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The potential of ethnomathematical and mathematical connections in the pre-service mathematics teachers' meaningful learning when problems-solving about brick-making

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Abstract

This research explores the potential of ethnomathematical and mathematical connections in fostering meaningful learning through problem-solving in brick-making. Despite the importance of such connections in mathematics education, students often struggle with contextualized verbal problems related to daily life. A qualitative ethnographic methodology involved a workshop divided into three stages. Fourteen pre-service mathematics teachers in northern Colombia enrolled in an ethnomathematics course participated. Participant observation was used during the workshop to document how students solved problems and engaged with the material. Data analysis was guided by the Extended Theory of Connections and the Onto-semiotic Approach. The study examined the mathematics emerging from brick production, focusing on problems involving area, volume, and proportional reasoning. Ethnomathematical connections were emphasized, providing a foundation for pre-service teachers to solve problems related to the area and volume of bricks. Various mathematical connections were identified, such as representation, procedural understanding, meaning, and modelling. The research concluded with feedback from researchers, highlighting the educational potential of integrating mathematics with real-world tasks like brick-making. This study provides valuable insights for pre-service teachers in designing contextualized, meaningful math problems.

Keywords:
Mathematical and ethnomathematical connections, Mathematics education, Meaningful learning, Onto-semiotic approach, Pre-service mathematics teachers

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1. INTRODUCTION

In the broad research agenda, the importance of meaningful learning has been highlighted. This learning occurs when individuals establish connections between new knowledge and their previous knowledge, encompassing ideas, concepts from various sciences, and everyday experiences (Bryce & Blown, 2024; Montes-Osorio & Deroncele-Acosta, 2023; Quesada, 2008; Quispe & Janto, 2022). This type of learning is evident when knowledge lasts over time and is applied in different problem-solving contexts. In curricular organizations, such as the Leinwarnd (2014), the need to provide students with opportunities to learn mathematics in a meaningful and in-depth way is emphasized. Based on Ausubel's theory, the Ministerio de Educación Nacional (2006) maintains that the significance of learning extends to its insertion into useful and effective social practices, integrating physical and sociocultural contexts.

In this research, meaningful learning is understood when the person has prior knowledge associated with their daily life, assuming that the brick is a useful object for building houses, which involves essential concepts to understand works of architecture, commerce, engineering, etc., and in mathematics the person can relate this knowledge with patterns, geometric figures, budgets, including geometric-spatial thoughts. In addition, these ideas are a fundamental basis for problems-solving about bricks or similar figures.

In the field of Mathematics Education, student learning has been explored from a sociocultural perspective, particularly through Ethnomathematics (D'Ambrosio, 2020) and other approaches that promote the social construction of mathematical knowledge (Cantoral et al., 2015). Ethnomathematical connections underline the importance of meaningful learning, where daily mathematical knowledge is linked to institutional mathematics (Rodríguez-Nieto, 2021). Studies have identified these connections in everyday life, such as in the preparation of yuca buns (Rodríguez-Nieto et al., 2019; Rodríguez-Nieto, Font Moll, et al., 2022) and tortillas, evidencing geometric concepts and useful tools for teaching school mathematics from everyday tasks (Rodríguez-Nieto, 2021).

On the other hand, in the works of a carpenter, Castro-Inostroza et al. (2020) showed conventional (meter, inch) and non-conventional (tolerance) measurements as well as geometric notions in angles and symmetries in the construction of furniture and ships. In the field of artisanal fishing, studies are recognized in Bocas de Cenizas, where non-conventional measurement systems such as the quarter, the jeme, the finger and the armful were identified (Rodríguez-Nieto et al., 2019); Mansilla et al. (2023) investigated measurements and geometry in fishing in southern Chile, assessing the longlines, cast nets and their link in the classroom through ethnomathematical connections. Sudirman, Rodríguez-Nieto, et al. (2024) connected ethnomodelling and ethnomathematics to delve deeper into fishing in Indonesia and promote the teaching of mathematics linked to the commercial sector, including sales, income, size, weight and feeding of fish. Kusuma and Dwipriyoko (2021) investigated how musical intelligence influences the development of mathematical connection skills by integrating Ethnomathematics and the Mozart Effect to boost students' motivation in learning mathematics. Other authors such as Afgani and Paradesa (2021) proposed mathematical problems similar to PISA with the Islamic ethnomathematical approach including daily practices that were valid and practical for the state and local educational community in southern Indonesia.

This research focuses on problem solving in the context of bricks to promote meaningful learning. The brick has a cultural meaning linked to the foundations and construction of houses that people acquire through commercial and economic means. This artifact has a shape that includes measurements taken by mathematical and other non-conventional instruments, becoming an activity where the culture of the ancestors transcends to the present day (Pabón-Navarro et al., 2022). The Ethnomathematics program has studied mathematics immersed in diverse cultural activities, for example, the work of bricklayers with bricks (D'Ambrosio, 2020), highlighting the mathematical ideas present in all cultures (Aroca-Araújo, 2022). Over time, this line of research has gained relevance, focusing on linking emerging mathematical knowledge with institutionalized mathematics in classrooms through mathematical and ethnomathematical connections (Font Moll & Rodríguez-Nieto, 2024; Ledezma et al., 2024; Rodríguez-Nieto, 2020, 2021; Rodríguez-Nieto et al., 2024).

Research on teacher training in ethnomathematics is scarce, although it has begun to gain ground in Colombia (Aroca-Araujo et al., 2016). Alarcón-Anco and de la Cruz (2021) demonstrated the positive impact of ethnomathematical algorithms on meaningful learning in university students. According to Marrero (2021), ethnomathematics can be applied in pedagogy to explore social dynamics and contemporary diversity. This discipline facilitates didactic adaptation to changes in individuals, groups, and communities through various modalities of symbolization or symbolization, influenced by social, cultural, and mathematical codes. This underlines the complexity of integrating ethnomathematics into the development of curricula, educational programs, and the planning of teaching and learning processes, with the aim of promoting meaningful learning based on students' prior experience and knowledge in modern mathematics. Sudirman, Rodríguez-Nieto, et al. (2024) modeled everyday situations related to fishing in order to address contextualized mathematical tasks with students, considering everything from basic operations, calculation, measurements to aspects of economics and commerce.

Campos-Capcha et al. (2023) highlight that ethnomathematics employs natural and cultural elements to facilitate meaningful learning among students (p. 1289). Quispe and Janto (2022) point out that the use of Quechua (native language) in ethnomathematics improves knowledge in geometry and problem solving, thus reinforcing the effectiveness of this educational strategy for children. For their part, Alarcón-Anco and de la Cruz (2021) emphasize how, through the use of ethnomathematics, many university students have significantly improved their ability to perform mathematical tasks through everyday activities. Umbara et al. (2023) showed that the ethnomathematics of the Sundanese community is relevant to aspects of mathematical literacy that encompass mathematical content, context, and processes and activities of counting, measuring, explaining, and the techniques of equipment and technology of living beings.

