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The STEAM methodology and PBL in the integration of knowledge and development of mathematics competencies

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ABSTRACT

The development of mathematical competencies in middle school students is currently a challenge, to overcome it teachers implement various methodologies and strategies that seek to make the knowledge of this discipline more accessible. In this sense, this research analyzes the effectiveness of the STEAM (Science, Technology, Engineering, Arts, Mathematics) methodology and Project-Based Learning (PBL) in the development of mathematical competencies in eleventh-grade high school students. The main objective was to evaluate how STEAM and PBL methodologies promote mathematics learning and the development of skills such as critical thinking, creativity, and teamwork. The research was developed under a non-experimental design, with a mixed approach with a mostly quantitative part, with a descriptive, cross-sectional level, through a survey of a sample of 17 students of the eleventh grade of secondary education belonging to the Santa Teresa National Institute and the application of an interview to the two teachers of Physics and Mathematics. All this took place during the second half of 2023. The results reveal that students positively value the integration of disciplines and the practical application of mathematics, showing significant improvements in the understanding of mathematical concepts. In addition, it was observed that collaboration

in STEAM and PBL projects strengthened teamwork skills, although the need for greater variety in practical projects was identified.

INTRODUCTION

The STEAM methodology, combining science, technology, engineering, art, and mathematics, allows students to develop skills and competencies in these areas, encouraging their creativity and critical thinking. On the other hand, project-based learning (PBL) is a pedagogical strategy that involves students in solving real problems, which allows them to apply the knowledge acquired in everyday situations, thus awakening interest in the disciplines studied in class. As Tomalá (2024) puts it, "the STEAM methodology positively influences students' perceptions of mathematics, enhancing their problem-solving skills" (p.15).

Along the same lines, the author highlights a significant positive relationship between student participation in STEAM activities and their performance in mathematics, also underlining the importance of interactive activities in this context. Each component of STEAM provides a set of properties that, together, allow the student to develop logical, creative, and critical thinking, essential skills to solve problems or situations posed, establishing significant facts and connections.

This methodology considers that science, engineering, and technology sports can be integrated into didactic situations and learning tasks within the mathematics class. This implies that students' mathematical learning can be guided by the theoretical principles that underpin this didactic approach (Glancy & Moore, 2013, as cited in Olvera et al., 2022).

Currently, the Ministry of Education of Nicaragua (MINED) has carried out various actions to improve the quality of education, including the development of a project for friendly learning of mathematics. According to Herrera, the implementation of this project in secondary education has shown significant improvements, establishing an overall level of elementary learning compared to the indices before its application. (2023)

Despite these advances, there is still a need for improvement in the learning of mathematics. Although MINED has promoted the training of teachers in pedagogical areas, the use of innovative strategies, and the incorporation of information and communication technologies in the classroom, it is necessary to continue promoting the use of technological methodologies and tools that allow teachers to develop significant learning. In students and move towards quality education.

According to Osuna et al. (2019)

> STEAM education seeks to connect those "hard" concepts of science, technology, engineering, and mathematics with real problems. That is, the teaching-learning process is active and collaborative between disciplines, using creativity to generate practical solutions so that, from an early age, scientific and engineering curiosity are promoted and remain in them naturally. (p. 29).

In this same sequence of ideas, this author points out that today's society demands the development of multidisciplinary skills and critical thinking, and also states that the STEAM methodology can serve as a catalyst to enhance the learning and understanding of mathematical concepts through activities based on problems in accordance with the realities of each person.

To contribute to this improvement, the strategy called "Integration of knowledge through the STEAM and PBL methodology for the development of mathematical skills" is proposed, integrating the disciplines of Mathematics and Physics. This strategy aims not only to improve the teaching-learning process but also to develop fundamental competencies, such as logical-mathematical reasoning, problem-solving, creativity, and the ability to apply knowledge in interdisciplinary contexts.

On the other hand, one of the most widely used strategies in the development of mathematical competencies is Problem-Based Learning (PBL) , according to Castillo-Castillo et al., (2023) is a learning method that is based on the principle of using problems as a starting point to acquire and integrate new knowledge as a criterion that helps the development of students' skills and attitudes.

Research is a fundamental function of educational institutions at different levels since it constitutes an indispensable pillar for the generation of knowledge. This is considered a key element in the educational process since it allows the creation of knowledge and promotes learning, which drives the creation of new knowledge. In addition,the research strengthens the link between school and society, by addressing real problems and proposing solutions that impact the social context. For this reason, training institutions at different levels must foster students' capacity for research, integrating this activity as a pedagogical strategy within the curriculum.

