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Articles Section

Potential and challenges in teaching systems of 1st degree equations via problem solving

Potencialidades e desafios no ensino de sistemas de equações de 1º grau via resolução de problemas

Posibilidades y retos de la enseñanza de los sistemas de ecuaciones de primer grado mediante la resolución de problemas

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Abstract

The aim of this article is to highlight the potential and challenges involved in developing a teaching via problem solving approach for learning systems of linear equations. Twenty-eight 8th-grade students participated in the study. The data collection tools were the students' worksheets, which were analyzed using descriptive-analytical and interpretive methods. In the first stage of instruction, students relied on a trial-and-error strategy. In the subsequent stages, we observed their understanding of the concept and algorithmic processes. Some challenges were related to difficulties with algebraic calculations and monitoring problem-solving. We concluded that the potential of the instruction was to foster the development of students' understanding of the content of systems of linear equations, thereby promoting the development of algebraic thinking.

Keywords: Mathematics Teaching. Algebra. Linear Systems. Algebraic Thinking. Problem Solving.

Resumo

O objetivo do artigo é revelar as potencialidades e desafios no desenvolvimento de uma proposta de ensino via resolução de problemas para a aprendizagem de sistemas de equações de 1º grau. Participaram 28 alunos do 8º ano do Ensino Fundamental. Os instrumentos de coleta de dados foram as folhas de atividades dos alunos, cujos registros foram analisados de forma descritivo-analítica e interpretativa. Na primeira etapa do ensino, os alunos recorreram à estratégia de tentativa e erro. Nas demais etapas, observamos a compreensão do conceito e dos processos algorítmicos. Alguns desafios foram referentes às dificuldades em cálculos algébricos e no monitoramento da resolução dos problemas. Concluímos que a potencialidade do ensino foi proporcionar a evolução da compreensão do conteúdo de sistemas de equações de 1º grau, favorecendo o desenvolvimento do pensamento algébrico.

Palavras-chave: Ensino de Matemática. Álgebra. Sistemas lineares. Pensamento algébrico. Resolução de Problemas.

Resumen

El objetivo del artículo es poner de manifiesto las posibilidades y los retos que plantea el desarrollo de una propuesta didáctica basada en la resolución de problemas para el aprendizaje de los sistemas de ecuaciones de primer grado. Participaron 28 alumnos de 8.º de primaria. Los instrumentos de recogida de datos fueron las hojas de actividades de los alumnos, cuyos registros se analizaron de forma descriptiva-analítica e interpretativa. En la primera etapa de la enseñanza, los alumnos recurrieron a la estrategia de prueba y error. En las demás etapas, observamos la comprensión del concepto y de los procesos algorítmicos. Algunos retos se referían a las dificultades en los cálculos algebraicos y en el seguimiento de la resolución de los problemas. Concluimos que el potencial de la enseñanza fue facilitar la evolución de la comprensión del contenido de los sistemas de ecuaciones de primer grado, favoreciendo el desarrollo del pensamiento algebraico.

Palabras clave: Enseñanza de Matemáticas. Álgebra. Sistemas Lineales. Pensamiento Algebraico. Resolución de Problemas.

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1. Introduction

The learning of algebra and, consequently, the development of algebraic thinking, is a factor of extreme importance for the world. In Brazil, the study by Becher (2009) showed that students had difficulties understanding and signifying situations and concepts, translating written language into algebraic language, and using algebraic formulas, properties, and techniques. In Portugal, Morais (2012) found students with difficulties in representation and generalization in different mathematical situations. In Turkey, Töman e Gökburun (2022) identified students with erroneous calculations in algebraic expressions and a low level of algebraic thinking, associated with difficulties in transitioning from arithmetic to algebra. In Australia, Chinnappan (2004) showed that the students in their study found obstacles to solving equations with more complex structures related to algebraic conceptual knowledge.

These difficulties students find in learning algebra (and in algebraic thinking) in Brazil and worldwide open space to studies that examine its causes and others that seek to reconstruct/mitigate this challenging situation. Therefore, the resulting gap concerns research on classroom teaching. In this sense, an important algebraic content, the focus of this article, is the teaching of systems of equations. While Ferreira (2013) showed that this content is taught briefly and superficially, Battaglioli (2008) pointed out that mathematics books prioritize algebraic calculations; in turn, Delazeri (2017) states that this scenario exposes students to difficulties with systems of equations while having limited understanding of the content. Cunha Neto (2020) affirms that this panorama is made precarious by classroom teaching that does not favor an environment to discuss judgments, concepts, and the formation of theoretical thinking, giving few conditions for students' cognitive development.

Faced with this problem, Campos (2019) and Campos e Farias (2020) guide the teaching of systems of equations permeated by problem-solving activities, thus allowing the establishment of connections between natural and algebraic language. The National Common Curriculum Base – BNCC (BNCC, 2018, p. 528) establishes that the teaching of systems of equations should enable the student to "solve and elaborate everyday problems". However, Proença, Campelo e Santos (2022) showed that, as far as the curriculum is concerned, the BNCC for elementary school mathematics does not suggest how to deal with problem solving in the classroom, showing more of a focus on content applications, and the authors indicated the use of a teaching approach such as that of Proença (2021).