According to Matienzo (2020), learning is enriched when students relate new knowledge to previous experiences, which facilitates deep and lasting understanding. Posso-Pacheco et al. (2022) emphasize that this process should not be limited to the individual, but requires collaboration between teachers to foster problem-solving skills through communication and group leadership. On the other hand, Cordero Tigsi and Segarra Tenesaca (2023) highlight the importance of adapting teaching to cultural diversity through music to strengthen meaningful learning in early childhood education and community families in a bilingual school "Mushuc Ñan" Tungurahua. Blanco et al. (2021) add that teachers can enhance these meaningful connections through interdisciplinary methods that integrate knowledge in various areas of knowledge.

After reviewing the literature, special research routes are identified where the use of ethnomathematics is required to improve the meaningful learning of students, pre-service teachers and mathematics teachers. In addition, there are worrying difficulties about the teaching and learning of geometric figures, specifically, students find it difficult to express in their own words the definition of volume and to find the volume of prisms (e.g., parallelepipeds, boxes, and wooden cubes). They also relate the area to the interior of a figure, but not to its specific measurement, and they associate the perimeter with the sides, but not with the total length of the contour (Cantillo-Rudas et al., 2024; Downton & Livy, 2022; Ruiz-Soto, 2018).

Students experienced difficulties in "identifying the prism, the differentiation between the regular parallelepiped and the rectangular parallelepiped, as well as correlating two-dimensional figures with three-dimensional ones" (Vásquez-Ramírez, 2019, p. v). Also, Geometry should not be undervalued in classrooms and should be promoted daily with activities that promote visualization, demonstration, problem solving and connections between concepts and representations (Sudirman, García-García, et al., 2024). The motivating idea of this research is to promote connection-based learning by relating prior knowledge to new knowledge. Therefore, this article analyzes the potential of ethnomathematical and mathematical connections in pre-service mathematics teachers' meaningful learning when solving problems in the context of brick making.

To achieve the proposed objective, this research is based on the Extended Theory of Connections (ETC), essential for understanding mathematical concepts and their application in daily life (Rodríguez-Nieto et al., 2024), the onto-semiotic approach (OSA) and the definition of meaningful learning.

ETC Theory has improved its functionality based on the networking carried out with the OSA, where mathematical connections are made up of practices, processes, objects and semiotic functions that relate them (see Figure 1).

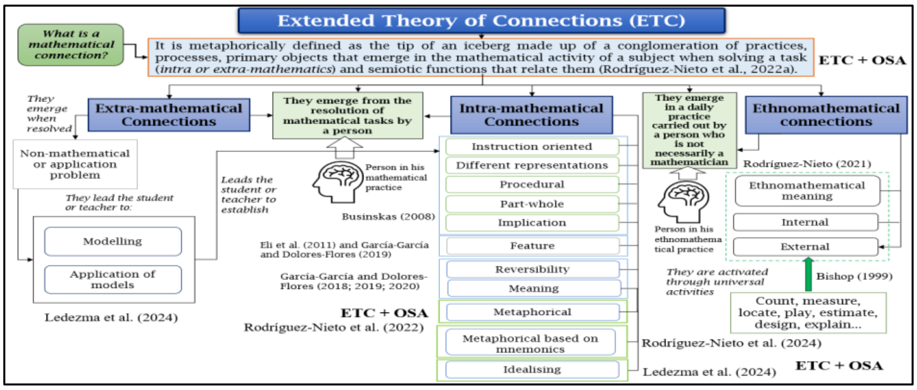

Figure 1. Synthesis of the extended theory of connections

The literature on mathematical connections reports three groups: intra-mathematical and extra-mathematical (see Table 1) and ethnomathematical connections. Intra-mathematical connections "are established between concepts, procedures, theorems, arguments and mathematical representations" (Dolores-Flores & García-García, 2017, p. 160), and in extra-mathematical connections "a relationship is established between a mathematical concept or model and a problem in context (non-mathematical) or vice versa" (Dolores-Flores & García-García, 2017, p. 161).

Table 1. Categories of mathematical connections

Mathematical Connections description
Instruction-oriented
It refers to the understanding of a concept C based on two or more previous concepts A and B, required for a student to understand it. In addition, these connections can be identified in two ways: 1) the association of a new topic with previous knowledge, and, 2) the mathematical concepts and procedures connected to each other are considered prerequisites or skills that students must master before the development of a new concept (Businskas, 2010).
Modelling
They are relationships between mathematics and real life and are evident when the subject solves non-mathematical or application problems where he has to propose a mathematical model or expression (Evitts, 2004).
Procedural
They appear when the subject uses rules, algorithms or formulas to complete or solve a mathematical task. These mathematical connections are of form, A is a procedure used to work with the concept B (García-García & Dolores-Flores, 2021). Likewise, "it includes the explanations or arguments that a student offers to use these formulas and how they apply them to achieve a result" (García-García & Dolores-Flores, 2021, p. 5).
Different representations
They are identified when the subject represents a mathematical concept using alternate or equivalent representations (Businskas, 2010; García-García & Dolores-Flores, 2021). Equivalents are transformations of representations made in the same representation or register (algebraic-algebraic). Alternate representations refer to representations where the register in which they were formed is modified.
Feature/Proposition
This connection is identified when an individual expresses some characteristics of concepts or described their properties in terms of other concepts that make them different or similar to others (Eli et al., 2011), or states/uses a proposition in which such concept has a determining role (Ledezma et al., 2024).
Reversibility
It occurs when a subject starts from a concept A to reach a concept B and reverses the process starting from B to return to A (García-García & Dolores-Flores, 2021).
Part-Whole
These types of connections are manifested when the subject establishes logical relationships in two ways (general-particular and inclusion). The generalization relationship is of the form A is a generalization of B, and B is a particular case of A (Businskas, 2010; García-García & Dolores-Flores, 2021). The inclusion relationship occurs when a mathematical concept is contained in another (García-García, 2019).

Mathematical Connections description
Meaning They are identified in two ways. 1) When the mathematical connection refers to the moment in which the subject gives meaning to a concept, distinguishes it from another concept and what it represents by finding it as a definition constructed for a mathematical concept. 2) The mathematical connection between meanings is manifested when the subject connects meanings attributed to a concept to solve a problem (García-García, 2019).
Implication They are identified when a concept P leads to another concept Q through a logical relationship ($P \rightarrow Q$) (Businskas, 2010).
Metaphorical Tthey are understood as the projection of the properties, characteristics, etc., of a known domain to structure another less known domain (Rodríguez-Nieto, Rodríguez-Vásquez, et al., 2022).
Metaphorical connection based on mnemonics This connection is "understood as the relationship established by the subject between a mnemonic rule (often a familiar resource) and a mathematical object, rule, or mathematical procedure to memorize and use strategically more easily" (Rodríguez-Nieto et al., 2024, p. 18). These types of connections are inclusive and recursive where three elements must be taken into account: a) *keywords* that are similar to the word (or term) being referred to. b) *acronyms* it is identified when the first letter of each word is used in a list to construct another word. c) *acrostics* which consist of constructing a sentence, where the first letter of each constitutes the term studied (Rodríguez-Nieto et al., 2024).
Idealising This connection relates an ostensive to a non-ostensive. Its function is to dematerialize the ostensive and turn it in to an ideal mathematical object (for example, the bottom of a tank rounded is considered circle/circumference) (Ledezma et al., 2024).