A student with basic research skills is able to identify problems in their environment, delimit them, and analyze them to offer solutions based on their knowledge. This article proposes the STEAM and PBL methodology as a strategy for the development of mathematical competencies, integrating the disciplines of mathematics and Natural Physical Sciences, and promoting research and teamwork. Its main objective is to implement a STEAM methodology

and PBL as a strategy to develop mathematics learning through the integration of knowledge in the disciplines of Physics and Mathematics. Focusing on the contents of Quadratic Functions, Solving Quadratic Equations, Parabola Elements, Energy Transformation, Conservation Principles, Heat and Temperature, Heat Transfer, and DIY and Recycling Topics.

The research problem focuses on the challenge of improving the development of mathematical competencies in secondary school students, a current challenge in Nicaragua. Despite the efforts made by the Ministry of Education, difficulties persist in learning mathematics, which motivates the implementation of innovative methodologies. In this context, the research analyzes the effectiveness of the STEAM methodology and Project-Based Learning (PBL) to promote mathematical learning and develop skills such as critical thinking, creativity, and teamwork in study.

MATERIALS AND METHODS

Type of Research

The research was developed from hermeneutics as a method of understanding that allows reflection on the experience of life from the daily practice or world of the life of the being (Gadamer, 2005).

In this sense, the methodological approach was based, first, on the documentary review of the authors who support the STEAM methodology and PBL; second, on the reflection of teachers on the experiences obtained about the pedagogical proposal applied in the development of the integrated contents of the disciplines of physics and mathematics and at the same time the opinion of students regarding their learning experience.

The research was carried out under a non-experimental design as expressed by Agudelo (2008)

"Non-experimental research has less rigorous control than experimental research and it is more difficult to infer causal relationships, but non-experimental research is more natural and closer to everyday reality." (p. 42), a reality that the researcher wants to approach to have a more effective assessment of student learning through this methodology.

This author also states that non-experimental research is that which is carried out without deliberately manipulating the independent variables. It is based on variables that have already occurred or occurred in reality without the direct intervention of the researcher. Therefore, the study is observational, in these types of studies, the researcher is dedicated to observing and recording phenomena or events as they develop naturally, without intervening or manipulating variables, as defined (Bakemen & Gottman, 1989, p.60) "Systematic observation is a particular

way of measuring or quantifying behavior, which consists of observing spontaneous behavior in natural contexts."

The focus of this research is mixed since it implements the quantitative and qualitative research approaches, as Guelmes and Almeida (2015) express "considers, therefore, that mixed research methods are the systematic integration of quantitative and qualitative methods in a single study to obtain a more complete "picture" of the phenomenon". (p.24)

The study is descriptive since it seeks to detail how certain situations and phenomena manifest themselves, specifying relevant properties of people, groups, and communities (Sampieri et al., 2014). In this case, the objective is to analyze the key elements of STEAM and PBL methodologies and their impact on student learning.

Regarding its temporality, the research is cross-sectional, since a single measurement of the variable under study was carried out. The population is made up of 96 students in the eleventh grade of secondary education from the Hermano Narváez National Institute, in the municipality of Santa Teresa, Carazo, distributed in three sections: two in the morning shift (A and B) and one in the afternoon (C), as shown in the following table.

Board 1

Distribution of student enrolment.

Section	Numbers Of Student
A	42
B	37
C	17

Note. This table shows how enrollment is distributed by classrooms for the eleventh grade of the Santa Teresa National Institute.

Since the study population is naturally distributed, and the characteristics of the individuals are the same, each group or section was considered as a sample point.

The choice of the sample was based on simple random sampling, where the elements have an equal probability of being selected. This is mentioned by Hernán, Blanco, and Valledor (2019), It guarantees that all individuals that make up the population have the same opportunity to be included in the sample. Therefore, for the selection of the group, the following procedure was followed:

1. Identify the groups (sections): In this case, the groups are the 3 sections of the school: A, B, and C.
2. Assign a number to each group: Assign a number to each of the sections: Section A: 1

   Section B: 2

   Section C: 3

Perform the random selection: for the selection, random numbers were applied, this was calculated with the help of a calculator, the selected group was section C.

