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## The Impact of Project Creation on Learning Mathematics in a Transdisciplinary Setting

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**Abstract:** This article proposes that the reader be nourished by avant-garde elements for new educational practices in the teaching and learning of mathematics. The writing is based on an investigation that was carried out with high school students from Puerto Rico. From a qualitative paradigm with a research design in action, it was explored how students in higher grades resolve situations within their environment. Emphasis was placed on how they analyze through situations in context, and how they build knowledge through the search for a possible solution to the problem through the Project Based Learning strategy. The emphasis in treatment was for students to experience a transdisciplinary environment. Their impressions from the study were the revealing focus of how students learn when they are presented with a situation in their environment, taking roles themselves, solving them through a project. As part of the project they used their knowledge of science and mathematics to solve the situation. Similarly, they learned mathematical concepts that are part of the Trigonometry course and that are measured in the academic achievement tests called PR Goals, previously known as Puerto Rican Academic Achievement Tests (PPAA).

**Keywords:** *Project-based learning, transdisciplinary practice, situations in context, learning strategy.*

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### Introduction

In a moment, thinking about how limitations are created in the learning of mathematics in students, leads to reflect on studies that propose new educational practices in context. Wanting to give a result for what has already been a problem in generations is the starting point of this study carried out by the University of Puerto Rico, Rio Piedras Campus in 2016. The study revealed through action research in a qualitative paradigm, how do high school students learn mathematics when exposed to new educational practices of solving situations in context in a transdisciplinary setting. These situations in context to resolve them were supported by the Project Based Learning (PBL) strategy. Based on historical researches Knoll (1997), reveals that the use of the word project was born as an educational and learning tool in the architectural education movement that began in Italy in the 16th century. Teachers gave students advanced and challenging tasks, such as designing churches, monuments, or palaces. These tasks introduced students in the demands of their profession and, at the same time, allowed them to apply, independently and creatively, the rules and principles of composition and construction that they had learned in the lessons and workshops. In the late 18th century, the engineering profession was established and incorporated into new techniques in industrial universities and colleges. Pujol-Cunill (2017) states that this transfer of project learning from Europe to America and from architecture to engineering had an important influence on the use of PBL. Thus, there are different authors who have adapted this constructivist strategy to use it in their classes. In this study, the ideas of Velázquez and Figarella (2012) were taken, where they use the PBL strategy to solve a problem in context. This strategy is constituted from the perspective of problematization in learning. The problematization refers to "the process of facilitating the creation of cognitive conflicts in students, in a way that moves them to high levels of cognition, to analyze, reflect, investigate, create, act and evaluate to build new learning experiences" (Velázquez & Figarella, 2012, p. 21).

The National Council of Teachers of Mathematics (NCTM, 2000) states that everyone needs to understand mathematics and students should have the opportunity and the necessary supports to learn relevant mathematical content with depth and understanding. It is remarkable to see that traditional strategies of quickly subjecting the student to solving

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verbal problems alienate the student from the real context. However, most teachers continue this formalism for years because it is what is in the texts and in the guides, limiting themselves to a comfortable zone that makes it impossible to search for innovative strategies.

A study carried out by Streefland (1991), with Indonesian students at the elementary level, encountered obstacles when applying the new approach of Realistic Mathematical Education (RME). The obstacles were: the very dependent attitude of the students, they were not used to working collectively, the lack of reasoning capacity and the lack of understanding of the basic concepts. Along the same lines of study, English (2007) highlighted that, in problem solving, students should identify the structure of a problem before seeking an answer. He argues that writing experiences, relating findings, and explaining thoughts challenges students to use those same processes.

Members of the Universities of Chicago and California, Richland, Stigler, and Holyoak, reveal that studying mathematics within the American educational system offers insight into the broader relationships between student knowledge, student cognition, and teacher practices. Many schools are failing by not teaching their students the conceptual basis for understanding mathematics, an aspect that could contribute to the flexibility of transfer and generalization (Richland et al., 2012).

Starting elementary school, students make efforts to know what has developed throughout the history of the discipline (Saxe et al., 2015). What children build in their lives daily outside of school is disconnected with the teachings within the school. For emerging communities to recognize that children come to schools with cognitive resources, which they may be able to leverage to make sense of these concept systems, would be a major advance in fostering learning in mathematics. The results of a study in Nigeria suggest the need for a shift to more student-centered learning to replace the teacher-centered approach to learning that has not been effective in classroom outcomes (Bature & Atweh, 2019). From the perspective of the focus group students, it was felt that teachers in training found it difficult to implement the collaborative strategy during classroom instruction. They believed that the authoritarian approach of teachers to classroom instruction was still observed.

The purpose of this research was to contribute to new educational practices based on PBL. During the trajectory, it was explored how students in the secondary level resolve situations within their environment. Emphasis was placed on how they analyze through situations in context, and how they build knowledge through the search for a possible solution to the problem through the PBL strategy.

The focus of study has not been limited to simply observing the solution to the problem, but rather to studying the processes that the students were creating to arrive at the solution. The students were the protagonists and were attended from the grassroots to accompany them, restore their creativity, and observe how they build knowledge that helps them face situations in their daily lives. During the students' learning process, the principles of Mathematics in Context were experimented, where the students went through experiences of situations from a sociocultural and community setting. The theoretical approach to Mathematics in Context (Quintero, 2010) relates to the same non-traditional thoughts of the theoretical framework of RME founded by the Dutch mathematical educator Dr. Hans Freudenthal. Freudenthal (1973) sees mathematics as a human activity and this thought changes the traditional paradigms of what mathematics is. This theoretical thinking agrees with the foundations of the PBL strategy developed in the curriculum, where the focus is on solving situations in context by creating a project collaboratively. This learning theory is a connection gap between school mathematics and world problems, which integrates activities through situations.

The RME opens the way to new non-traditional thoughts on the didactics of mathematics. The term realistic refers more to the intention of offering students' situations that they can imagine, than to the reality or authenticity of the problems. Freudenthal (1991) characterizes the RME by: 1) Thinking mathematics as a human activity, (he calls it as mathematization), where mathematics must exist for everyone; 2) The notion that the development of mathematical understanding goes through different levels where contexts and models have a relevant role and that this development is carried out by the didactic process called guided reinvention, in an environment of different knowledge; 3) Mathematization requires didactic phenomenology as a research methodology, that is, the search for contexts and situations that generate the need to be organized mathematically.