This article adopts, as the basis of practice, the proposal of teaching organization via problem solving with a focus on the conceptual formation of Proença (2021) for the content of a system of 1st degree equations. This teaching organization is structured in four stages, namely: (i) use of the problem as a starting point; (ii) formation of the concept; (iii) definition of the content; and (iv) application to new problems.

This article is derived from the research of the first author's doctoral thesis (Luz, 2023), which dealt with linear systems in high school and indicated the need for further research on this content in elementary school, as well as the use of the teaching methodology of Proença (2021) to involve students in solving problems for learning mathematical content. Thus, this article is inspired by that study and its activities, in which the objective is to reveal *the potentialities and challenges in the development of a teaching proposal via problem solving for the learning of systems of 1st degree equations to students of the eighth grade of elementary school.* Thus, this article presents the theoretical framework section, followed by the methodology section, the analysis and discussion of the results, the conclusion, and the references.

2. Algebraic thinking, the teaching of algebra, and systems of equations

For the National Common Curriculum Base – BNCC (BNCC, 2018, p. 270), algebra aims to develop algebraic thinking, which is fundamental for students to use mathematical models that enable the

"understanding, representation, and analysis of quantitative relations of magnitudes and mathematical situations and structures". Thus, Ponte, Branco and Matos (2009) point out three demands of competencies and skills related to algebraic thinking: *representing* – involving reading, comprehension, writing and operation with algebraic symbols; *reasoning* – encompassing the ability to relate, generalize, deduce and understand rules; and, *solving problems and modeling situations* – based on the use of algebra in solving problems in Mathematics and other domains. In this sense, Kuhn e Lima (2021) observe that, in the view of the BNCC, algebraic thinking must enable students to formulate, employ, and interpret Mathematics in different contexts, and that pedagogical practice is of great importance for this to really happen.

On the other hand, government assessments such as the 2018 PISA (Brasil, 2021a) and the 2019 SAEB (Brasil, 2021b) indicated that Brazilian students performed poorly on mathematics tests, particularly in algebra-related content. In this context, research in Brazil and abroad corroborates the noted difficulties in teaching algebra across different contexts. In Brazil, Becher (2009) noted that students had difficulty formally representing a problem, particularly translating written language into algebraic language. Morais (2012) observed in Portugal that students have obstacles to representing and generalizing different mathematical situations. On the other hand, Töman e Gökburun (2022) and Chinnappan (2004) observed that students in Turkey and Australia, respectively, found algebraic calculations challenging.

When we deal with the teaching of systems of equations, the subject of this article, we find a framework of difficulties. Jordão (2011) noted in his research that students have difficulty interpreting problem statements and solving systems of three equations. Delazeri (2017) observed students having difficulties with systems of equations and having a limited understanding of this content. Finally, in Indonesia, Maharani (2020) showed that students had limitations in choosing steps to solve systems of equations due to the requirement for more elaborate mathematical reasoning.

To circumvent this panorama, Borralho e Barbosa (2009) and Becher (2009) suggest teaching practices that promote meaningful learning so that difficulties in algebra are reconstructed. Thus, Campos e Farias (2020) propose activities that encompass algebra through problem-solving, thereby establishing relationships and connections between natural language and algebraic language. Thus, we judge the teaching approach through problem solving as a valid strategy to be tested in order to circumvent and reconstruct the aforementioned obstacles to teaching systems of equations. We will address this approach in the following section.

3. Problem solving to teach mathematics

Proença (2018) infers that, to become a problem, a mathematical situation must cause the student to mobilize previously learned mathematical concepts, principles, and procedures that lead them toward the path of the answer. Thus, its resolution does not establish the use of rules or formulas and, if this occurs, the mathematical situation tends to have the configuration of an exercise. The author also points out four steps for solving a problem that cover the domain of cognitive knowledge, namely:

(i) *Representation:* the moment when the student understands and interprets the problem they want to solve. Thus, they use their **linguistic knowledge**, which encompasses the comprehension of the mother tongue to recognize words and relationships between subjects and objects; **semantic knowledge**, which allows identifying mathematical terms and their relationships; and **schematic knowledge**, responsible for recognizing the problem in its essence, verifying whether it is algebra, geometry, among others (Proença, 2018).

(ii) *Planning:* deals with the use of a strategy in the search for solving the problem. Thus, it involves the use of **strategic knowledge** to manage an action plan, which may include the use of drawing strategies, tables, trial and error, etc. (Proença, 2018).

(iii) *Execution:* refers to the moment of executing the proposed strategy, in order to obtain an answer to the problem. In this sense, the student is guided by their **procedural knowledge**, that is, in performing mathematical calculations and drawings, which reveals their use of logical thinking as they seek to establish spatial and quantitative relationships (Proença, 2018).