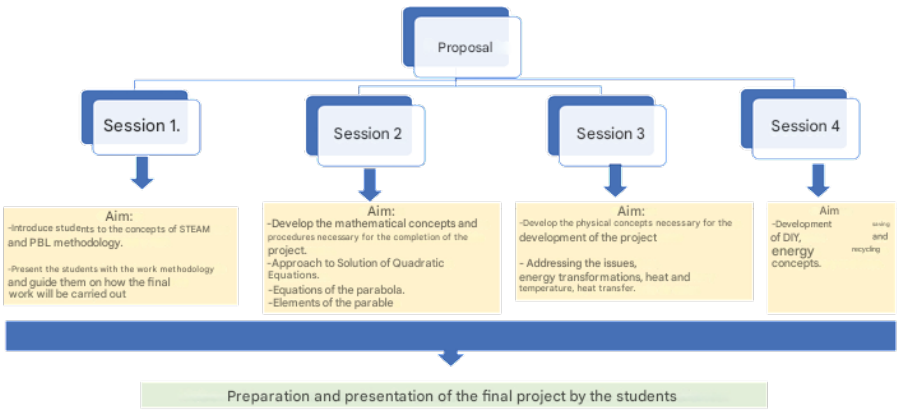
Two teachers were also part of the study, one from the discipline of mathematics and the other from the discipline of Natural Physical Sciences.

For the collection of information, an observation guide was made, which was aimed at identifying the following categories: student behavior, interest, motivation, integration into the group, complete completion of the activities. In the same way, a questionnaire was applied to the students, with the aim of knowing their appreciation of the activities developed as part of the strategy.

The development of the proposal was structured in four sections each with a time of 90 minutes, each section had its planning and objectives in order to develop the skills required for the development of the proposed project which consisted of making a Solar cooker, applying knowledge of the Disciplines of Mathematics and Physics.

Figure 1

Organization of the development of the didactic proposal



ANALYSIS OF THE RESULTS

The analysis matrix is presented below, which corresponds to the opinions of the teachers.

Board 2

Interview analysis Applied to teachers.

No.	Question	Mathematics Teacher	Physics Teacher	Summary
1	How do you consider the strategy applied?	I think it is very good the STEAM methodology is one of the methodologies that are applied to develop learning in mathematics, but I had never applied it	I think it is very good I liked it because it allowed me to integrate the contents of my subject with those of other disciplines, especially having integrated it with discipline that perhaps I thought could not be done.	The two teachers value the strategy positively, highlighting that an important aspect is the integration of knowledge from the three disciplines.
2	What do you think was the main challenge faced in developing the strategy?	The main challenge was to establish a final project whose elaboration would integrate the knowledge of the 3 disciplines, especially considering that the biggest problem was in integrating content with social content, did I think it couldn't be done?	I consider that the biggest challenge was to achieve a good integration and as a challenge even to achieve it in the time we have assigned	The biggest challenge for teachers is to integrate the contents of their disciplines to achieve the realization of a product or project.

No.	Question	Mathematics Teacher	Physics Teacher	Summary
3	How do you consider the results of this strategy?	I consider them very good since I managed to observe motivation in the students and that they were attentive at the time of explanation.	Excellent because in this way I managed to relate theory with practice.	The teachers' assessment of the strategy is positive, which they say is very good.
4	What is the greatest achievement that you consider was achieved with the strategy?	For me it was seeing that the students were motivated, they were enthusiastic about trying the kitchen to see if it worked for them, A comment from one of the groups was that they measured the focal length several times, to determine where it warmed up the most, I liked that because they associated what I taught them in class.	Well, I think it was the integration and teamwork, the kids were motivated, and they liked how we developed the class	Teachers agree that the greatest achievement achieved is having awakened motivation and interest in learning

No.	Question	Mathematics Teacher	Physics Teacher	Summary
5	Do you think that the methodology applied developed research skills? How?	I think so, since the students took on the task at the CTE to look for information and ways to make the kitchens, how they could do them.	I think so since they researched how they could do the project and what materials they could use, in addition to the physical principles that were present, because in my class I requested that, they not only make the kitchen but also tell me where they were applying what they saw in my class.	Teachers agree that this methodology allows the development of skills such as teamwork and research.
6	Do you think that the strategy promotes meaningful learning for students?	I think so, in fact, one of the great dilemmas in mathematics is to eliminate the taboo that mathematics does not serve me in everyday life, where I apply it since this way of developing content allows the student to see the direct application of mathematics in the proposed project.	I think so since the project helped the students to experience what we gave them in class.	Teachers agree that the strategy develops significant learning

From Table 1 .The strategy from the point of view of the teachers involved manages to achieve the proposed objectives, both for the topics of each of the disciplines, as well as to achieve significant learning, in the same way they express that students are motivated and demonstrate creativity when generating answers to the problems presented during the classroom activities. Reaffirming what González and Abarca expressed, the STEAM methodology is an attractive and dynamic way of understanding mathematical concepts in the classroom, to promote the development of creativity and the capacity for innovation, provoking learning that would hardly occur in a classroom in a regular class. (2020)

In this line, the teachers claim to have awakened the research curiosity in the students, an achievement that they attribute to the integration of contents of their disciplines in the designated project (Solar Kitchen). This coincides with what was pointed out by Fenyvesi et al. (2014), cited by González and Abarca (2020), who highlight that the STEAM methodology is based on the integrated learning of scientific and artistic disciplines. This integration occurs mainly through activities or projects that collaboratively combine the contents and tools of the different areas.

