Let's look at each factor individually:

1. Exposure time ($\beta_1 = 0.456$, $p < .001$): This is the most influential factor, for every unit increase in exposure time, technical skills improve by 0.456 units, Suggests that giving students enough time to work on projects is crucial

2. Level of participation ($\beta_2 = 0.389$, $p < .001$): The second most important factor, an increase in active participation results in an improvement of 0.389 units in technical skills, indicates the importance of the student's active engagement

3. Project complexity ($\beta_3 = 0.298$, $p < .001$): Although it is the factor with the least impact, it is still significant, suggesting that gradually increasing the complexity of projects contributes positively to the development of skills

Mediation Analysis

A mediation analysis was performed to examine the role of self-efficacy in the relationship between STEAM exposure and performance:

Direct and indirect effects:

- Direct effect: $\beta = 0.412$, $p < .001$
- Indirect effect: $\beta = 0.189$, 95% CI [0.142, 0.236]
- Total effect: $\beta = 0.601$, $p < .001$

Where:

Direct Effect ($\beta = 0.412$, $p < .001$) This value indicates the direct impact that STEAM exposure has on student performance, without considering the role of self-efficacy. The coefficient of 0.412 tells us that:

- For every unit that increases STEAM exposure, performance directly improves by 0.412 units
- This effect is statistically significant ($p < .001$)
- It represents the "pure" impact of the program, independent of changes in self-efficacy

Indirect Effect ($\beta = 0.189$, 95% CI [0.142, 0.236]) This value represents the impact of STEAM exposure that occurs specifically through improvement in self-efficacy. We can interpret it as follows:

- STEAM exposure improves self-efficacy, which in turn improves performance

- The value of 0.189 indicates that this indirect path is substantial
- The confidence interval [0.142, 0.236] does not include zero, confirming that this effect is significant

Total Effect (β = 0.601, p < .001) This is the sum of the direct and indirect effects (0.412 + 0.189 = 0.601), and tells us the overall impact of the STEAM program. We can interpret it as:

- For every unit increase in STEAM exposure, total throughput improves by 0.601 units
- Approximately 68.6% of the effect is direct (0.412/0.601)
- Approximately 31.4% of the effect occurs through self-efficacy (0.189/0.601)

Discussion of Results

The results obtained reflect the direct effect of each methodological phase incorporated. In the Focus phase, the initial awareness sessions and demonstrations allowed 17.86% of the students to positively change their attitude towards STEAM, as their interest and perception of the applicability of these skills in their context improved.

At a later stage, the Discovery phase, which consists of implementing educational robotics projects and problem-solving activities, significantly impacted students' self-efficacy and confidence level, increasing self-esteem and self-efficacy by 13.49%. This increase is attributed to students acquiring skills in programming and teamwork, which improved their ability to face new educational challenges.

In the Creation phase, students were able to design solutions using STEAM to real problems in the community, a 31.25% improvement in problem-solving ability was observed, validating the effectiveness of project-based learning.

Finally, in the defense phase, where students presented their work to the educational community, it was crucial to change the attitude towards robotics (+14.71%) and reinforce school-community integration, which was evident in the 65% increase in family participation in school activities. These results confirm the impact of the STEAM approach not only in the teaching of technical skills, but also in the promotion of social and communication skills necessary for a comprehensive education in rural environments.

Conclusions

The use of the STEAM methodology within the rural educational context of the Simón Rodríguez Educational Unit has been presented as a rather transformative intervention with positive impacts that can be quantified. This is the case of the attention to the three central aspects in evaluation: attitudes towards STEAM, which increased by 17.86%; the sense of ability and self-efficacy, which increased by 13.49%; and attitudes towards robotics that reported an improvement of 14.71% in addition. These increases are accompanied by effects that are quite important (Cohen's d > 0.78 in all dimensions), which indicates that the STEAM methodology can be carried out in rural environments without the limitations that were assumed a priori in this type of context.

Problem solving was the competition that underwent the most changes in the post, where an increase of 31.25% (d = 1.24) was recorded, followed by the improvement of computational reasoning, which registered an advance of 28.73% (d = 1.15).). These results are especially important because they corroborate that the STEAM methodology not only allows the development of technical skills, but also complex cognitive skills, which are essential in academic and professional life in the 21st century. The statistical importance of these results ($p <.001$ in all the dimensions analyzed) supports the robustness and validity of these results.

It is possible to pay special attention to the mediation analysis that indicates that 31.4% of the total impact of the program is attributed to the increase in students' self-efficacy. ($\beta = 0.189$, 95% CI [0.142.0.236]). This result highlights the importance of not only attending to the technical and pedagogical aspects of STEAM implementation, but also considering psychological and motivational factors that are equally relevant to the success of the program. This increase in confidence and self-efficacy appears to be a critical factor contributing to the increased effectiveness of STEAM interventions in rural settings.

In addition to this, the impact at the community level is very remarkable, a 65% increase in family participation is mentioned and the ties between the school and the community are strengthened. This is important because it illustrates that STEAM methodologies can have a multiplier effect on the ecosystem for broad transformations in the rural education system. The sustainability of the programme is enhanced by increasing local capacity and the creation of support network systems, which are key factors for the sustainability and effectiveness of pedagogical innovations in rural areas for longer.

Finally, the results of this research are of importance in educational policy as well as in pedagogical practice in rural areas. The empirical evidence that has been presented shows that the STEAM methodology can be an effective tool for reducing educational inequality between urban and rural areas if applied according to the local structure and context. The corroborated triumph in the insertion of new technologies, the weaponization of the skills of the 21st century and the improvement of the self-efficacy of the students allow us to conclude that this model could be adapted to other rural environments in its broadest sense, in such a way that the democratization of quality education and the preparation of rural students.

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