On the other hand, the ethnomathematical connection is understood as the relationship between the mathematical knowledge developed by people in daily practices and the institutional or public mathematics proposed in curricular materials (Rodríguez-Nieto, 2021). Rodríguez-Nieto (2020) has characterized ethnomathematical connections as internal, external, and ethnomathematical meaning. Internal connections are "the relationships that a subject makes between units of measurement (conventional or non-conventional) of the same measurement system used in an everyday practice, considering equivalences and conversions" (Rodríguez-Nieto, 2020, p. 12), and an external connection "is promoted when a unit of measurement (conventional or non-conventional) is used in a similar way in different measurement systems of different everyday practices" (Rodríguez-Nieto, 2020, p. 26). The ethnomathematical meaning connection "is identified when a person attributes a meaning to a mathematical concept or object by making an expression-content relationship, emitting what a cultural object or artifact, a measurement, a design, among other universal activities, means to him, based on everyday practice" (Rodríguez-Nieto, Rodríguez-Vásquez, et al., 2022). For example, three people use the "sack or costal" similarly in different daily practices (corn planting, coffee planting and bean planting) and attribute a meaning to it as the non-conventional, recursive and cultural measure that is equivalent to one meter (see Figure 2).

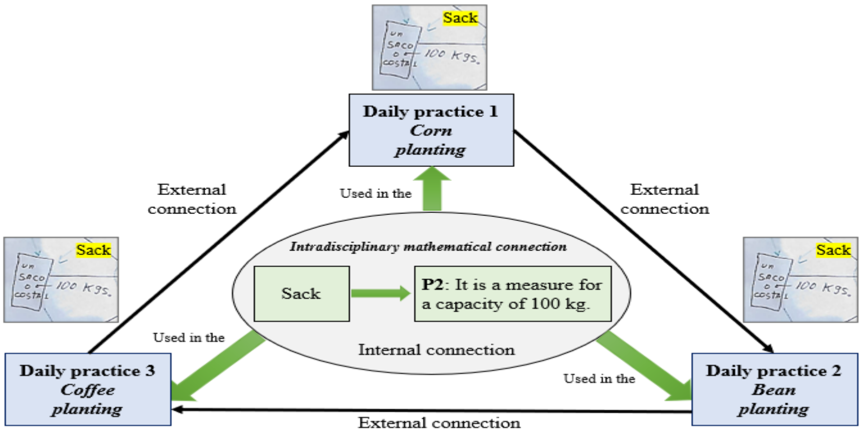

Figure 2. Example of internal and external connections
(Adopted from Rodríguez-Nieto & Alsina, 2022)

OSA theory describes mathematical activity from an institutional or personal perspective, which is modeled in terms of practices and the configuration of primary objects and processes that are activated in these practices (Font Moll et al., 2016). These practice, hereinafter referred to as mathematical practices, refer to situations or expressions (e.g., verbal, graphical, or symbolic) that an individual performs to solve a mathematical problem, communicate the solution obtained, and also to validate or generalize it to other contexts and similar problems (Godino, 2022).

In mathematical practices, six primary objects intervene: 1) problem situations, 2) linguistic elements, 3) concepts/definitions, 4) propositions/properties, 5) procedures, and 6) arguments. In addition, the primary objects that emerge can be personal or institutional, ostensive or non-ostensive, unitary or systemic, intensive or extensive, and content or expression, that is, they can belong to one of the five dualities (Godino et al., 2019). The configuration of primary objects is made up of the connections between primary objects and can be institutional (epistemic) or personal (cognitive). The epistemic configuration is the system of primary objects that, from an institutional perspective, are involved in the mathematical practices carried out to solve a specific problem and the cognitive configuration is the system of primary mathematical objects that a subject mobilizes as part of the mathematical practices developed to solve a specific problem (Godino et al., 2019).

Through the activation of primary mathematical processes such as communication, problem posing, definition, enunciation, elaboration of procedures (algorithms, routines, ...) and argumentation, the set of primary objects emerges. These mathematical processes are derived from the application of the process-product perspective to said primary objects, that is, they are derived by applying the process-product duality to the five dualities, in such a way that the following relationships are obtained: personalization-institutionalization; synthesis-analysis; representation-meaning; materialization-idealization; generalization-particularization (Font Moll et al., 2016; Godino et al., 2019). Godino et al. (2019) stated that problem solving and mathematical modelling should rather be considered as mathematical "hyperprocesses" that combine some of the aforementioned processes.

Finally, the notion of semiotic function must be considered, which allows associating practices with the objects and processes that are activated and allows for the construction of an operational notion of knowledge, meaning, understanding and competence (Godino et al., 2019). Font Moll and Rodríguez-Nieto (2024) characterizes a semiotic function as a triadic relationship between an antecedent (expression/initial object) and a consequent (content/final object) established by a subject (person or institution) according to a certain criterion or code of correspondence. Semiotic functions are inferred when looking at mathematical activity from the expression/content duality. The notion of semiotic function (OSA) is more general than the notion of mathematical connection (ETC), since connections are considered particular cases of semiotic functions of a personal or institutional nature. In the ETC, the mathematical connection may or may not be true, showing from the OSA perspective that when a subject makes a correct connection it coincides with the institutional one and when it is incorrect it is of a personal nature (Rodríguez-Nieto, Font Moll, et al., 2022).

Another important concept in this research is meaningful learning which is characterized by considering the previous experience of people as important and what matters is how the new prior knowledge adheres or interconnects to the previous knowledge underlying the cognitive structure of the person, forming knowledge networks (Ausubel, 1983; Garcés-Cobos et al., 2018). For the purposes of this research, meaningful learning

> […] It occurs when new information "connects" with a pre-existing relevant "subsunsor" concept in the cognitive structure. This implies that new ideas, concepts and propositions can be learned significantly to the extent that other relevant ideas, concepts or propositions are adequately clear and available in the cognitive structure of the individual and that they function as an "anchoring" point to the first ones (Ausubel, 1983, p. 14).

According to Vallori (2014), meaningful learning involves a continuous, long-term process where the individual's knowledge patterns are contrasted and modified. This process includes moments of balance, conflict and subsequent rebalancing. In short, it seeks to build a balanced cognitive structure through the integration and transformation of new information.

2. METHOD

This research is qualitative and follows two stages used in the ETC for the case of ethnomathematical connections: one based on ethnography (see Figure 3) and another concerning a classroom workshop (Cohen et al., 2002; Rodríguez-Nieto & Escobar-Ramírez, 2022) to explore mathematical and ethnomathematical connections.