From the teaching perspective, STEAM learning is recognized as a model that promotes the integration and development of scientific-technical and artistic subjects in a unique interdisciplinary framework (Yakman, 2008).

To respond to the objectives set out in the research and as part of the methodology proposed in the study, a questionnaire was applied to the students, which had 10 items, they were grouped into three dimensions, dimension one has to do with the experience with the strategy, dimension two that has to do with the methods of STEAM teaching and the third dimension that has to do with the methods of STEAM teaching with the impact on learning.

The group of students to whom the strategy was applied was distributed as shown in Figure 2.

Figure 2

Distribution of students by sex

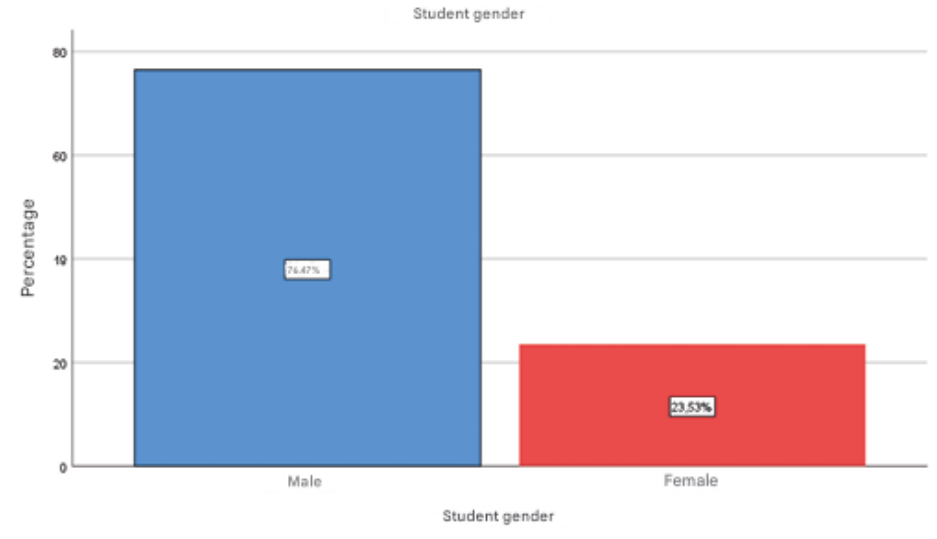


Figure 2 shows the difference between the number of males and females in the classroom, since 76.47% are males and only 23.53% are females.

Figure 3

Distribution of students by their origin.

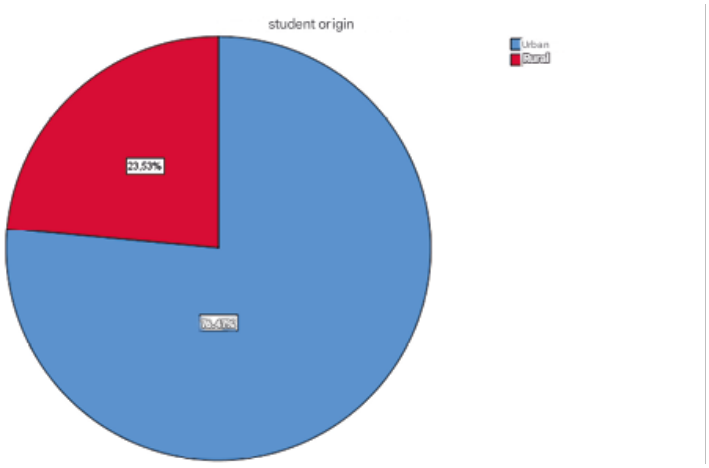


Figure 3 indicates the distribution of students by their place of origin, where 76.64% belong to the urban area and 23.53% belong to the rural area, this distribution is according to what was expressed by the teacher of the class group, is that the school as one of its policies given the demand of students from the rural areas of the municipality of Santa Teresa is that the morning shift is guaranteed to students from remote rural areas and in the afternoon students from urban areas are located.