In a study conducted by the Quality Improvement Agency for Lifelong Learning (QIA, 2008), it was found that instruction based on one of the principles of Mathematic in Context enables students to use different models to solve a problem, organize solutions and / or diagnose the causes of errors in the solutions. This principle contemplated in this research is the use models and collective reflection, where everyone's models are respected.

As part of the principles of Mathematics in Context are the levels of the mathematization process. The specific level works with situations or problems in the environment in which the student is (Quintero, 2010). The possible solutions to the problem, students generate representations and models that are later simplified into algorithmic procedures that give it an organizational form. This is called vertical mathematics, where the student internalizes on an abstract level. Students need to go through the concrete level first before learning algorithmic methods, since the conceptual base can

connect it with their real life and see the relevance of the concept learned. In this way, they manage to recognize that there are alternative ways through a problem and develop their own chains of reasoning.

National assessment studies have shown that, in the last years of primary school, Dutch students working with modern texts are generally more successful than students working with traditional texts, with the exception of the topics of written algorithms and measurements (Anderson et al., 1996). It should be noted that changes have been made in the way of teaching and in the treatments offered to students in each subject, in such a way that new alternatives of teaching were found so that the point of interest has been how it is that they learn mathematics and apply it to their social environment. Based on the findings of a study in Thailand of implementing Science-Technology-Engineering-Mathematics (STEM) activities, it was clear that to develop students' conceptual understanding of scientific concepts and scientific reasoning skills based on STEM activities, the use of activity an engineering design alone was ineffective compared to activities with a multidisciplinary approach (Changtong et al., 2020). Two statistical results verified this statement. One is the fact that those who participated in the independent engineering design obtained a statistically lower mean in the pretest of the 10-item compared to the other two groups. In fact, the participating students who participated in this study performed equally well at school, as they were all rated at the same level of academic achievement by the school.

### Methodology

In this action research, qualitative methodology was used to satisfy the purpose of exploring and documenting the experiences of students who are impacted by the PBL pedagogical strategy, with a focus on the principles of Mathematics in Context. Action research involves participation, in which you not only learn from others, but others also learn from you. "The experience, opinion and contribution of each participant is what the research is with built and develops" (Blandez, 2000, p. 24). The action research it is presented as a cyclical process that can be used to improve the art of teaching, helping teachers organize and facilitate effective student learning programs (Stringer, 2008). Figure 1 shown below explains this cyclical process that was used in this study. Action research and action learning are parallel processes that allow teachers (researchers) and students to work together to achieve effective learning processes. Stringer's approach to action research applied to teaching is based on a simple look, heuristic thinking and acting, which frames both the instructional work and activities of the teacher and the learning of the student body. All three components act as a compass or map that guides teachers through the systematic steps of a query:

- ✓ Observe: Acquire information (data)
- ✓ Think: Reflect on the information
- ✓ Act: Use the results of reflection and analysis (create, plan, implement, evaluate)

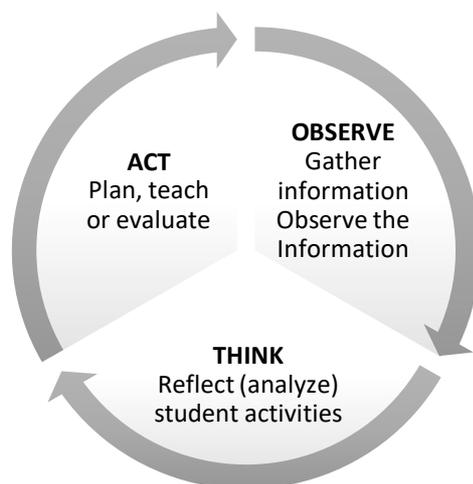


Figure 1: Action Research Cycle model adapted from Stringer (2008)

This spiral interaction model is repeated continuously, providing constant guidance to the ongoing teaching, and learning processes Figure 1. The cycle is developed in three instructional phases, these are: planning, instruction, and evaluation. Next, in Figure 2, the adapted model of Stringer that was applied in this investigation is presented.

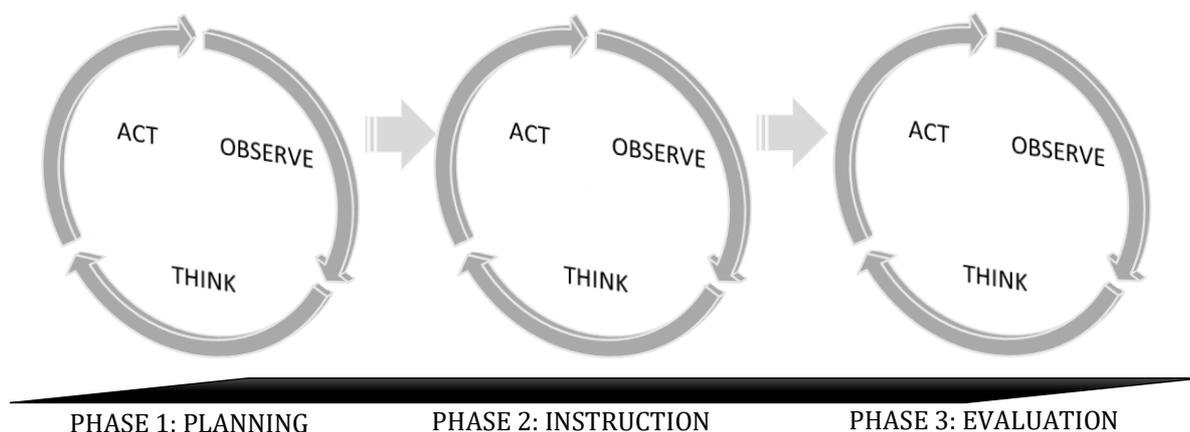


Figure 2: Model adapted from Stringer (2008) of the phases of instruction

The cyclical Look-Think-Act parts of action research are incorporated into each phase of instruction, providing carefully articulated processes that enhance both teacher instruction and student learning. The action of looking is the bridge to acquire information (data). When we think, we reflect on the information (analyze). Then there is the act, where the results of reflection and analysis are used (plan, implement, evaluate).

The nature of qualitative research has been defined by various authors. Bogdan and Biklen (1998) delimit it as an investigation that produces descriptive data: the properties of people, spoken or written, and observable behavior. On the other hand, Lucca Irizarry and Berrios Rivera (2003) explain it as the body of knowledge that makes up the different research designs and strategies that produce data or information of a textual, visual or narrative nature, which are analyzed, in turn, by means non mathematicians. Corbin and Strauss (2008) detail it more aligned to the object of studies of this investigation because they highlight the experiences of people, behavior, emotions, feelings, social and cultural phenomena between communities, where an interpretative analysis of the information.