(iv) *Monitoring:* the last step includes the moment the individual checks whether the answer found is in accordance with the problem's question, as well as the act of reviewing the path taken to find the solution (Proença, 2018).

In view of what a problem is and the process for solving one, in Mathematics teaching, a mathematical situation can be introduced and problems can be addressed throughout it. One possible teaching methodology is the proposal of teaching organization via problem solving, with a focus on conceptual formation, by Proença (2018), structured in four stages for the teacher's work in the classroom.

1st stage – use of the problem as a starting point: this initial stage covers teaching *via* problem solving, in which a problem is used as a starting point for a mathematical concept/content/subject. In this sense, five actions of the Teaching-Learning of Mathematics via Problem Solving (EAMvRP), proposed by Proença (2021), are used, which we will explain below:

a) Choice of the problem: in this first action, carried out outside the classroom, the teacher will choose a mathematical situation that will be a possible problem, aiming for students to use their prior mathematical knowledge to solve it. For this, the chosen problem cannot request the content to be worked on in its statement, but rather allow students to relate their strategies to this new content. Therefore, the situation may be elaborated by the teacher or reworked in full from an existing situation. This enables students to build the mathematical content/concept/subject that will be taught by the teacher, favoring the establishment of relationships between the mathematical knowledge used and the new knowledge to be learned. Regarding this mathematical situation, the author indicates that it should present the possibility of more than one answer and different resolution strategies.

b) Introduction of the problem: in this action, already in the classroom, it is indicated that students be divided into smaller groups, which helps the sharing of ideas, knowledge, and experiences. At this moment, the teacher should encourage students to try to solve it however they want or find most convenient. It is at this moment that the proposed mathematical situation may become a problem for them.

c) Assisting students during resolution: for this third action, the teacher's work should be aimed at helping with mistaken interpretations, frequent doubts, and the rationality of the answer found in solving the problem. Proença (2018) states that, at this moment, the teacher should act as an observer, encourager, and guide of the learning process. Therefore, by observing what students do, the teacher should draw on the stages of problem solving and their respective knowledge to assess students throughout this process. In this sense, Mota e Lozada (2022) corroborate these points, emphasizing the importance of the teacher in helping students in problem-solving processes that encompass understanding the statement, collecting data, and searching for strategies to alleviate possible difficulties encountered by individuals.

d) Discussion of students' strategies: this action concerns the moment of sharing the resolutions adopted by the student groups. In this sense, it is a space that allows students to perceive and build relationships between the knowledge used along the path to solving the problem. The teacher's role in this action consists of pointing out the mistakes and obstacles encountered, leading students to synthesize what they have learned and understood.

e) Articulation of students' strategies with the content: for this last action, the teacher must articulate the students' strategies with the mathematical content/concept/subject that will be taught.

Proença (2018) indicates that the teacher should seek the central points of the strategies, discussing the relationships that exist with the new content.

In summary, this first stage favors the development of algebraic thinking, precisely because it allows students to mobilize prior knowledge in order to *represent* contexts in algebraic language (Ponte; Branco; Matos, 2009). This helps clarify whether students are able to build a symbolic representation. In addition, this first stage allows us to verify the demand for *reasoning*, involving the generalization of contextual numerical data into algebraic forms, which enables *solving problems* (Ponte; Branco; Matos, 2009).

2nd stage – formation of the concept: this second stage covers the conceptual approach to the mathematical content/subject to be introduced. Thus, Proença (2021) suggests that the teacher should propose activities based on the use of examples, non-examples, and the identification of characteristics related to the concept. Thus, at this stage, students will develop their *mental constructs* regarding their understanding of the conceptual aspect of the content studied. At this stage, algebraic thinking for systems of 1st degree linear equations takes up more space to be developed, since the demands of *representing* and *reasoning* end up being favored.

3rd stage – definition of the content: at this stage, the teacher's work involves presenting the definition and the algorithms related to the content addressed. In this sense, Proença (2021) emphasizes that the teacher should be concerned with establishing relationships between formal mathematical language and the language adopted in the concept formation stage. This can be done through collective debates discussing understandings of mathematical structures, arriving at syntheses of the adopted representations. At this stage, the demand to *represent* must be brought in, given the use of mathematical symbols, and the demand to *reason* is favored, since students must operate with equations and systems of equations.

4th stage – application to new problems: according to Proença (2021), in this last stage, the teacher should approach their classes by proposing new and different situations that are understood as new or possible problems. Thus, the objective will be to verify the transfer of learning of the mathematical concepts and algorithms studied, evaluating how students come to develop the four stages of problem solving and their respective knowledge. In this panorama, the mathematical situations must be contextualized by referring to different themes and areas, such as biology, science, politics, economics, social life, among others. In this last stage, the demands of *representing* and *reasoning* are required, in view of how students attribute symbols to the contexts involved and how they operate with them in the form of systems of 1st degree equations. Thus, the demand to *solve problems and model situations* highlights students' capacity to use the knowledge they have built.