Figure 4

Distribution according to the age of the student

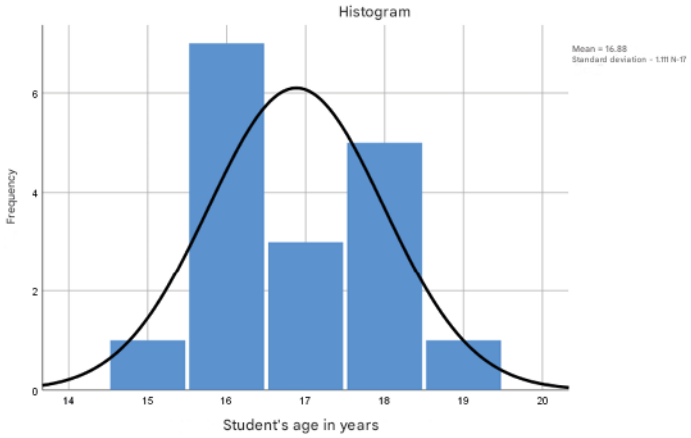


Figure 4 shows how the age of the students is distributed, which has a mean of 16.88 years and a deviation of 1.111 years, having an age range between 15 and 20 years, the age meets an approximately normal distribution, as demonstrated by the normality test carried out and the curve that is superimposed on graph 3.

Figure 5

Response Distribution on Strategy

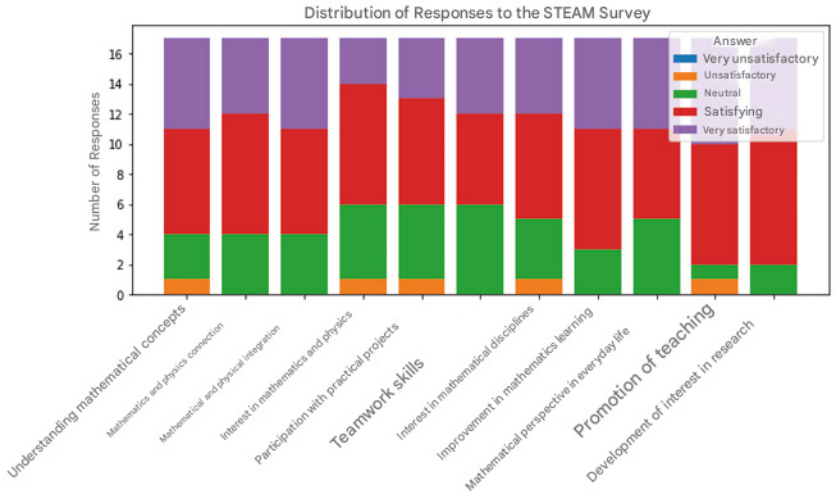


Figure 5 shows the opinions of the students in the eleven items contained in the instrument where it can be observed that there are no students whose answer is in the category of very dissatisfied and that only in the items of comprehension of mathematical concepts, interest in mathematics and physics participation in practical projects, interest in the discipline of mathematics and favoring of teaching there is an opinion of dissatisfied, it is important to note that the number of these students who value unsatisfactory is on average 2 students. This data is supported by the control of grades that the classroom teacher has, where the existence of two students with learning problems is evidenced, most notoriously in their attitude toward studying. (Angel et al., 2023)

On the other hand, Figure 5 shows an excellent assessment of the students in

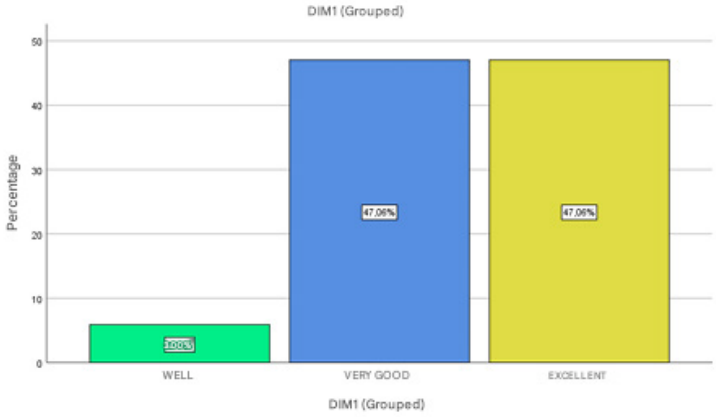
Whereas, the proposal developed, especially in what has to do with the development of teamwork skills, interest in research, and the connection of mathematics, and physics to problems of everyday life, there is also evidence of a notable improvement in the understanding of mathematical content.