#### Research participants

The research participants were 15 females and 15 males. The first 30 students were chosen to bring the signed informed consent forms. The 30 students are 11th grade taking the trigonometry course. The participants were 30 students from the eleventh year of high school, of both genders, 15 male and 15 females. All enrolled in the trigonometry course at a public school in Puerto Rico. Eleventh grade students are young people between the ages of 15-16.

The context of the investigation occurred during the class schedule established by the school organization and sometimes outside of the schedule. The time assigned to this course is one hour each day, from Monday to Friday. The students lived the experience of solving a situation of the school community, through the PBL pedagogical strategy. The instructional practice was planned so that the evaluated students carried out a school project.

Table 1: Table of the names of the students in the investigation

<b>Names of study participants</b>	<b>Names of focus group participants</b>
<input type="checkbox"/> Aina (female) (Catalan origin)	<input type="checkbox"/> Mía (female) (English origin)
<input type="checkbox"/> Adela (female) (German origin)	<input type="checkbox"/> Sebastián (male) (Greek origin)
<input type="checkbox"/> Adrián (male) (Latino origin)	<input type="checkbox"/> Samara (female) (Arabic origin)
<input type="checkbox"/> Alan (male) (Celtic origin)	<input type="checkbox"/> Jayden (male) (English origin)
<input type="checkbox"/> Amadea (female) (Latino origin)	<input type="checkbox"/> Ramses (female) (Hebrew Origin)
<input type="checkbox"/> America (female) (German origin)	<input type="checkbox"/> Diego (male) (Hebrew Origin)
<input type="checkbox"/> Azucena (female) (Arabic origin)	

### Focus group participants

Mia describes herself as an active student, very responsible with her homework and has a high academic achievement in mathematics. Sebastian describes himself as a very calm student, he likes to help others and offer tutorials to clarify mathematical concepts discussed in class. He has the qualities of a leader and takes initiative. Samara describes herself as a student full of energy. She likes leadership and helping other colleagues. She is an average student in academic achievement in mathematics. Jayden describes himself as a student of academic excellence in mathematics. He is very active and likes challenges. Requires additional assignments. Ramses describes herself as an average student in academic achievement in mathematics. She is passive and collaborative. Diego describes himself as a student of high academic achievement in mathematics. He has a good sense of humor and likes to cooperate with other colleagues.

The participants' school was called the Escuela Euclides de Alejandria for the purposes of this study. The Escuela Euclides de Alejandria is a higher-level public school, located in an urban area. The school specializes in occupational programs such as: Accounting, Entrepreneurship, Medical Billing, and Office Systems during the day. It has an interior patio with trees and a gazebo. It is classified as a school in transition and is on the Schools Classification List, according to the Flexibility Plan of Education Department of Puerto Rico (DEPR, for its initials in Spanish, 2016), since students do not reach the minimum percentages on the Puerto Rican Tests of Academic Achievement.

### Procedures and instruments to collect data

The following diagram describes the procedures for data collection, as presented in Figure 3. The order described indicates the way in which the information was acquired.

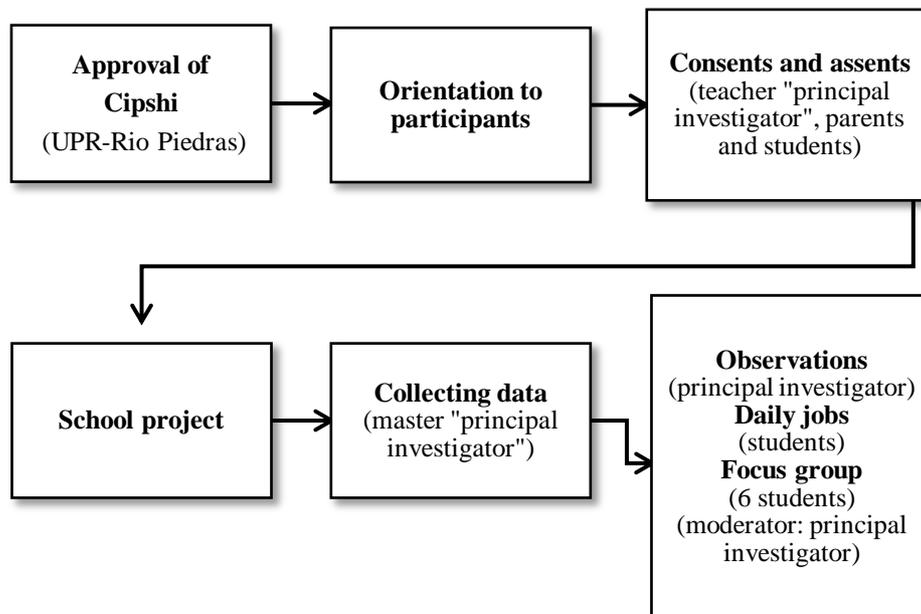


Figure 3: Components for data collection in the research recovered from (Collazo, 2016)

### Information gathering strategies

The strategies incorporated in this study, which aim to collect the information, come from the qualitative methodology. These are: notes taken by the researcher from the observations; works completed by the participants themselves, and a focus group.

### Observations

The researcher observed daily the phenomenon that occurred during the school project. Notes were taken daily on the participants' reactions, their environments, and how the participants carried out the project.

### Daily work of students according to treatment

The Maximizing Yield Through Integration (MYTI) science and mathematics integration project at the University of Puerto Rico, Rio Piedras Campus (UPRRP) designed six units related to solid waste issues (Puerto Rico Math and Science Partnership [PRMSP], 2009). The first units were designed for 2013 and there was a review in 2015. They were developed within the themes of the introduction to solid waste. Specifically, in this study Units 3 and 4 were used. The

decision to work with these units was justified because when the students carried out the activities, they responded to the problematic situation presented which was the orchard of their destroyed school. Unit 3 is titled Preparation of Home Compost, and Unit 4 is titled Compost Analysis. MYTI objectives were to:

1. Training teachers with Master of Science and mathematics in these integrating units, and then put the units into practice in the classroom,
2. Make use of the integration of content and processes, and with this improve the learning of science and mathematics; as well as making the student and society aware of the problem of garbage (solid waste) that reaches the clandestine dumps of Puerto Rico without any control.
3. Improve students' attitudes towards science and mathematics and their possible link with their future professional training.