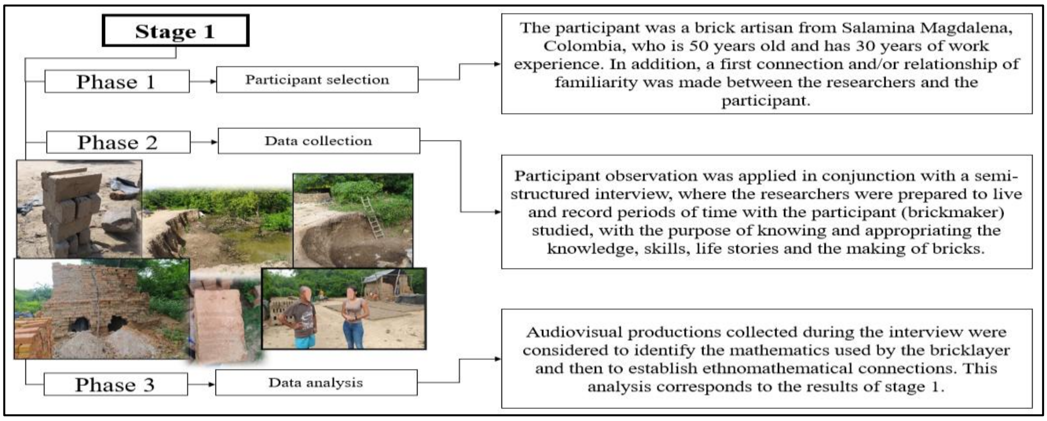

Figure 3. Detailed explanation of stage 1

Stage 1 of the research is based on ethnography, which explored the daily practice of a clay brick trader (P1). Restrepo (2016) argues that ethnography etymologically refers to ethnos (people, sociocultural group) and grapho (writing, description), which allows the appropriation of people's cultural experiences and also to report episodes or events as they occur in the reality of daily life. It should be noted that this stage is essential to develop stage 2 and achieve the first results.

Stage 2 involves a workshop developed in the classroom with pre-service mathematics teachers (PMTs) (see Figure 4).

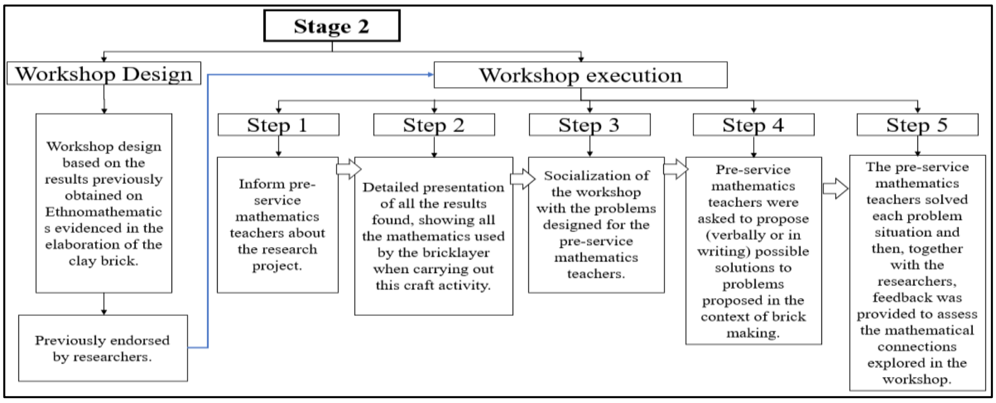

Figure 4. Detailed explanation of stage 1

The workshop was designed based on the mathematical knowledge acquired in the daily practice of the bricklayer and was developed in five steps in the classroom of the participants (see Figure 4): 1) Inform the PMTs about the research project based on the ethnomathematical connections evidenced in the elaboration of the clay brick and presentation of the researchers. 2) Through a PowerPoint presentation, the student researcher presented and explained in detail to the PMTs all the results found in the ethnographic study, showing all the mathematics used by the bricklayer when carrying out said artisanal activity (see Figure 4). 3) The researchers socialized the workshop with the designed problems. 4) The PMTs were asked to solve the proposed problems in the context of the elaboration of the clay brick where conversions between conventional and non-conventional units of measurement, proportions, ratios, area, volume, among others, are worked on. Finally, 5) some students (voluntarily) solved the proposed problems on the board, explaining step by step the way in which they developed them. In addition, the researchers together with the students encouraged feedback to assess the mathematics explored in the workshop in terms of mathematical and ethnomathematical connections.

On the one hand, the participants of the second stage of this research were fourteen PMTs (teachers in training in the mathematics degree program of a public university in the department of Atlántico, Colombia) who were taking the Ethnomathematics course in their seventh semester and were from different neighboring municipalities of the Caribbean Coast, as well as the departments of Magdalena and Bolívar. The participants are labeled as PMT1, …, PMT14.

On the other hand, the methods of this research are shown, where in the first stage ethnography was followed (Restrepo, 2016), participant-observation articulated with the semi-structured interview where P1 was asked questions related to his personal life, age, experience and above all about how he carries out his daily practice of making bricks, involving measurements, molds or patterns, materials, decision-making, etc. Regarding data analysis, it was considered essential to analyze the information using ethnomathematical connections (Rodríguez-Nieto, 2021) when it comes to the ethnographic study (see section 2.1) and, then, mathematical connections are used for the development of the workshop (see section 2.2), taking into account the cognitive configuration that involves primary objects, processes, semiotic functions and mathematical connections (Rodríguez-Nieto et al., 2024).

3. RESULTS AND DISCUSSION

3.1. Results

This section presents the results according to the development of the two stages established in the methodology section. In addition, it will show the potential of connections in meaningful learning.

3.1.1. On the results of etnography (stage 1)

After conducting the semi-structured interview, the mathematics used by P1 to make the clay bricks was recognized; for example, he uses two molds as patterns to shape the large and small bricks. In addition, in Figure 5 the artisan indicates the height, width, and length of the bricks with their respective measurements in centimeters. Additionally, these bricks have the shape of a rectangular parallelepiped (institutional mathematics) and at the same time, the idealizing connection of the ETC is activated.

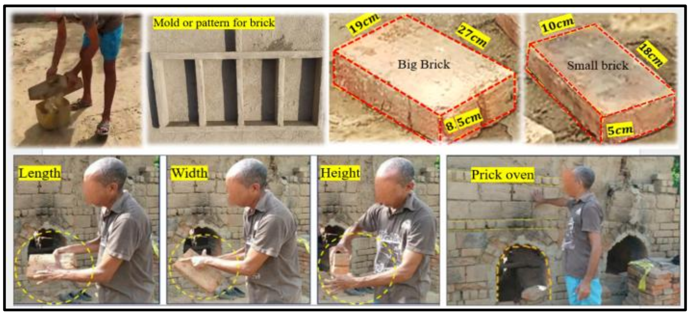

Figure 5. Mathematics in the making of clay bricks

Figure 5 also shows that the craftsman burns the bricks in a wood-fired oven and the mouths of the oven are rounded and elongated (daily practice mathematics) and parabolic (institutionalized mathematics). Therefore, Figure 6 shows some ethnomathematical connections with a correspondence code that supports each connection (see Pabón-Navarro et al., 2022).

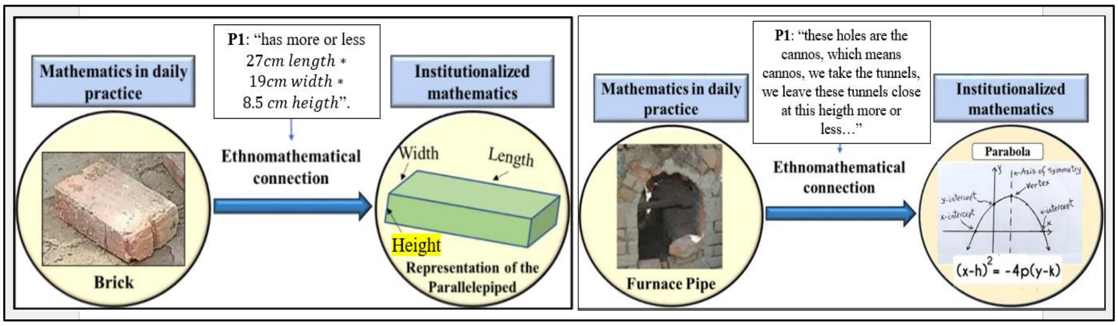

Figure 6. Ethnomathematical connections for the parallelepiped and the parabola

3.1.2. On the results of the implementation of workshop (stage 2)

In the methodological section it was explained that the implementation of the workshop was developed in five moments, which direct this section of results by highlighting a special element which is the contribution to the practice of the PMTs. In the transcription the following labels were used: Researcher (I) and Pre-service Mathematics Techers (PMTs1,…, PMTs14).