4. Methodology

This is qualitative research in the form of pedagogical research. According to Souza e Kerbauy (2017), qualitative research aims to present, treat, and understand social contexts. Lankshear e Knobel (2008) state that pedagogical research is conducted through the teacher's professional practice with the aim of addressing questions, concerns, and/or problems identified by the teacher.

The participants in our research were 28 students (15 female and 13 male, all under legal age) from an 8th-grade elementary school class in a public school in a city in the Midwest of the state of Paraná, in which the teacher-researcher of this study (first author) was also the mathematics teacher. In order to preserve the identity of the participants, in the analysis of results we will name each individual according to the class diary, calling them A1, A2, A3, and so on.

In our research, the data collection instruments we adopted were the record sheets of the students' nine activities, which made up our teaching proposal. "Records that collect written data from

the participant's point of view can offer useful clarifications about their thoughts" (Lankshear; Knobel, 2008, p. 215). The data collection procedure took place throughout the development of these nine activities.

Thus, our teaching organization proposal followed the 4 Stages of Proença (2021), focusing on problem solving to develop the content of systems of 1st degree equations, also aiming at the development of algebraic thinking. We used 14 50-minute classes, between September 20, 2023 and October 10, 2023. In this sense, Chart 1 below shows Activity 1, which covered the 1st stage of **using the problem as a starting point** of our teaching organization for the content of systems of 1st degree equations:

Chart 1 – Activity 1 – stage 1 - using the problem as a starting point

Activity 1 Notes: - Pair activity. - Solve it as you like it (what you find more convenient). - If you find the solution, do not say the answer out loud or show it to other pairs. - Cell phones and calculators are not allowed. **Mathematics situation** Two online platforms are used to study mathematics in Mariana's school. For this quarter's grade, Mariana had to answer a total of 12 questions from these platforms. Each question of the *Super Quiz Platform* was worth 1 point, and each question of the *Math Academy Platform* was worth 3 points. Mariana answered all 12 proposed questions correctly, obtaining 28 points as the final grade for the activities carried out. How many questions from each online platform did Mariana hit?

Source: The authors.

Through Chart 1, we see that the guidelines for Activity 1 were for students to be divided into pairs, being able to solve the proposed mathematical situation however they wanted, without using cell phones or calculators and without communicating with other pairs. This activity was carried out in 2 50-minute classes and included the actions of *introducing the problem, assisting students during the resolution, discussing students' strategies, and articulating students' strategies with the content*, proposed by Proença (2018).

Chart 2 below brings to light Activities 2 to 6, which involved the 2nd stage of **formation of the concept** of our teaching organization, which lasted 4 50-minute classes:

Chart 2 – Activities 2 to 6 – stage 2 - Formation of the concept

<table>
<tr><th colspan="2">Activity 2</th></tr>
<tr><td>a) Table 1 below shows only 1st degree equations with one or more variables.

QUADRO 1
$I)\ x + 3 = 5$
$II)\ 3x - y = 9$
$III)\ a + 2b - 3{,}7c = \frac{5}{8}$
$IV)\sqrt{2}\,m + 4n + \frac{p}{7} = 10$

What characteristics do you observe that a first degree equation can have?</td><td>b) Now, Chart 2 brings an equation that ARE NOT 1st degree equations:

QUADRO 2
$I)\ x^2 + 9 = 12$
$II)\ 3a - 2{,}6$
$III)\ 5x^3 + 2x^2 + \sqrt{3}\,x = 0$
$IV)\ 10\,w - \frac{8}{t} = 2$
$V)\ 3x - 1$

What characteristics do you observe that a first degree equation CANNOT have?</td></tr>
<tr><td colspan="2">Activity 3
Give an example:
a) From a first degree equation with a variable.
b) From a first degree equation with two variables.
c) From a first degree equation with three variables.
d) From an equation that is not of the first degree.

Activity 4
Let us resume the system of equations of the 1st degree seen in the problem of online platforms that we studied in previous classes:
$\begin{cases} q + m = 12 \\ q + 3m = 28 \end{cases}$
What characteristics do you observe that a system of first degree equations can have?

Activity 5
Give an example:
a) From a system of equations of the 1st degree with two equations and two variables.
b) From a system of equations of the 1st degree with three equations and three variables.

Activity 6
In view of what you have studied in the last classes, write in your own words what you mean by:
a) First degree equation.
b) Systems of equations of the 1st degree.</td></tr>
</table>

Source: Reorganized from Luz (2023, p. 101-103).