The MYTI unit design is one with a focus on integration and contextualization. Science and math concepts are an integral part of each of the lessons. However, the focus of attention in these lessons is that they have been developed through the context and the environments in which the students are exposed daily. At the same time, the lessons are aimed at raising social and cultural awareness of the importance of minimizing solid waste to improve the environment in which they themselves live. All six units have an emphasis on Solid Waste, Compost and Water.

The students had worksheets related to the activities of Unit 3, which has the title Preparation of the Home Compost, and Unit 4, Analysis of the Compost. In addition to written worksheets, students made charts to interpret what was happening at all stages of composting. Each of the activities integrated concepts of science and concepts of mathematics. These activities helped students resolve the contextual situation of the need to rebuild the school garden. Photographs of student work were taken.

#### *Focus group dynamics*

For the data collection, six students who constituted the focus group were selected. Korman (1986) defines a focus group, as a meeting of a group of individuals selected by researchers to discuss and elaborate, from personal experience, a theme or a social fact that is the subject of research. At the beginning of the group discussion, it should be considered that informal conversations take place first, where the moderator (main researcher) must be able to participate and motivate.

This informal talk time could last from 15 to 20 minutes, but not more. Special care was taken so that no participant felt out of context or isolated during this period. Then, research-aligned questions were raised during the conversation. This introductory part of the focus group is divided into the following parts: a) welcome, b) presentation of the topic of discussion at first glance, c) lines of development of the focus group, d) initial question on the topic.

The driver (principal investigator) must in this regard create the atmosphere that the participants share certain characteristics in common and that they have valuable information to contribute.

#### *Logistics of the focus group conversation*

Welcome	
Presentation of the topic	
Focus group development lines	Inform them that the conversation is recorded in audio. Questions have been developed to complement our conversation.
Initial question on the topic	
Questions about the development of the topic	✓ Have you previously been in contact with situations in context in math courses? ✓ How did you feel working collaboratively with others? ✓ How did you solve the situation of the state of the school garden? ✓ What representations did you develop to resolve the school situation? What mathematical processes do you prefer when solving situations?
Closing question	✓ How were they impacted in this project?

### Analyzing of Data

Data analysis from this research encompasses a correspondence between research for action and research for active learning, see Table 2.

Table 2: Parallel teaching model / learning processes

	Research for action teacher	Active learning Students
<b>Observe</b>	(collects information) Observe student learning activity	(collects information) Acquire information, looking, listening and doing
<b>Think</b>	(reflect, analysis)	(reflect, analyze) Detailed recall process, select, organize
<b>Act</b>	(act) Provides students with feedback	(reflect, analyze) Detailed recall process, select, organize

Source: adapted from Stringer (2008) recovered from Collazo (2016)

Both correspondences were analyzed from: observations, daily work and focus group. In the qualitative process, the collection and analysis occur practically in parallel. Furthermore, it is not standard, since each study requires its own analysis scheme (Hernandez, Fernandez & Baptista, (2006). Some characteristics mentioned by Baptiste (2001) are highlighted in this study: explaining environments, situations, events and phenomena.

#### Part 1: Written Data

Handwritten annotations and documents were converted to PDF documents. Then they were transferred to the computer. All material was reviewed in its original form. During the review, a second log (different from the field log) began to be written, which is usually called the analysis log and whose function is to document the analytical process step by step (Hernandez et al., 2006).

#### Part 2: Daily Jobs

For this part, all the material (written notes, photographs, documents) was reviewed. All the material was scanned and stored in the same processor. Following ethics and observing the principle of confidentiality, the participants' real names were replaced by other names. After reviewing the material again, I wrote a third analysis log to document the analytical process step by step. At this point it was necessary to optimize the photographic images for a more rigorous analysis of the actions and works of the students.

#### Analysis log

As recommended by some scholars (Hernandez et al., 2006), this blog has the function of documenting the analysis procedure and the researcher's own reactions to the process, and contains fundamentally:

- Notes on the method used (the process and each activity carried out are described).
- Annotations regarding the ideas, concepts, meanings, categories that emerge from the analysis.
- Notes regarding the credibility and verification of the study, so that any other researcher can access the work.

#### Part 3: Focus group

In this part, the materials of the informal conversation with the six students were transcribed. The process of transcription of the audio recording was worked as follows: 1) by the principle of confidentiality, the real name of the students was replaced by other names; 2) a format with wide margins was used (for recommendations or comments); 3) interventions were separated between questions; 4) all the words, sounds and paralinguistic elements were transcribed: impressions, interjections (such as: oh !, mmm !, eh! And others); 5) pauses, silences, significant expressions were indicated (crying, laughter, knocking on the table, someone entered and the rest); 6) was analyzed line by line qualitatively.

#### Interpretation

Once the materials were transcribed, the general meaning of the data was explained, everything was reviewed and reprocessed. Coleman and Unrau (2005) highlight that in this way it helps to remember cases and experiences in the field.

### Findings

In phase 1 of the planning, the students were exposed to a situation in the garden of their school, which was destroyed. In this phase the students presented their ideas to develop a project. After phase 2 of the instruction, the students carried out the activities of Unit 3 and 4 of composting and analysis of compost integrating the MYTI sciences and mathematics explained above, as part of the school project. Finally, in phase 3 of evaluation, when the students were exposed to the dynamics of the focus group. Below are the three phases in Table 3, which were worked within the Action Research cycle.

Table 3: Composition of the phases of Action Research

<b>Phase 1</b> <b>Planning</b> Situation in Context: * Image Presentation * Presentation of the School Project * Home Garden and Compost Workshop	<i>Observations:</i> Planning and preparation of the School Project  <i>Thoughts:</i> The students reflected on the selection, order and organization of the School Project  <i>Actions:</i> Formulation of the Action Plan
<b>Phase 2</b> <b>Instruction</b> Initiation of Activities: * Unit 3 activities. * Unit 4 activities. * Start of preparation of the land and planting.	<i>Observations:</i> Initiation of the six compost creation and analysis activities.  <i>Thoughts:</i> Reflection of the students on their learning processes and representations.  <i>Actions:</i> Feedback and valuable information on activities as part of the project.
<b>Phase 3</b> <b>Evaluation</b> Result of the School Garden: * Compost ready. * Sowing Kidney Bean Seeds. * Focus group.	<i>Observations:</i> Review of results and student performance.  <i>Thoughts:</i> Identify successes and strengths, weaknesses and gaps.  <i>Actions:</i> Planning of corrective measures, ways to improve teaching and learning.