3.1.2.1. Step 1

Initially, the PMTs were invited to participate in the workshop and they decided to participate voluntarily, understanding that this research is part of a project with educational and not economic and/or political purposes. In this context, the first connection was made regarding familiarization with the participants (see Figure 7).

Figure 7. Presentation of the research project to PMTs

3.1.2.2. Step 2

Subsequently, a material is presented to the PMTs, where they are shown the results found in the ethnographic study on the production of clay bricks, which are described and detailed in the results section of stage 1. The results were presented through PowerPoint slides (see Figure 8), and the results obtained were explained in detail to the participants, showing all the mathematics used by the brick maker (see Figure 9).

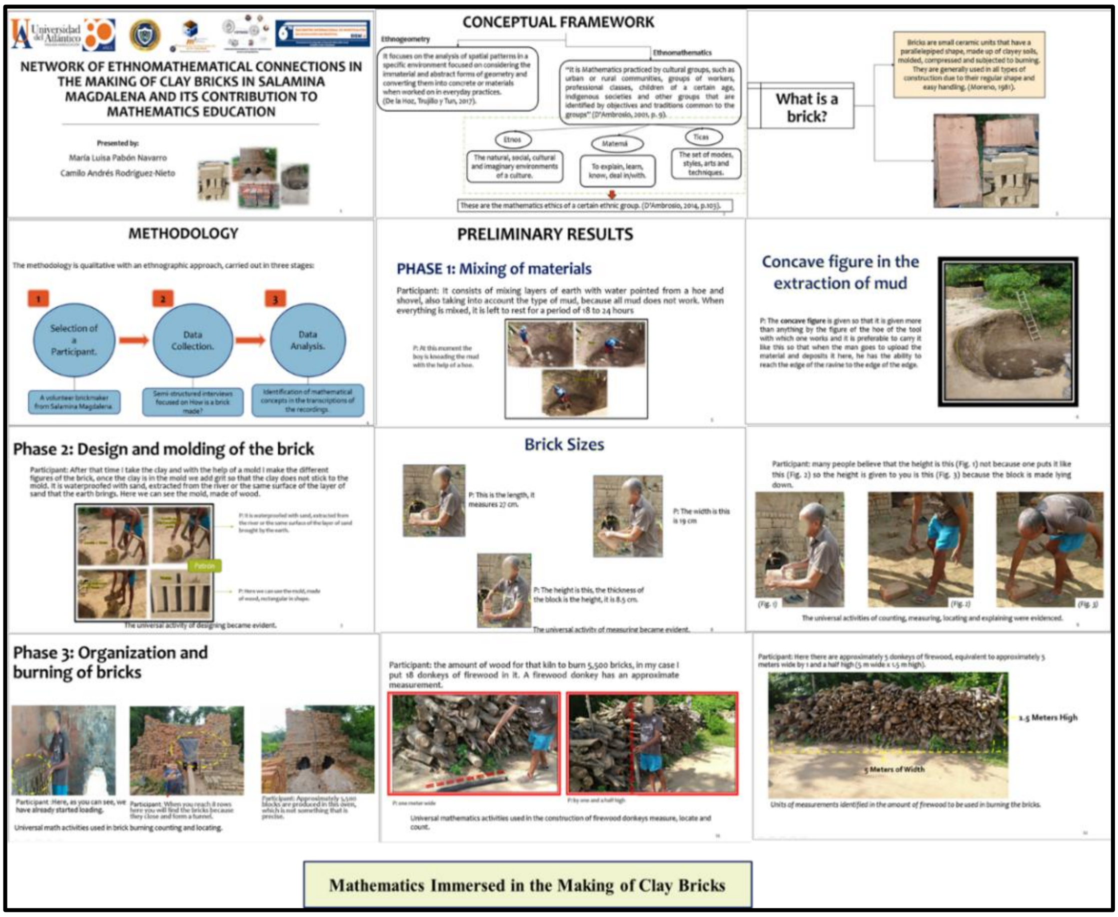

Figure 8. Presentation of the results

Figure 9. Detailed presentation of the results to the participants

After presenting the results to the participants, they received their opinions regarding the information that was provided to them, highlighting the importance of this research. Likewise, doubts and concerns were clarified, giving a respective space for questions and feedback, receiving significant contributions from each of them, highlighting the importance of the study of Ethnomathematics and its great value in the teaching of mathematics.

3.1.2.3. Step 3

Next, the researcher socializes the workshop with the problems designed to be solved and gives the necessary guidelines for its development. Five mathematical problems are proposed where conversions between conventional and non-conventional units of measurement, proportions, ratios, area volume, among others, are worked on (see Table 2).

Table 2. Problem situations

Problem situations	Description
1	Mr. Edgardo has been making clay bricks of different sizes for approximately 20 years. The most commercial one is the large brick, which measures approximately 27 cm long by 19 cm wide by 8.5 cm high. Please represent this graphically. What is the volume of the brick manufactured by Mr. Edgardo?
2	Last month, the construction company Construyendo Sueños contacted Mr. Edgardo to make a certain amount of bricks, which should have an approximate area of $640cm^2$, taking into account that Mr. Pedro only makes two types of bricks of the following sizes: Large Brick with approximate measurements of 27 cm long by 19 cm wide by 8.5 and a Small Brick with measurements of 10 cm wide by 18 cm long by 5 cm high, represent them graphically. Explain to Mr. Edgardo in your own words which brick the construction company is asking for and why.
3	To burn bricks, Mr. Edgardo has a traditional kiln that can hold a total of 5,500 bricks per firing. He needs to burn a total of 38,500 bricks. How many firings will he have to carry out?
4	The sale of large bricks costs 550 pesos each unit. Mr. Edgardo needs to know how much the buyer should pay him for 15,000 bricks. Help him resolve this concern.
5	For each burn, Mr. Edgardo uses 18 tons of firewood (A tons of firewood is an approximate measurement that is 1 meter wide, 1 meter long and one and a half meters high). Represent this graphically. If he wants to carry out 10 burns, how many tons of firewood does he need?

The workshop is then delivered in physical form so that participants can personally analyze each of the proposed problems for their subsequent resolution.

3.1.2.4. Step 4

Participants were asked to solve the proposed problems in the context of clay brick making. Initially, for the workshop, the PMTs proposed a solution to a first problem of volume analysis of bricks of different sizes as follows (see excerpt from the transcript).