Through Chart 2, in accordance with what Proença (2021) recommends, we verified that Activities 2 and 4 sought to bring, respectively, students' comprehension and understanding regarding the characteristics of a 1st degree equation and a system of 1st degree equations. In Activities 3 and 5, the students were able to propose examples and non-examples of these concepts covered. Finally, Activity 6 guided a moment in which the participants could bring a definition (mental construct) for a 1st degree equation and for a system of 1st degree equations. Moving on, Chart 3 below shows Activities 7 and 8 of the 3rd stage of **defining the content** of our teaching organization, which lasted 4 50-minute classes:

Chart 3 – Activities 7 and 8 – Defining the content

Classification of a system of equations of the 1st degree

The following table shows the classifications, possible abbreviations of a linear system in relation to its solution:

Classification	Abbreviation	Solution
Possible and Determined System	PDS	It admits a single solution.
Possible and Indeterminate System	PID	It admits infinite solutions.
Impossible System	IS	It does not admit solutions.

RESOLUTION METHODS

Substitution Method

Activity 7

With the help of your teacher, solve and classify the systems of equations of the following 1st degree, using the substitution method.

$A)\ \begin{cases} x + y = 9 \\ x + 2y = 14 \end{cases}$ $B)\ \begin{cases} 4x + y = 1 \\ 2x - y = -1 \end{cases}$

Now it's your turn. Solve and classify the systems of equations of the 1st degree below using the substitution method. If in doubt, ask the teacher for help.

$C)\ \begin{cases} x + y = -5 \\ x - y = -1 \end{cases}$ $D)\ \begin{cases} 2x + y = 21 \\ x - y = 9 \end{cases}$

Addition Method

Activity 8

With the help of your teacher, solve and classify the systems of equations of the following 1st degree, using the addition method.

$A)\ \begin{cases} x + y = 4 \\ 2x + 3y = 9 \end{cases}$ $B)\ \begin{cases} x + y = 10 \\ 3x - 2y = 30 \end{cases}$

Now it's your turn. Solve and classify the systems of equations of the 1st degree below using the addition method. If in doubt, ask the teacher for help.

$C)\ \begin{cases} x + 3y = 12 \\ 2x - y = -11 \end{cases}$ $D)\ \begin{cases} x - y = -5 \\ x + y = -7 \end{cases}$

Source: The authors.

We observe from Chart 3 that, in this 3rd stage, the teacher-researcher introduced the class by discussing the classification of a system of 1st degree equations and then worked on the resolution algorithms – the substitution method (Activity 7) and the addition method (Activity 8). Finally, Chart 4 below brings Activity 9, referring to the 4th stage of **application to new problems** of our teaching organization, which also lasted 4 50-minute classes:

In Chart 4, we found that Activity 9 has 4 mathematical situations (possible problems) equivalent to systems of 1st degree equations studied by our students during classes. Items *a* and *d* were prepared by the teacher-researcher, with item *d* containing superfluous information that is not relevant to solving the problem. Items *b* and c, in turn, were adapted from the 2022 Paraná Test, an assessment designed as a diagnostic evaluation applied quarterly by the Paraná State Department of Education (Seed-PR). So that the mathematical situations presented could be understood as problems, the response alternatives from the original test were suppressed. In this scenario, Activity 9 aligns with the guidelines of Proença (2021), who points out that, at this stage, the student must have contact with a range of new mathematical situations so as to transfer the mathematical concepts and algorithms they have learned in order to solve these possible problems.

Given the activities developed and the data collected on them, the data analysis was based on descriptive-analytical and interpretative analysis. According to Gil (2007), descriptive analysis allows the characteristics and relationships of a phenomenon or population to be described and analyzed. Rosenthal (2014), in turn, elucidates that interpretative analysis allows the researcher other ways of looking at the phenomena studied, building correlations and meanings.

Chart 4 – Activity 9 – Application to new problems

Activity 9
Solve the following math situations:
a) Antônia loves shopping on the *Shanghai China Store* website. As this month is her grandson Frederico's birthday, she wants to buy him shirts and pairs of socks as a gift. In this way, she saw that the website of the store she surveyed sold two kits with the gifts she would like to give him:
Kit 1: A *Beijing* shirt and a pair of *Hong Kong* socks – Total: 30 reais.
Kit 2: Two *Beijing* shirts and three pairs of *Hong Kong socks* - Total: 67 reais.
What is the value of a *Beijing* shirt and a pair of *Hong Kong* socks sold by *Shanghai Store?*

b) (2022 PARANÁ TEST – Adapted) In a cosmetics store, two promotional packages are being sold, whose products and prices are presented below.

2 deodorants and 1 moisturizing cream R$ 52.50	1 deodorant and 2 moisturizing cream R$ 49.50

Regardless of the package, the unit price of each deodorant is the same, as is the price of each moisturizing cream. Determine the unit values of the deodorant and moisturizer sold in these promotional packages.

c) (2022 PARANÁ TEST – Adapted) Lúcia went to a cafeteria and bought a cheese pastel and a can of soda, paying R$10.00 in total. Bernardo went to the same snack bar and bought his family 20 cheese pastries, the same as the ones Lúcia bought, and 5 cans of soda, paying a total of R$140.00. Lucia and Bernardo paid the same price for each can of soda and the same amount for each pastry. What was the price, in reais, of each can of soda that Lucia and Bernardo bought at this snack bar?

d) Yesterday Antonieta turned 13 and to celebrate she went to the movies at 7 pm with her best friend. There, Antoinette bought a lemon soda and a bag of popcorn for a total of 18 reais. Her friend bought 3 lemon sodas and a bag of popcorn for 30 reais. What was the value of the lemon soda and the bag of popcorn in the cinema that Antoinette and her friend went to?