Source: Stringer (2008) model adapted from Collazo (2016)

As a preamble, the main question of the study began. On how students solve situations in context. Qualitatively, the moment in which the students were visualizing situations within their school environment was explored and they also developed possible solutions. The situation presented to the students was motivational since the situation was part of their environment. To collect their impressions of the situation, four questions were developed and written data from the participants was retrieved. For example, how do you feel when you see these photos? This is an open-ended question, where the student was able to express his feelings freely in the face of the situation. What could be the factors that caused what you are observing? This question explores whether they know the root of the problem. And, how do you visualize yourself in this situation? This question gave us information about what alternatives students offer.

Through these questions, the students reflected on possible alternatives to improve and help rebuild the destroyed garden (situation in context). This means that they internalized the situation, know their environment, and are concerned with giving alternatives to solve the problem.

To present the School Project to the students, they were shown a presentation on the structural part of the project entitled: Rescuing the School Garden: Sowing Consciousness. The distribution was planned, and the volunteer window was opened for the different roles (Advertisers, Data Collectors, Material Distributors, Garden Supervisors and Data Interpreters), who were part of the project. Most of the students voluntarily signed up for a role. It should be added that the purpose of this structure was to allow students to develop ideas from their different functions. The dynamics of choosing each role was opportune. It was carried out in a free and spontaneous way. Despite deciding to guide them with a role or responsibility, the students enjoyed the moment of filling each vacancy and getting the team to assemble fully.

Each group was able to meet and write their own ideas on possible ways to organize themselves to work on the project. They were very valuable ideas and many of them were worked exactly as they said. It was observed clearly that students know technological tools to interpret the data. Sure, it was to be expected, since it is a school with an occupational program, and they integrate technology most of the time.

A relevant aspect within the organization was that a student brought up the idea of opening a group on WhatsApp to inform and communicate about the garden. WhatsApp is an instant messaging application for smartphones, to send and receive messages through the internet. Well, they managed to open the group and included the researcher me as part of the group. On the second day of opening it, one of the students wrote that if they could explain what the school project was, since she had not been able to be at school for health reasons. At that moment, the same students began to interact and explain the details of the project to her. In this way, the student was integrated in a very effective and motivated way. Through WhatsApp technology, was spoken weekly in the group and photos were sent.

*School project (horizontal mathematics and vertical mathematics)*

The school project presented four important steps. The first step that was already explained in the previous paragraphs was to expose the students to the problem (the situation in context. Then in step 2, we deal with how the students rescued the garden. In step 3, we describe how were the experiences of creating and analyzing compost, where in effect they integrated concepts of science and mathematics. In the third step, the principle of the level of horizontal mathematic (concrete level) was developed within Mathematic in Context and was worked with the students' ideas freely. Now, in step 4, we observed how the students created representations and models to interpret the data on compost decomposition of the compost and growth. Finally, in step 5, gives rise to the presentation of the reconstructed School Garden, which is the solution of the situation in context.

A relevant aspect in the observation of the students was when they began to inform the school community about the collection of solid waste such as: a bottle of soda, vegetable peels, fruits, coffee grounds, dried leaves, among others. Teachers, students, parents, school lunchroom employees, and administration were motivated to extend the invitation to recycle in this way. They concentrated on explaining to the school community the purpose of collecting the materials and contributing to the environment.

While the materials collection process was taking place, the students were invited to a workshop home garden and compost with the Agronomist Rafael Diaz at the school, who is currently vice president of the Metropolitan District of the College of Agronomists of Puerto Rico. In advance, an agreement was reached between the teachers to carry out this workshop. The day the workshop was offered, two teachers did not remember the agenda that they had been notified in writing and in time. The three ways that were announced were verbal, electronic and on the bulletin board. The students were some worried about their classes, others very happy because they would not go to do the same. Two relevant topics developed by the Agronomist were: the integration of agricultural trade into the school, and the importance of agriculture in Puerto Rico. He explained in detail what hydroponic crops are and those of self-irrigation systems.

Another of the topics that were incorporated in the workshop was knowing what pH is. To the Agronomist's surprise, the students knew what pH is and what the proper pH is, because they were taught it in chemistry class.

The students were curious about the compost with the worms that the Agronomist brought for the demonstration. The students took the pH (See figure 4) out of the vermicompost and the Agronomist took them to the patio. He showed them the mathematical part that is necessary to know to get the fertilizer with the necessary ingredients.



*Figure 4: Diagram of pH study images in the vermicompost*

This diagram (see Figure 5) shows what the Agronomist was explaining to them about what the necessary ingredients are to achieve a good fertilizer for the viability of the seedbed. This explanation is about the mathematical part. At that

moment, a student asked: "Why don't you do this more often? Everything is class!! This expression leads us to think that the concrete part and the contact with nature is important to motivate the students and, in this way, they can learn.

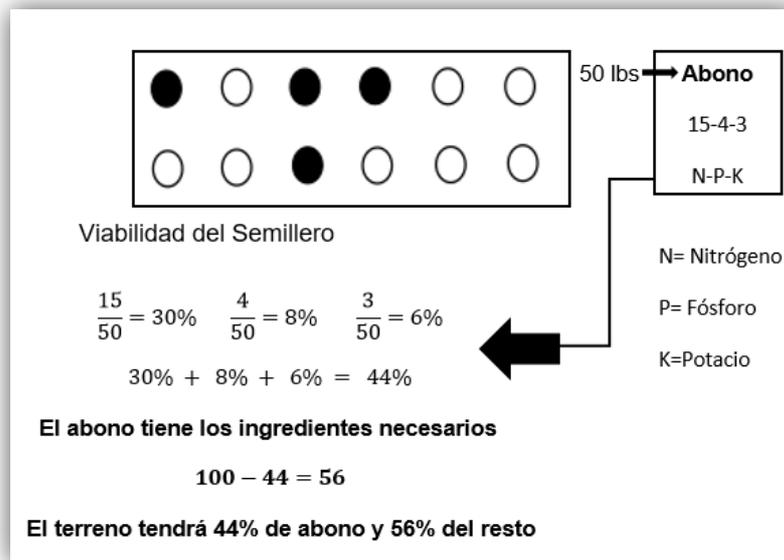


Figure 5: Representative diagram on the viability of the seedbed

The students worked on the activities of Unit 3, Preparation of the homemade compost, which was explained in Chapter 2 (Collazo, 2016). The first activity they collaboratively carried out was Activity # 2 "To classify for composting!", From Unit 3. Each group received a bag of sheets of solid waste. They had indicated them to classify the solid waste as compostable or non-compostable and to place their responses on the record table. In addition, they had to predict the time it would take for each material to decompose.