I : *Can you propose a solution for: Mr. Edgardo has been making clay bricks of different sizes for approximately 20 years. The most commercial one is the large brick, which measures approximately 27 cm long by 19 cm wide by 8.5 cm high. Represent it graphically. What is the volume of the brick manufactured by Mr. Edgardo? (see Figure 10).*

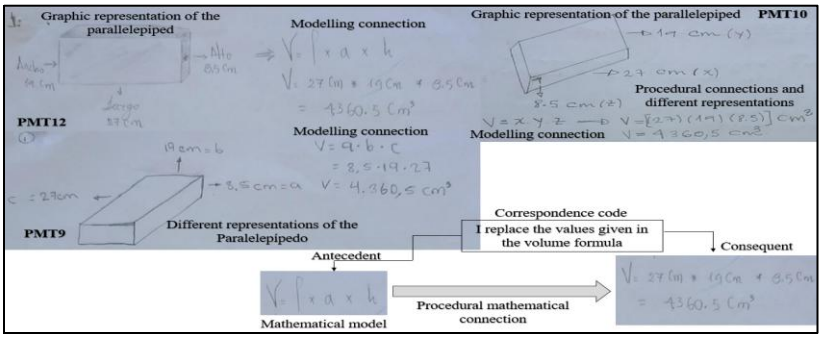

Figure 10. Problem about the volume of the clay brick

PMT9, PMT10, PMT 12, (see Figure 10) proposed a solution to find the volume of the brick stating that it shows the representation of a parallelepiped; first they establish modeling type connections in the form of a horizontal mathematization when considering the formula that allows them to find the volume of a parallelepiped V= l * a* h where "l" is the length of the figure, "a" is the width and "h" It is the height; Then, the procedural connection was recognized starting with the replacement of the values of l, a and h or in some of the cases, as expressed by the participant PMT10 x, y, z in the algebraic-symbolic expression of volume. Other mathematical connections evidenced are those of alternate representations when relating the graphic representation of the brick with a parallelepiped and its symbolic representation. In addition, the participants made connections of the type of alternate representations between the graph of the parallelepiped and equivalents when writing: V= 27cm*19cm*8.5cm, performed the multiplications using procedural connections and found the volume of the brick (4,360.5cm^3).

In terms of ethnomathematical connections, it is evident that the mathematics used by future teachers based on the elaboration of the mud brick is related to the DBA (Ministerio de Educación Nacional, 2016) in which for fifth grade statements were found referring to establishing relationships between surface and volume, where students must find their area and volume measurements with direct and indirect measurement. Finally, in the DBA of eighth grade of secondary school (Ministerio de Educación Nacional, 2016) it is emphasized the use of different strategies to find the volume of regular and irregular objects in the solution of problems in mathematics and in other sciences (e.g., relating units of capacity with units of volume (liters, dm^3, etc.) in the solution of a problem and estimating volume measurements with standardized and non-standardized units).

From an onto-semiotic perspective, a synthesis of the mathematical activity carried out by PMT1 is presented, where mathematical connections are organized in terms of practices, processes, primary objects (PO) and semiotic functions that relate them (see Table 3).

Table 3. Primary object configuration for problem 1

PO	Description
Problem Situation (PS)	Mr. Edgardo has been making clay bricks of different sizes for approximately 20 years. The most commercial one is the large brick, which measures approximately 27 cm long by 19 cm wide by 8.5 cm high. Please represent this graphically. What is the volume of the brick manufactured by Mr. Edgardo?

PO	Description
Linguistic Elements (LE)	*Verbal*: parallelepiped, rectangle, volume, measurements, segment, line, among others. *Symbolic*: $V = l * a * h$ where "*l*" is the length of the figure, "*a*" is the width and "*h*" It is the height, $V = (27cm)(19cm)(8.5cm)$, see Figure 11. *Graphic*: representation of the parallelepiped in Figure 11.

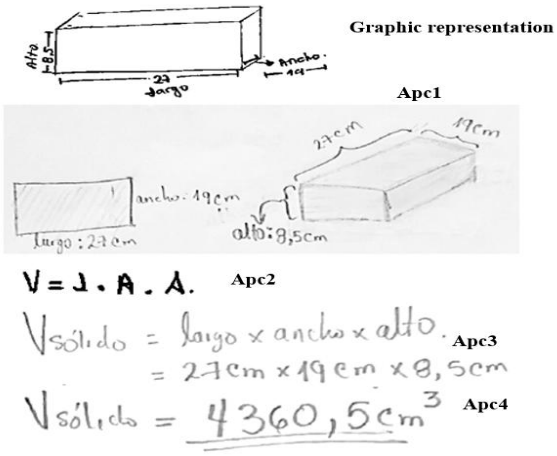

Figure 11. Symbolic and graphic representation

Definitions (D)	**Previous concepts**: plane geometric figures, parallelepiped and properties, area and volume of geometric figures. **D1:** parallelepiped: They are polyhedrons, specifically prisms that meet the following conditions: They have 6 faces, 12 edges and 8 vertices. This rectangular prism has faces that are parallelograms that are parallel and equal in pairs. **D2:** the volume of a geometric figure is defined as the amount of space occupied by the object or figure in three-dimensional space.
Propositions (Pr)	***Proposiciones previas*:** recognize flat geometric figures, arithmetic operations, etc. **Pr1:** the clay brick is shaped like a parallelepiped. **Pr2:** the formula for determining the volume is: $V = L * A * A$. **Pr3:** the volume of the brick is equal to: Vsolid = 4,360.5 cm^3.
Procedures (Pc)	Main procedure (Mpc): find the volume of the clay brick with measurements of 27 cm long by 19 cm wide by 8.5 cm high. **Procedimiento auxiliar 1 (Apc1):** draw the clay brick assuming that it is shaped like a parallelepiped and place the corresponding measurements **Apc2:** structure a model or formula to determine the volume: $V = L * A * A$. **APc3**: substitute the brick measurements into the formula: $V = 27cm * 19cm * 8.5cm$. **APc4**: multiply the measurements to obtain the volume of the brick equal to $Vsólido = 4{,}360.5\ cm^3$.
Arguments (A)	**Argument 1 (A1):** **Thesis:** The clay brick represents a parallelepiped. **Reason 1 (R1):** It has the characteristics of said geometric figure, 6 faces, 12 edges and 8 vertices. **Conclusion**: actually, the mud brick represents the parallelepiped.

PO	Description
	Argument 2 (A2): **Thesis:** the formula to determine the volume is: $V = L * A * A$. **Reason 1 (R1):** PMT1 assumes that there is a formula to find the volume of a parallelepiped. **Reason 2 (R2)**: write the formula symbolically considering the product between the length, width and height. **Conclusion**: the formula to find the volume of the brick if it is $V = L * A * A$.
	Argument 3 (A3): **Thesis:** the volume of the brick is equal to: $Vsolid = 4{,}360.5\ cm^3$. **Reason 1 (R1):** PMT1 substituted the brick values or measurements in the formula $V = 27cm * 19cm * 8.5cm$.. **Reason 2 (R2)**: PMT1 performed multiplications to get the result. **Conclusion**: Finally, the volume of the brick is $4{,}360.5\ cm^3$.