Source: The authors.

5. Analysis and discussion of the results

To carry out the 9 proposed activities of our teaching organization, students were divided into 15 groups (13 pairs and 2 students individually – by the participating students' own choice). Chart 5 below shows students' performance in solving the problem proposed as a starting point in Activity 1:

Chart 5 – Resolution of activity 1 of stage 1

Groups		**Stage of problem resolution**				**Resolução**	
Number	*Students*	*Rep.*	*Plan.*	*Exec.*	*Monit.*	*Strategy*	*SF*
1	2 and 35	√	√	√	√	TAB+TE	√
2	4 and 9	√	√	√	√	TAB+TE	√
3	5 and 28	√	√	√	√	TE	√
4	6 and 23	√	√	√	√	TE	√
5	7 and 13	√	√	√	√	TE	√
6	8 and 31	√	√	√	√	TE	√
7	10 and 17	√	√	√	√	TE	√
8	12 and 16	√	√	√	√	TE	√
9	14 and 15	√	√	√	√	TE	√
10	18	√	√	√	√	TAB+TE	√
11	19 and 20	√	√	√	√	TAB+TE	√
12	21	√	√	√	√	TE	√
13	22 and 32	√	√	√	√	TE	√
14	26 and 30	√	√	√	√	TAB+TE	√
15	27 and 33	√	√	√	√	TE	√

Caption:
Rep: Representation; Plan: Planning; Exec: Execution; Monit: Monitoring;
Tab: Table; TE: Trial and Error; SF: Final Solution.

Source: The authors.

Through the chart above, we can observe that all groups succeeded in solving the proposed problem, correctly carrying out the 4 stages of problem solving (representation, planning, execution, and monitoring). In addition, of the 15 participating groups, 10 used the trial-and-error strategy, and 5 used the strategy of building a table with trial and error to reach the final solution.

The use of these strategies initially reveals the need for an evolution in the demand to **solve problems and model situations** of these students' algebraic thinking, because even though they had already studied the content of the 1st degree equation at school, no research group used the strategy of writing an equation for the proposed problem. This result was observed in the study by Sousa e

Proença (2019), who investigated 7th-grade elementary school students and showed the predominance of the trial-and-error strategy in solving the proposed problems on 1st degree equation content. This may possibly be due to a teaching approach in which these students only solved exercises involving polynomials, equations, algebraic expressions, etc., solely to apply algorithmic procedures. Thus, it may be that the students had little contact with contextualized problems in which the algebraic concept must be mobilized.

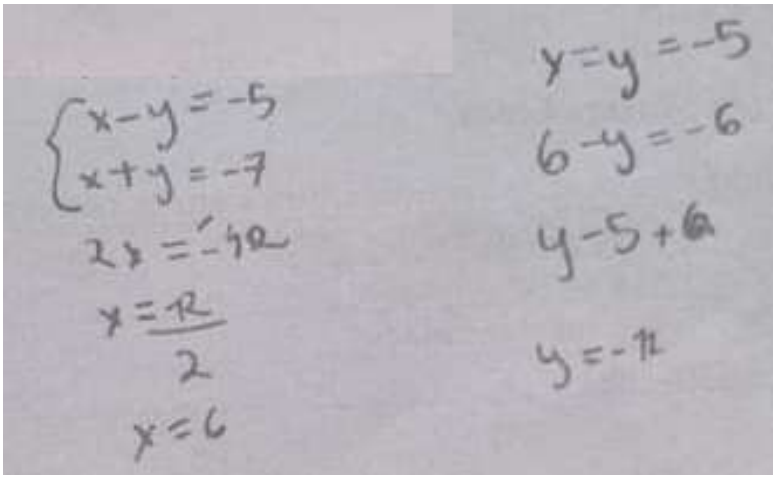
Chart 6 below brings to light students' performance in carrying out the activities of stage 2 of conceptual formation:

In Activities 2 to 6 above, we can verify that the investigated groups were able to identify characteristics and also give examples and non-examples of 1st degree equations and systems of 1st degree equations and, at the end, present a definition of the concept (mental construct) of the content studied. This indicates a development of the demands to **represent** and **reason** of algebraic thinking, given that students were able to recognize and interpret concepts of systems of 1st degree equations, as well as generalize this concept through examples and non-examples. Conceptual formation work on the content of linear systems with 2nd-year high school students, carried out by Luz (2023) and Luz e Proença (2025), obtained similar results for the individuals surveyed, revealing the maturation of algebraic thinking regarding this content, inherent to conceptual formation. In view of this, we can point out that this work in Stage 2 of the teaching organization via problem solving of Proença (2021) showed potential to develop the formation of the concept of equations and systems of 1st degree equations, allowing students to evolve in the demands of **representing** and **reasoning**.