The second activity they worked on was Assembling the decomposition column. They made the decomposition column with bottles of soft drinks brought from different people from the school community. The activity consisted of five instructions and was collaborative work. This as part of the subscription to the school garden to be able to rebuild it. In these images unity and collaboration are perceived. We might think that we are creating a society with a culture of collaboration to resolve situations in our environment.

The third activity was, "Filling our decomposition columns!" (see figure 6) In this activity they used compostable materials donated by the students themselves, by the school canteen, by nearby restaurants and by people from the metropolitan community. In keeping with this activity, students modeled the compost on a poster and posted it on school walls to bring the information to the school community. Teachers and students asked what compost is and the students informed them about it.

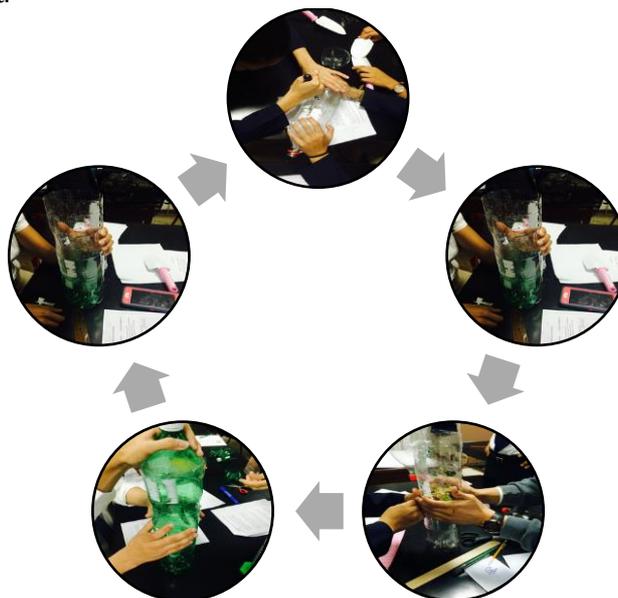


Figure 6: Image diagram of the construction of the decomposition column

Using the T-84 calculator, the students obtained the average compost temperature ( $24.5^{\circ}\text{C}$ ). They also verified the pH with a "Hydron Test Papers" test. The average was (7.0 to 8.0), some groups gave 6.0. On the other hand, the students were motivated and excited because they started planting green beans and managed to improve the land. It should be noted that the University of Puerto Rico, Rio Piedras Campus donated prepared compost and the students mixed it with the soil that was there. They used a ruler to measure the distance between each seedbed. They made them by forming equilateral triangles of angles of  $60^{\circ}$ . Unity, collaboration and dedication to rebuild the garden were observed among the students.

The fourth activity was Activity # 5 in Unit 4: Finding a mathematical model to estimate the ages of the trees. In the previous activities, students had the opportunity to work on horizontal mathematics (concrete part). They acquired contact with nature, learned what a compost is and what it is used for. They understood what the concept of decomposition is. Now in these activities they worked with written situations, in which they could imagine what they were reading, since they had previously gone through the experience of working with the concepts in real life.

In one of the situations in context, the students went through the experience of using the T-84 graphing calculator to make a scatter plot that relates the diameter of a tree to its age. To find the model they used data from a table, which was collected for a certain variety of oaks. In the first stage of the activity, the data was saved in lists  $L_1$  and  $L_2$  of the graphing calculator. In the second stage they plotted a scatter plot with these data. Then in the third stage they plotted a linear regression that modeled the data. In the fourth stage they calculated the correlation coefficient, which gave them  $0.9502 \dots$  and they answered that while the result is closer to zero it means that the variables are strongly correlated. In stage 5, they evaluated the domain values to estimate the age of the oak. Next, the images of the graphs are presented (Figure 7).



Figure 7: Linear model of contextual situation 1, TI-84 calculator

*Some impressions of the students at the specific level recovered from the focus group*

According to the question of the first phase Alan expressed:

*I think the workshop was excellent, with valuable and essential content on the procedures necessary for the School Garden to bear fruit. The planning was quite organized since there was always something to do while we were entertaining ourselves doing this project that benefits us all.*

America said:

*The part of planning the project seemed like a lot of fun, since it was something different from the way and dynamics of the normal class. Regarding the workshop, I found it very interesting and dynamic [T] he parts I liked the most was when we took the pH of the soil in the garden before fixing it and a soil that the lord of the workshop [the Agronomist] brought with worms.*

*Student impressions of collaboration and organization*

According to the question of the second phase Jayden expressed:

*In doing the first three activities I was totally delighted until we started using [the] famous scientific [graph] calculator. During the last three activities I was very confused because everything had to be with the calculator. The experience was unique, and I was able to try something new.*

Samara said:

*I felt very good because working with my colleagues is very good. It is the first time that we have worked together in a home garden and for the first time we have done quite well so far. And we hope that we continue working together like this.*

*Impressions of the students in the school project*

According to the question of the third phase Jayden expressed:

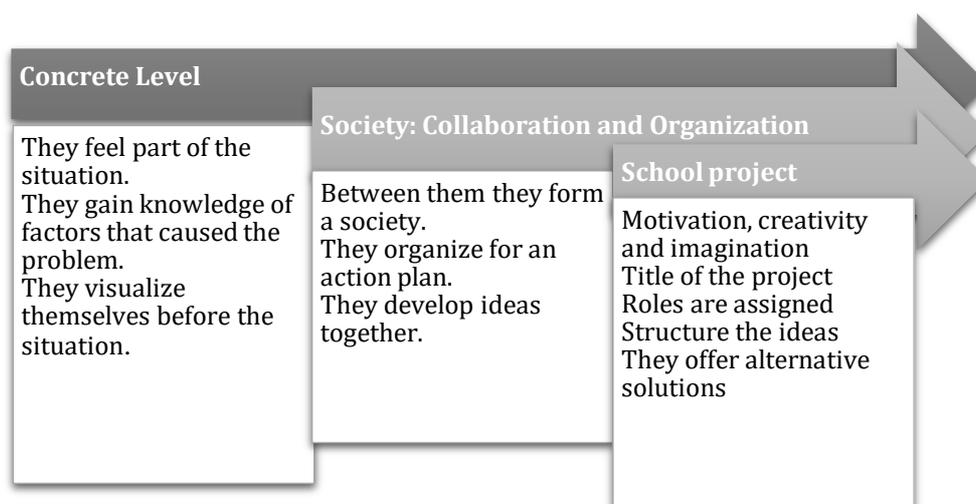
*Well, the first thing we did to resolve the state of the school situation was, this, right, first clean the garden because there was a lot of leaf lying on the ground, then this, we began to form as if it were a common garden. We add beans so that the earth, true, has nitrogen, what na. There we continue with the compost in what they grew. And then there they put, right, what we wanted to plant, fruits or vegetables.*

Samara said:

*Well, the compost, first we start with the compost, eeh, and the workshop. The workshop helped us a lot to know how we had to do things, the pH and all that.*

The first research question explored the phenomenon of the manifestation of students solving situations within the school environment. The question addressed three very important structures within the research (see Table 4).