Continuing with the development of the designed workshop, participants are suggested to solve the following problem:

I : *Last month, the construction company Construyendo Sueños contacted Mr. Edgardo to make a certain amount of bricks, which should have an approximate area of 640 cm², taking into account that Mr. Edgardo only makes two types of bricks of the following sizes: Large Brick with approximate measurements of 27 cm long by 19 cm wide by 8.5 and a Small Brick with measurements of 10 cm wide by 18 cm long by 5 cm high, represent them graphically. Explain to Mr. Edgardo in your own words what brick the construction company is asking for and why (see Figure 12).*

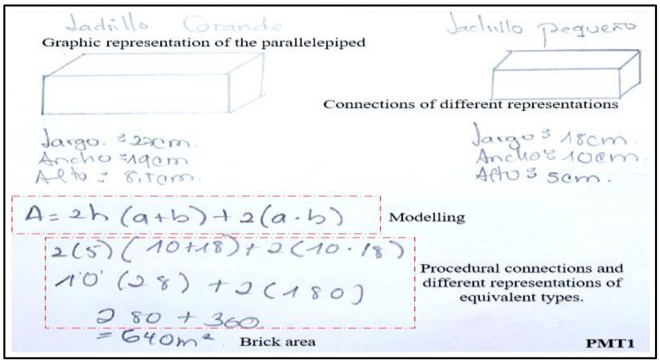

Figure 12. Areas of the large brick and small brick

In this part (see Figure 12), PMT1 made mathematical modeling connections by translating the problem situation into mathematical language and then activated procedural connections to find the area of the brick. In addition, PMT1 established ethnomathematical connections of meaning and internality involving representations of the clay brick to find the area and thus know which brick needed to be delivered to the builder; the participant explains the procedure (see transcript extract).

PMT1 : *To do this exercise, I first draw the bricks and then identify the measurements of length, width and height taking into account what you (I) explained to us in the socialization of your research, then I apply the area of a parallelepiped which is Area equal to two times the height times the longest width plus two times the width times the length*

(A=2h(a+b)+2(a∗b)) and then I replace the values; I only found the area of the large brick since for me it was the one indicated to obtain 640cm^2 which was what the problem asked me. So, the brick that the gentleman must make for the construction company is the large brick.

Likewise, the DBA (Ministerio de Educación Nacional, 2016) for sixth grade emphasize proposing and developing estimation, measurement and calculation strategies for different quantities (angles, lengths, areas, volumes, etc.) to solve problems. It is also related to the learning evidence within which the student estimates the result of a measurement without performing it, according to a previous reference and applies the chosen estimation process and assesses the result according to the data and context of a problema.

On the other hand, participants are offered a solution to the following problem situation:

I : *Mr. Edgardo has a traditional brick kiln that can hold a total of 5,500 bricks for each firing. He needs to burn a total of 38,500 bricks. How many firings will he have to carry out?(see Figure 13).*

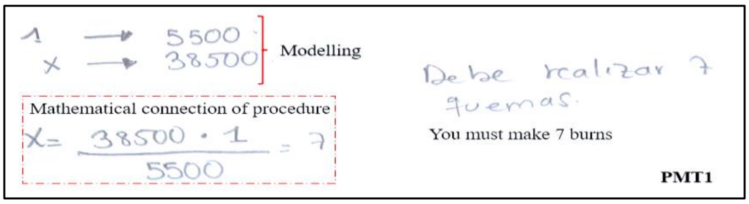

Figure 13. Problem of proportionality burning bricks

Participant PMT1 considers that one burn is equivalent to 5,500 bricks ready for sale, and poses the problem as shown in Figure 13. It is important to highlight that the participant solved the problem using the rule of three following modeling and procedural connections. Modeling helps create formulas or models that help find relationships between data and procedural connections to perform operations on specific relationships.

I : *the sale of large bricks costs 550 pesos each unit. Mr. Edgardo needs to know how much the buyer should pay him for 15,000 bricks. Help him resolve this concern (Figure 14).*

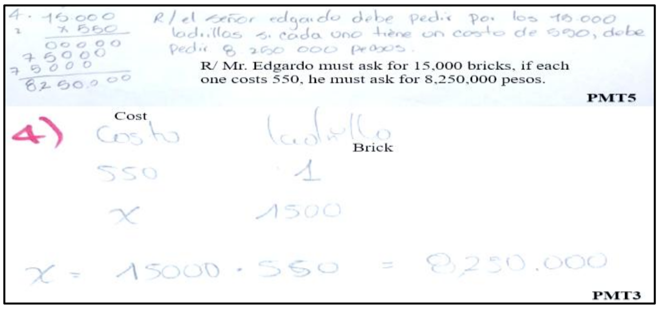

Figure 14. Problem of proportionality cost of bricks

PMT5 believes that by simply multiplying the number of bricks that the bricklayer must deliver by the cost of each brick, he obtains the amount of money that he must be paid; on the other hand, PMT3 expresses that it is necessary to carry out a simple rule of three to arrive at the final result; as can be seen in Figure 14, both results are correct but as future teachers it is necessary to follow an orderly and coherent procedure, as expressed by PMT3 (see transcript extract).

PMT3 : *We must show our students the formal way of doing the problems because that way they will understand us better. Suddenly, in some classrooms we will find pila students who will do it like him (PMT5), but the ideal is to show them the procedure step by step.*

However, according to the five general processes of mathematical activity established in the Basic Standards of Competence in Mathematics Education (Ministerio de Educación Nacional, 2016) from the communication process it establishes that:

> "The different ways of expressing and communicating mathematical questions, problems, conjectures and results are not something extrinsic and added to a purely mental mathematical activity, but rather they intrinsically and radically configure it, in such a way that the dimension of the forms of expression and communication is constitutive of the understanding of mathematics" (p. 54).

Finally, the researcher in the designed workshop poses the following exercise:

I : *for each burn, Mr. Edgardo uses 18 tons of firewood (A tons of firewood is an approximate measurement that is 1 meter wide, 1 meter long and one and a half meters high). Represent this graphically. If he wants to carry out 10 burns, how many tons of firewood does he need?*

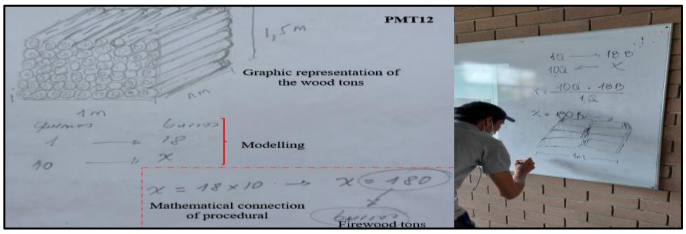

Figure 15. Problem of proportionality of firewood tons

In this problem, PMT12 considers the amount of wood burned and proposes a solution like the one presented in Figure 15. The participant developed the problem situation using a rule of three, using graphical representations, modeling and procedures.

Finally, within the last three problem situations posed in the designed workshop, participants are asked to carry out proportionalities as recommended by the DBA (Ministerio de Educación Nacional, 2016) of the fourth grade where the student must choose standardized and non-standardized instruments and units to estimate and measure length, area, volume, capacity, weight and mass, duration, speed, temperature, and from them make the necessary calculations to solve problems and in turn use direct and inverse proportionality relationships to solve various situations.