Chart 7 below elucidates how students performed in carrying out Activities 7 and 8 in stage 3 of defining the content:

Through Chart 7, we see that most groups of participating students solved the systems of 1st degree equations correctly, both by the substitution method and by the addition method, showing that they established relationships between formal language and the conceptual formation worked on in the previous stage. However, we had students who were unsuccessful due to obstacles encountered in algebraic calculations. Figure 1 below shows the difficulties of students A08 and A31 in solving Activity 8-d:

Figura 1 – Difficulties of students A08 and A31 in activity 8-d



Source: The authors

We verify in Figure 1 that students A08 and A31 used the addition method in Activity 8-d, but made a mistake when dividing the number -12 by 2, giving it a positive sign and finding the incorrect value x=6. Continuing, in the second equation, the students, in addition to substituting the incorrect

Chart 6 – Resolution of activities 2 to 6 of stage 2

Activity 2		
Command	*Characteristics of the concept*	*Number of groups*
a) Point out characteristics of a 1st degree equation.	It has letters.	4
	It has numbers.	4
	It has letters and numbers.	6
	It has real numbers.	3
	Has decimals/numbers with a comma.	7
	It has fractions.	8
	It has roots/square root.	7
	We can use different letters.	8
	Letters repeat in the same equation.	1
	The greatest exponent of the letter is 1.	10
	All equations have an equal sign.	11
b) Point out characteristics of an equation other than being a 1st degree.	There is no equal sign.	12
	The letters have an exponent other than 1.	14
	There are letters in the denominator.	13
	The letters have exponents 2.	5
	No answer.	1
Activity 3		
Give an example	*Responses*	*Number of groups*
a) From a first degree equation with a variable.	They presented the example correctly.	15
	They presented the example incorrectly.	00
b) From a first degree equation with two variables.	They presented the example correctly.	12
	They presented the example incorrectly.	03
c) From a first degree equation with three variables.	They presented the example correctly.	13
	They presented the example incorrectly.	02
d) From an equation that is not of the first degree.	They presented the example correctly.	15
	They presented the example incorrectly.	00
Activity 4		
Systems of equations of the 1st degree		
Characteristics listed		*Number of groups*
All equations are of the first degree		*6*
The letters are the same/repeat in the equations		13
They have a key.		8
They have letters.		5
All variables have exponent 1.		7
They have an equal sign.		5
It has addition and subtraction operations.		3
Activity 5		
Give an example	*Solution*	*Number of groups*
a) From a system of equations of the 1st degree with two equations and two variables.	They presented the example correctly.	12
	They presented the partially correct example (missing keys and equality sign).	2
	They didn't do them.	1
b) From a system of equations of the 1st degree with three equations and three variables.	They presented the example correctly.	10
	They presented the partially correct example (with 3 equations and 2 variables).	4
	They didn't do them.	1
Activity 6		
Write	*Responses/ideas listed*	*Number of groups*
a) With your words, what is a first degree equation.	It has letters	09
	It has an equal sign	09
	It has unknown values.	02
	Variables have exponent 1.	10
	No answer.	01
b) With your words, what is a system of equations of the 1st degree.	A set of equations of the 1st degree.	11
	The letters repeat in the equations.	03
	They have a key.	03
	No answer.	03

Source: The authors.

value of x, also failed to use the equal sign in the third line of the equation, and, finally, the value found as y=-11 was mistaken. These obstacles in **procedural knowledge** indicate the need for an evolution in the **reasoning** demand of algebraic thinking pointed out by Ponte, Branco and Matos (2009), given the students' difficulty in understanding the rules and algorithms for the algebraic manipulation of a 1st degree equation.

Chart 7 – Resolution of activities 7 and 8 of stage 3

Activity 7			
Resolve and classify SE using MS	*Performance*	*NG*	*Difficulties*
$C)\ \begin{cases} x + y = -5 \\ x - y = -1 \end{cases}$	Correct resolution	14	-
	Incorrect resolution	01	Errors in algebraic calculations.
	They didn't do them.	00	-
$D)\ \begin{cases} 2x + y = 21 \\ x - y = 9 \end{cases}$	Correct resolution	09	-
	Incorrect resolution	03	Errors in algebraic calculations.
	They didn't do them.	03	-
Activity 8			
Resolve and classify SE using MA	*Performance*	*NG*	*Difficulties*
$C)\ \begin{cases} x + 3y = 12 \\ 2x - y = -11 \end{cases}$	Correct resolution	11	-
	Incorrect resolution	03	Errors in algebraic calculations.
	They didn't do them.	01	-
$D)\ \begin{cases} x - y = -5 \\ x + y = -7 \end{cases}$	Correct resolution	09	-
	Incorrect resolution	03	Errors in algebraic calculations.
	They didn't do them.	01	-

Caption:
SE: System of equations of the 1st degree.; MS: Substitution method;
MA: Addition method; NG: Number of groups.