Table 4: Categories of how students solve situations in



Source: (Collazo, 2016)

As part of the Project, questions are developed; these next three study questions were the secondary questions that go hand in hand with the first. Exploring students to answer these three questions is also part of the main question, but in this case they go specific.

What are the representations that students develop to solve situations in context? The answer to this question is summarized in that the representations they mentioned are concrete. In the creation and analysis of compost, they made representations with recycled materials that were developed to solve the problem. The search for pH and temperature were the variables where they created linear models.

The second secondary question was: What mathematical content do students use? The integration of science and math concepts was part of the content of the School Project. When students went through the experience of composting and analyzing compost, they integrated science and math concepts. Students interpreted the graphs they made on the T-84 Calculator and performed the algebraic function at the same time. When they did the algebraic function, then they gave it to graph and it was then that the linear model was seen. This was the case when they observed if the linear model increased or decreased and they made conjectures comparing the two variables identified in the situation. By taking out the correlation coefficient they could make future predictions. They learned that when the correlation coefficient result tended to zero it is because the variables are not strongly related. On the other hand, if the result tended to one, the variables being compared are strongly correlated.

Finally, the third question was: What mathematical processes do students prefer when solving situations in context? The answer to this question is summarized in that the graphic models' students prefer to make interpretations and understand what is happening in the situation. Samara expressed likes to write processes by hand for herself to create the procedure and everything. The construction of the procedure is the most important part to facilitate the solution to the problem.

## Discussion

The findings found support the proposal of the model based on the theoretical framework and the literature review. The discussion that develops from the interpretation of the results approves the offer of recommendations for teachers of public and private schools.

The discussion and creation of the models were supported by different research theorists, such as: Freudenthal (1991), Quintero (2010), Gravemeijer (1994), Velazquez and Figarella (2012), Sierpinska and Lerman (1996). Similarly, the theoretical foundations of Vygotsky (1981), Dewey (1985), Dunbar (1998) are connected in the study results.

As the students developed the project, they constantly interacted with their peers and in that social space the goals and objectives were achieved to rescue the school garden and learn the concepts of science and mathematics during the creation and analysis of the compost. Findings of student opinions align with findings of (Bature & Atweh, 2019) who suggest that effective collaboration during classroom instruction improves collaborative thinking of students, while solving difficult and challenging math problems, which helps increase students' confidence to solve challenging problems in the math classroom. Social interaction is necessary for group members, to learn from each other, for socio-emotional processes, and to help create a social space where there is trust, a sense of community, and strong interpersonal relationships (Kreijns et al., 2013).

As revealed, math courses generally need new approaches and ideas to work the logical reasoning part of math, which is where students need a lot of reinforcement. With this proposal, it was possible for all students to understand the concepts within the context or the real environment in a transdisciplinary approach. In turn, they understand the algorithm, internalize and conclude with reflections, conjectures, and predictions. In accordance with the transdisciplinary approach, the scientists (Suryanarayanan, Kleinman, Gratton, Toth, Guedot, Groves, Piechowski, Moore, Hagadorn, Kauth, Swan, & Celley, 2018), using the results of their study, suggested this transdisciplinary approach that proposes structuring the collaboration over time, in a way that brings scientists and non-scientists together with the key objects and locations of their shared concerns, thus setting the stage for the creation of new complexity-oriented insights. The role played by the agronomist in the Vermicompost workshop was an essential basis in scientific and mathematical knowledge as part of the project developed by the students.

The idea of exposing students to solving situations in context arose when studying the theory of learning Mathematics in Context. Among the principles of Mathematics in Context is to see mathematics as a human activity. In effect, the situation the students were solving became part of them and their school journal. The students felt part of the situation and knew the factors that caused the situation. Furthermore, they recalled that at one point they were part of the situation and saw themselves within it. Along these same lines, the authors Lopez, Franco-Mariscal & Ramos (2015); Benitez & Londono (2009) agree on the findings that solving situations in the real context and of daily life in chemistry and calculus sciences, students take an active role and capture interest in the study, while enabling relevant and integrated learning of knowledge. On the other hand, in one of the situations in context using the T-84 calculator to perform linear regressions, Azucena recommends that you first train well on the calculator, since she does not know how to deal with it. I understand that it is a very valid point and it would have been effective to give a workshop on the T-84 calculator before starting the activities for the benefit of the students who require it. For many it was the first time they had the experience of using a graphing calculator, so it was emotional for them.

The school project was a strategy well assimilated by the students. Simply saying "Project", the students showed a positive attitude, the feedback was positive, and their faces revealed emotion. The motivation was so great that they began to propose various ideas to finally be used in structuring the action plan. Evidence from the study on the performance of undergraduate students in the Science and Technology Teaching Course in Turkey, it was found that when the PBL method was used there was an increase in academic achievement compared to that of students who were instructed using the traditional method (Bilgin, Karakuyu & Ay, 2015).

Another experience that the students had was when comparing variables when it comes to a real situation. The representations were internalized in their minds, making conjectures and predictions as in the last two activities of the compost. On the other hand, we notice that we have students who are easily inclined towards algorithmic calculation, but we also have students like Mia who need to be told how much they need of this and that in order for them to do and go through the experience, and thus internalize their representations.