3.1.2.5. Step 5

To conclude the workshop, a feedback process was carried out by the researchers, assessing the knowledge obtained by the future mathematics teachers from municipalities close to Suan, especially on the mathematics explored in the elaboration of the mud brick. In this sense, it is recognized that the results obtained in the ethnographic phase contribute to the teaching and learning of mathematics and to the appropriation of a measurement system typical of the artisanal product for the elaboration of houses, such as the mud brick. With the feedback, the design and application of the workshop by the future mathematics teachers is concluded (see Figure 16).

Figure 16. Feedback from the designed and implemented workshop

3.1.3. Potential of connections in meaningful learning considering brick making

The findings of this research show that the PMTs have solved the mathematical problems formulated in the context of the elaboration and commercialization of clay bricks, which is fundamental for their meaningful learning of geometry and mathematics. In addition, these mathematics addressed during the workshop require previous knowledge of the PMTs related to the elaboration of clay bricks, which is one of the most important daily practices of their sociocultural environment and daily livelihood of several brick makers. Despite being an important daily practice, the PMTs had not experienced a workshop focused on solving problems about clay bricks.

In this context, there were PMTs who expressed the importance of solving contextualized problems rich in the application of mathematics. In fact, these types of problems require the establishment of ethnomathematical and mathematical connections for their resolution, which, without a doubt, have a close relationship with the experiences of PMTs who come from rural areas with agricultural activities and others live in the urban sector or towns but their relatives are bricklayers, carpenters, fishermen, that is, they recognize that at least in the form of the brick there is mathematics. In turn, the ethnomathematical and mathematical connections identified helped promote meaningful learning in several aspects:

1) In the case of mathematics applied to brick making, the meaningful learning approach transforms a practical activity into an enriching and contributing educational opportunity to work on various mathematical and/or geometric contents.
2) By applying mathematics to brick making, PMTs experience the ethnomathematical connection between academic content and its usefulness in everyday life (and vice versa). This not only strengthens the understanding of abstract mathematical concepts as proposed by García-García and Dolores-Flores (2018), but also improves motivation and interest in the subject by linking it to a practical and real context, understanding that

establishing mathematical and ethnomathematical connections is important (Rodríguez-Nieto, 2021).

3) Figure 17 shows some concepts that can be worked on with the elaboration of the brick and obtain significant learning.

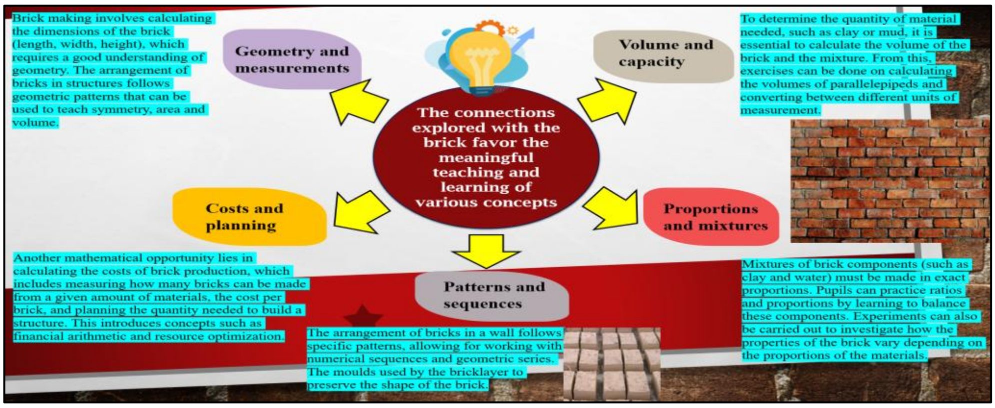

Figure 17. Contribution from brick making to meaningful learning

3.2. Discussion

The results of this research reveal the importance of daily practice in brick making in the teaching and learning of mathematics and geometry. Specifically, the application problems solved by the PMTs have fostered problem solving and, in turn, meaningful learning influenced by mathematical and ethnomathematical connections, among which the connections between the clay brick and the shape of the parallelepiped stand out.

Unlike other studies that have assessed the practice of brick making and its relationship with mathematics (Abah et al., 2020; Pabón-Navarro et al., 2022; Premkumar et al., 2020; Trujillo-Alarcón et al., 2022), the present research has been concerned with instructing and promoting meaningful learning with PMTs based on the mathematical and ethnomathematical connections that are fundamental to understanding concepts (Rodríguez-Nieto et al., 2024), which guarantees that their future teaching practice will be based on relating mathematics to real-life situations and not just developing content by rote learning.

In this context, the research carried out reaches the classroom directly through a workshop that aimed to enhance meaningful learning by valuing the daily practice of brick making, but also emphasized the marketing of bricks, including units of capacity, price, and forms of sale. This learning alternative, as well as being beneficial for PMTs, has also left essential commitments that mark a path towards the teaching of geometry in primary and secondary educational institutions, as well as the observation of classes by in-service teachers to learn the criteria and resources used to develop a good class with manipulable materials such as bricks. It should be noted that a study had previously been carried out on mathematics in brick making (Pabón-Navarro et al., 2022) but only with an ethnographic character without influencing the educational sector.

The cultural aspect inherent to brick making was a key element for the PMTs, as it allowed for a meaningful relationship between mathematical knowledge and everyday practice. Through the analysis of applied problems in the workshop related to the parallelepiped shape and the brick making process, the PMTs were able to appreciate the richness of ethnomathematical connections, where culture and mathematics are uniquely and effectively intertwined to contribute to the understanding of contextualized mathematics. This experience not only strengthened their problem-solving competence, but also underlined the importance of integrating cultural contexts in the teaching of geometric and mathematical concepts, promoting meaningful learning that transcends the classroom and enriches their future teaching practice as suggested by Pabón-Navarro et al. (2022).

4. CONCLUSION

Finally, this article communicates the potential of mathematical and ethnomathematical connections to promote meaningful learning for PMTs from a university on the Colombian Caribbean coast and considers the use of daily practices such as the production and sale of bricks to better understand mathematics and geometry, emphasizing the parallelepiped, volume measurements, sales, etc. However, we leave the possibility of further research on this topic and its impact on preschool, primary, and secondary education classrooms and on the practice of in-service teachers for future research. In fact, it would be convenient to establish internal, external and ethnomathematical connections (valuing everyday knowledge and its language) with students and to relate bricks with other objects that maintain similar characteristics and are used in different everyday practices.

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Declarations

Author Contribution	: CAR-N: Investigation, Methodology, Project administration, Visualization, Writing - original draft, and Writing - review & editing; MLP-N: Investigation, Methodology, Writing - original draft, and Writing - review & editing; BMC-R: Formal analysis, Investigation, Methodology, Resources, and Writing - review & editing; S: Resources, Supervision, Validation, and Writing - review & editing; VFM: Funding acquisition, Resources, Validation, and Writing - review & editing.
Funding Statement	: This study is part of the projects: Teaching project coded by DOC.100-11-001-18 (Universidad de la Costa) & Grant PID2021-127104NB-I00 funded by MICIU/AEI/10.13039/501100011033 and by “ERDF A way of making Europe”.
Conflict of Interest	: The authors declare no conflict of interest.
Additional Information	: Additional information is available for this paper.

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