In general, graph four ratifies what Byrne (2023) expressed, who states:

STEAM projects allow learning based on contextualized problem-solving. Instead of learning concepts and skills in isolation, students face authentic and complex challenges, so students have to apply knowledge and skills from different areas to find an effective solution. This fosters critical thinking, creativity, and teamwork skills, skills critical to success in today's world. (p.10)

Figure 6

Experience with the STEAM Strategy



To have an assessment by the dimensions, the variables DIM1, DIM2, and DIM3 were calculated, which are obtained by calculating the means of the scores assigned by the students in each of the items or indicators of the dimension, then we proceeded to group and categorize these means, establishing the categories of deficient, Average, Good, Very Good and Excellent. Figure 6 shows that 47.06% of the students consider their experience with the applied strategy to be very good and excellent, this is corroborated by what was expressed by the teachers involved in the study who, like them, value the strategy very well since they managed to show very positive results in terms of motivation. Teamwork, interest in research, and mastery of the mathematical concepts studied.

The aforementioned findings ratify what Mejía and García (2020) express that one of the great advantages of the STEAM Methodology are:

Interdisciplinarity: The STEAM methodology promotes the integration of various disciplines, allowing students to understand mathematics in a broader, applied context. By linking mathematics with other areas of knowledge, this subject becomes more relevant and meaningful for students.

Motivation: STEAM can also increase students' interest in mathematics through innovative approaches and interactive projects. Engaging in creative and hands-on activities makes learning more engaging and stimulating.

In addition, STEAM promotes key skills such as teamwork, problem-solving, creativity, and communication, which are essential both in the educational field and in the world of work. This reaffirms what was expressed by Samsul et al. (2022), who points out that critical thinking, analytical reasoning, and logical reasoning are essential skills for effective problem-solving within the STEAM framework.

To evaluate the results in the second dimension, corresponding to the STEAM methods, the means of the evaluations in items 5, 6, and 7 were calculated, the results of which are presented in Figure 7.

Figure 7

STEAM Methods

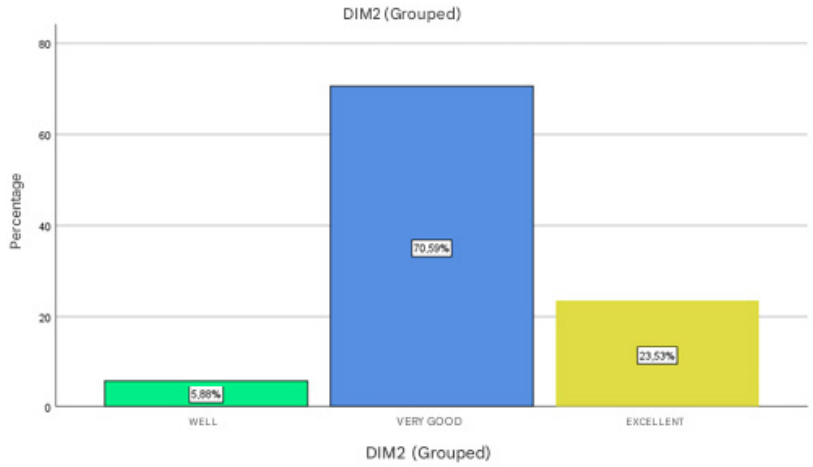


Figure 7 shows that students have a very good assessment of the STEAM methodology, agreeing with Cilleruelo (2014) "STEAM education allows an approach to the teaching-learning process from an active process driven by an experimental game that promotes the breaking down of barriers between disciplines and includes multiple possibilities at the crossroads of art, science, and technology. (p.15). These results agree with what was expressed by the teachers of the disciplines who value the STEAM methodology and PBL as a strategy for the development of learning in mathematics very positively.

Figure 8

Impact of Learning

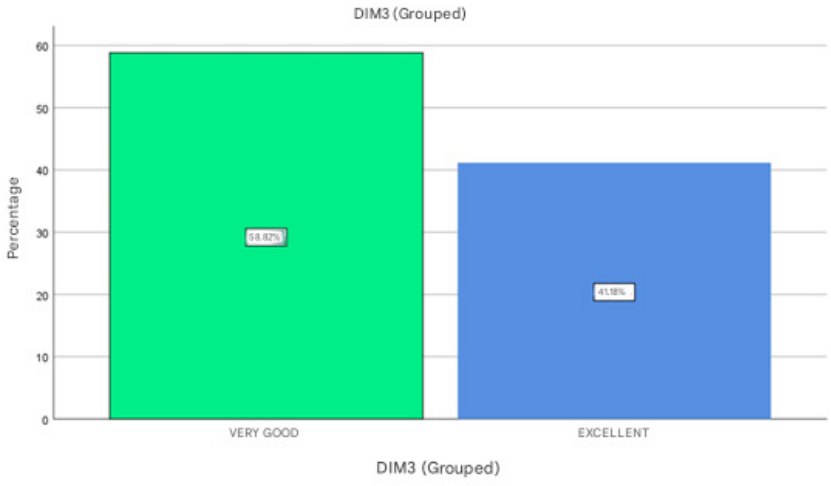


Figure 8 results from creating another variable (DIMA3) which corresponds to dimension three, this variable calculates the means of the scores of items 8, 9, 10, and 11 and then categorizes to establish a scale of assessment of the students in terms of the learning achieved with the strategy applied under the STEAM and PBL methodology.