Another important element that stood out was social media. In the middle of planning the School Project, the students had the idea of communicating through "WhatsApp", they also mentioned "Facebook". The social network became a useful tool for social and collective communication, not only did they care about the project, but they also made sure that all students were up to date with the activities. Weekly they photographed the Garden, quickly sent them to the group, and comments were raised about the development of the plants. Given this finding, it should be noted that the findings of a study of the Instructional Technologies and Materials Design (ITMD) courses revealed that there was technological interest in the teachers' point of view. Given the applications supported by the technology that the pre-service teachers received in the contents of the ITMD course, these applications they positively affected their beliefs and attitudes of effectiveness in the process (Calik-Uzun, Kul & Celik, 2019). The technological applications are established as an important point for both the student and the teacher.

A social space is characterized by strong interpersonal relationships, trust and a sense of cohesion. These qualities form the conditions to create an optimal social context for collaborative learning. The extent to which the social space becomes healthy depends on the social presence of the participants; the degree to which people experience their

presence together as "real" people in communication (Kreijns et al., 2013). Social networks, like the one used in this project, have become part of the culture of the students of this century.

The global vision is manifested in the moments in which the students expressed that they wanted to make a garden in their homes. Not only that, but they talked about marketing for other countries. They also mentioned that the dining room was nourished by the production of the garden. These expressions go beyond solving a single situation in context, they traveled beyond the physical plant of their school. A global vision was awakened in them. An investigation about the proactivity and vision of the micro and small companies in Celaya revealed in the results that in the companies of the city there is a great aspiration of the businessmen to get ahead, however, in contrast they have a low proactivity since, Despite having growth objectives, there is no consistency in the actions of the businessman (Lopez-Salazar, 2010). It should be noted that the awakening of these young people can be a starting point to boost the business vision. These three elements (integration, social networks, global vision) mark the development of a sociocultural extension. Forming a different culture, focused on the social, so that the student not only thinks about individualistic knowledge, but also thinks in a group.

Interaction is important in this process, as it creates a favorable social environment for ideas to overflow. In interaction, students learn from each other and this makes them feel important within the project. Taking what Vygotsky mentioned about social interactions, Bales (1999) makes a distinction in that social interactions must not only be directed towards cognitive processes, but also towards the socio-emotional processes that underlie these cognitive processes.

On the other hand, creativity makes the issue of solving the situation exciting. Creativity and development are objective and subjective processes that involve not only sharing public meanings and objects, but also personal experiences and transformations (Moran and John-Steiner, 2003). Curricular behaviorism and formalism can affect students' creativity if they are taken as a priority in teaching. Most of the time in these methods, students are presented with what to learn, without exposing them to external situations where the idea of expanding knowledge may come up.

These three elements (motivation, interaction, creativity) are fundamental for socio-emotional extension, which is one of the formations that is often not considered. However, students require this socio-emotional extension to make way for learning new knowledge.

Cognitive extension is supported by sociocultural and socio-emotional extensions. So, knowledge comes without waiting, it just happens at the right time. The integration is developed in the student's knowledge of different disciplines. In the case of this study, knowledge of science concepts and mathematics concepts was achieved.

Finally, the entire body of sociocultural, socioemotional, and cognitive extensions results in a conglomerate of elements that are developed during the creation of the School Project, which is essentially the PBL strategy.

### **Conclusion**

Action research enables self-reflection in the systematic phase of organizing ideas that are developed into an action plan as a prelude to learning preparation. The researcher constantly reflects on how his perception and interpretation can affect the observed phenomena. Reflexivity turns the researcher into an actor in his study and a search tool with which he builds design, as a product of the decisions he makes. The qualitative method with an action research design has required many explanations and relationships that emerge as the study develops. It is a job that requires a lot of dedication and dedication. The belief is that this study will enrich teachers with innovative ideas for educational practice from a social and cultural perspective within the Project Based Learning strategy, in order to learn mathematics.

### **Suggestions**

For the purposes of this study, proposals are expected to help teachers expand ideas to develop plans in the student learning process. As a result of this research, recommendations emerged that cover three dimensions that are elements that are part of educational development. All three dimensions are linked to future research, public policy, and the development of curriculum design.

#### *Future investigations*

Regarding future research, it is recommended that rigorous phenomenological studies be pursued that pursue the issues of solving situations in context with the PBL strategy. Observing school projects in different settings with different cultures and environments extends the development of ideas to improve the teaching and learning process.

Today's teachers who have a genuine commitment to education must take on the challenge of researching in their classrooms and reflecting on the educational practice they developed with their students. Likewise, share it among your colleagues informally, becoming a reciprocity of new ideas to continue improving instruction. Like students, teachers can communicate on social networks to exchange new practices. The union of different colleagues in education is necessary to continue exploring how students learn.

### Public politics

Field experiences from the beginning of teacher training enrich educational practice, both in the teacher being trained and, in the teacher, who is already in practice. As has already been clarified, the training of future teachers in Puerto Rico needs a transformation. When teachers specialize in a discipline, the tendency is to study concepts related to it. Interdisciplinary teacher training is required, where they not only know one subject, but also understand concepts from other subjects and integrate them into their discipline. Universities must create collaborative projects. For example, do a course where the enrollment is of students from different academic programs with the purpose of developing projects connecting concepts of science and mathematics, or history and mathematics, or English and mathematics, etc. In this way, the future teacher would have a tendency towards the holistic vision, where he could plan his curriculum and his classes focused on the reality of the students. Students in their daily lives connect different concepts at the same time to solve situations.

### Curriculum development design

The curriculum development design must be a flexible one, which does not incur a strict structure. Flexibility helps to make changes at the time that it warrants. Planning before carrying out the process must generate a "draft". However, modifications to the "draft" must be made during the classes. This enriches the teaching and learning process, since the student is part of the planning and can shed light on how he learns.

In the study, during the school project, a series of ideas emerged from the students themselves that contributed substantially to the action plan. This made the students highlight the central and leading space that corresponds to them during the process. I invite the teachers to reflect and analyze if the student has truly been the center in his classes as he should be.

### Limitations

A limitation of this research was the bureaucratic process of permits to carry out the study in a public school in Puerto Rico. Another limitation related to the qualitative paradigm is that quantitative data are often expected in research to reach conclusions. On the other hand, it is highlighted that there are not many qualitative investigations in mathematics education, and they are important to reach conclusions about how to learn.

It requires a holistic preference in describing the complexity of the phenomena. The researcher is the main link of the research, so he must recognize his biases and monitor how it can affect his perception and interpretation of phenomena. Together, the interaction between the researcher and the participants has been extremely important in the study. On the other hand, reflexivity turns the researcher into an actor in his study and an instrument of the search with which he builds design, as a product of the decisions he makes.

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