The results obtained show an excellent assessment since 58.82% of the students indicated that their learning achieved is very good and 41.18% indicate that it is excellent compared to that achieved with the traditional or usual ways with which their teachers generally develop these contents.

In general terms, the triangulation of quantitative results, student opinions, and teachers' perspectives indicate that STEAM and PBL methodologies offer excellent results in the learning of mathematics and other disciplines, such as physics. This agrees with Benites and Barzallo (2019), who states that "this methodology seeks to ensure that students acquire the necessary skills through scientific disciplines so that they can respond to the challenges of a globalized and changing society" (p.5). Both teachers and students value that this methodology encourages motivation, research, and a positive attitude toward mathematics.

The integration of disciplines in the classes allows students to connect mathematics with other sciences and solve everyday problems, thus enriching their learning and understanding of the real world.

CONCLUSIONS

This research focuses on evaluating the effectiveness of STEAM and PBL strategies in the development of mathematical competencies in middle school students. Through a statistical analysis of the student's responses and interviews with teachers, several significant findings were obtained:

Students expressed generally positive opinions about the STEAM strategy, with a high average score (approximately 4 on a scale of 1 to 5).

The STEAM strategy was especially effective in improving the understanding of mathematical concepts, as reflected in the high average score on the initial question.

Most students perceived the STEAM strategy as a catalyst for learning in mathematics, rating it as satisfactory or very satisfactory, with an average grade above 4.

The integration of physics and mathematics was valued as a positive aspect, broadening the students' perspective on the application of mathematics in everyday life.

The use of hands-on projects emerged as an effective strategy to increase participation in math classes.

Collaboration on STEAM and PBL projects considerably strengthened teamwork skills.

Some students suggested the need for greater variety in hands-on projects, indicating an area for improvement for future implementations.

Open feedback revealed a general interest in the methodology and a preference for a greater focus on research projects.

In conclusion, the results suggest that the STEAM strategy has had a positive impact on the development of mathematical competencies in middle school students. However, the importance of diversifying practical projects to enrich the learning experience is highlighted. These findings provide valuable information for the continuous improvement and effective implementation of STEAM strategies in educational contexts.

ANNEXES

Figure 9

Students in the realization of their project

UNIVERSIDAD NACIONAL AUTÓNOMA DE NICARAGUA, MANAGUA
UNAN-MANAGUA

Facultad Regional Multidisciplinaria de Carazo
Departamento de Educación y Humanidades

Encuesta de Evaluación de Estrategia STEAM para el Desarrollo de Competencias Matemáticas para estudiantes de educación media.

Estimado estudiante, agradecemos tu participación en esta encuesta. Tu retroalimentación es fundamental para evaluar la efectividad de la estrategia STEAM implementada en tu educación. Por favor, responde con sinceridad.

I. Datos Personales:

1. Sexo del estudiante — Hombre ☐ Mujer ☐
2. Edad ☐
3. Procedencia — Urbano ☐ Rural ☐

Escala de Evaluación: Utiliza la siguiente escala para evaluar tu experiencia, donde:

- ✓ 1: Muy insatisfactorio
- ✓ 2: Insatisfactorio
- ✓ 3: Neutral
- ✓ 4: Satisfactorio
- ✓ 5: Muy satisfactorio

Dimensión 1 : Experiencia con la Estrategia STEAM

	1	2	3	4	5
1. La estrategia STEAM me ha permitido comprender mejor los conceptos matemáticos.					
2. He notado una conexión significativa entre los conceptos matemáticos y las disciplinas de física y sociales.					
3. La integración de las disciplina de física y sociales ha enriquecido mi comprensión de las aplicaciones prácticas de las matemáticas en el desarrollo del proyecto.					
4. La estrategia desarrollada por el docente me ha desarrollado mayor interés y motivación por las disciplina de matemática y física.					

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Dimensión 2: Métodos de Enseñanza STEAM

	1	2	3	4	5
4. La utilización de proyectos prácticos ha mejorado mi participación en las clases de matemáticas.					
5. La colaboración en proyectos STEAM ha fortalecido mis habilidades de trabajo en equipo.					
6. La aplicación de la estrategia STEAM ha despertado mi interés por las disciplinas relacionadas con las matemáticas.					

Dimensión 3: Impacto en el Aprendizaje.

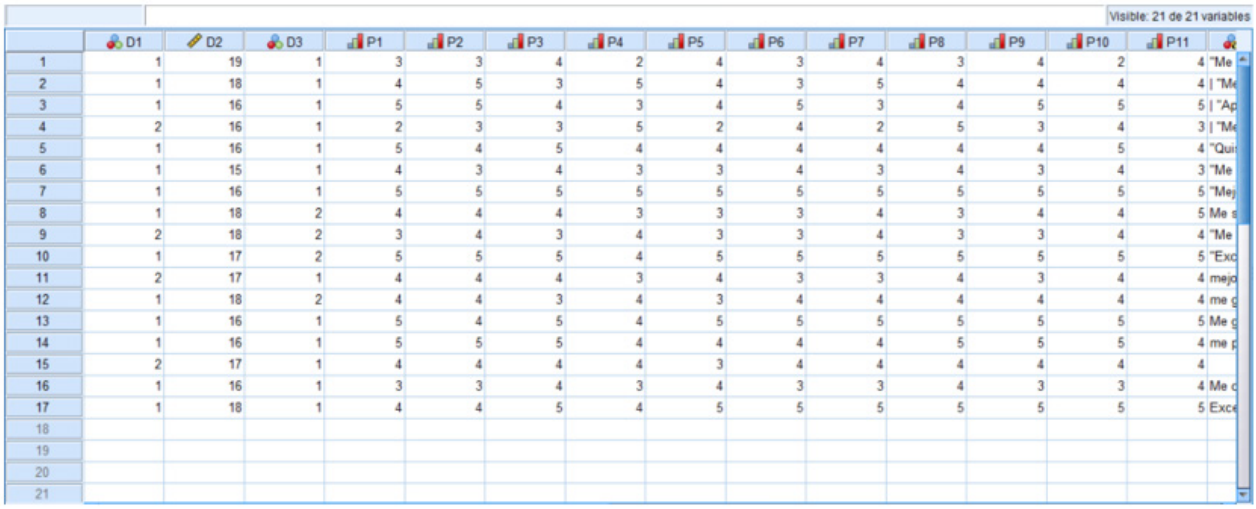
	1	2	3	4	5
7. Considero que la estrategia STEAM ha mejorado mi aprendizaje en matemáticas.					
8. Siento que la integración de física y sociales ha ampliado mi perspectiva sobre la importancia de las matemáticas en la vida cotidiana.					
9. consideras que esta forma de enseñanza favorece a tu aprendizaje.					
10. Siento que esta metodología desarrollo el interés por la investigación					

Comentarios Adicionales:

Por favor, comparte cualquier comentario adicional o sugerencia que puedas tener sobre la estrategia STEAM y su impacto en tu aprendizaje.

Figure 10

Database Image Capture in SPSS V25



Visible: 21 de 21 variables

	D1	D2	D3	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	
1	1	19	1	3	3	4	2	4	3	4	3	4	2	4	"Me
2	1	18	1	4	5	3	5	4	3	5	4	4	4	4	| "Me
3	1	16	1	5	5	4	3	4	5	3	4	5	5	5	| "Ap
4	2	16	1	2	3	3	5	2	4	2	5	3	4	3	| "Me
5	1	16	1	5	4	5	4	4	4	4	4	4	5	4	"Qui
6	1	15	1	4	3	4	3	3	4	3	4	3	4	3	"Me
7	1	16	1	5	5	5	5	5	5	5	5	5	5	5	"Mej
8	1	18	2	4	4	4	3	3	3	4	3	4	4	5	Me s
9	2	18	2	3	4	3	4	3	3	4	3	3	4	4	"Me
10	1	17	2	5	5	5	4	5	5	5	5	5	5	5	"Exc
11	2	17	1	4	4	4	3	4	3	3	4	3	4	4	mejo
12	1	18	2	4	4	3	4	3	4	4	4	4	4	4	me g
13	1	16	1	5	4	5	4	5	5	5	5	5	5	5	Me g
14	1	16	1	5	5	5	4	4	4	4	5	5	5	4	me p
15	2	17	1	4	4	4	4	3	4	4	4	4	4	4	
16	1	16	1	3	3	4	3	4	3	3	4	3	3	4	Me c
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