Source: The authors.

A similar result occurred in the study by Silva (2014, p. 15), since, when investigating this same mathematical content with 8th-grade elementary school students, the author observed that they presented "difficulties in understanding the subject with regard to letters, terms, sign changes when there is a change of term, and the resolution process". Thus, the difficulties in Stage 3 can be understood in the sense that, although the class teacher (first author) had debated students' errors in operating with the algorithm involving equations, we understand that their errors in this activity could have been discussed further.

Finally, Chart 8 shows the performance of the surveyed groups in solving Activity 9 of stage 4 of application to new problems.

When we observe Chart 8, with the resolution of Activity 9, in which students solved new problems equivalent to systems of 1st degree equations, we see that most students chose the resolution strategy using the addition method or the substitution method. When we compare this data with Chart 5, in which the groups solved Activity 1 using the problem as a starting point, mostly adopting the trial-and-error strategy, we have an indication of an evolution in the demands to **represent, reason,** and **solve problems** of algebraic thinking.

In addition, observing the stages of problem solving, we see that the individuals succeeded in the representation and planning stages of problem solving, with the development of **semantic**, **schematic,** and **strategic knowledge**. This was possible because we identified that they were able to understand the proposed problems, making the transition from written language to algebraic language, writing the equivalent systems of equations. In addition, they chose the appropriate resolution strategy for the systems of equations found. However, we observed that some groups had difficulties in the execution and monitoring stages along the path taken to solve the proposed problems. Figure 2 elucidates how these difficulties of students A09 and A25 occurred when solving item c of Activity 9:

From Figure 2 above, we verified that students A09 and A25 correctly wrote the system of 1st degree equations equivalent to the proposed problem and used the addition method strategy to solve it. Thus, the students correctly found the value of the pastel to be y=4 reais. However, in the calculation from the second to the third line, they made a mistake and divided 10 by -4, when the correct operation would have been the subtraction 10-4, evidencing difficulties in the use of **procedural knowledge.** Thus, the students found x=-2.5, which is an inadequate value for the price of the pastel and, even so,

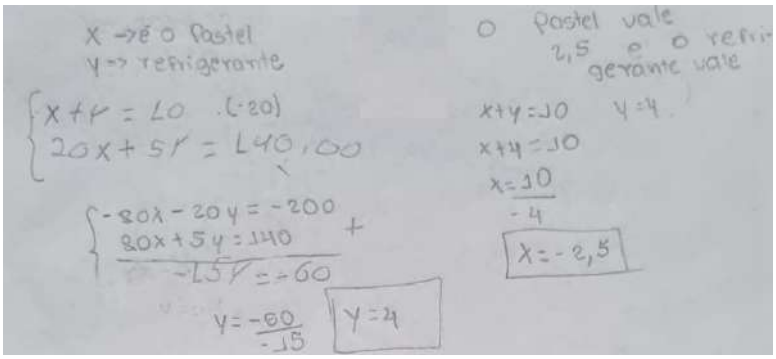
Chart 8 – Resolution of activity 9 of stage 4

Stages of problem-solving						
Activity 9	*REP.*	*PLAN.*	*EXEC.*	*MONIT.*	*Estrategy/ adopted procedure*	*SF*
a) *SE expected:* $\begin{cases} x + y = 30 \\ 2x + 3y = 67 \end{cases}$ *Expected response:* Socks: 7 reais. Shirt: 23 reais.	☑ 15 X 00 NF 00	☑ 15 X 00 NF 00	☑ 10 X 05 NF 00	☑ 10 X 05 NF 00	MA: 09 MS:05 TE: 01	☑ 10 X 05 NF 00
b) *SE expected:* $\begin{cases} 2x + y = 52{,}50 \\ x + 2y = 49{,}50 \end{cases}$ *Expected response:* Deodorant: 18.50 reais. Cream: 15.50 reais.	☑ 15 X 00 NF 00	☑ 15 X 00 NF 00	☑ 13 X 02 NF 00	☑ 13 X 02 NF 00	MA: 08 MS: 07	☑ 13 X 02 NF 00
c) *SE expected:* $\begin{cases} x + y = 10 \\ 20x + 5y = 140 \end{cases}$ *Expected response:* Soda: 4 reais.	☑ 15 X 00 NF 00	☑ 15 X 00 NF 00	☑ 10 X 05 NF 00	☑ 07 X 08 NF 00	MA: 10 MS: 05	☑ 07 X 08 NF 00
d) *SE expected:* $\begin{cases} x + y = 18 \\ 3x + y = 30 \end{cases}$ *Expected response:* Soda: 6 reais. Popcorn: 12 reais.	☑ 14 X 00 NF 01	☑ 14 X 00 NF 01	☑ 14 X 00 NF 01	☑ 13 X 01 NF 01	MA: 10 MS: 04 NF 01	☑ 13 X 01 NF 01

Caption:
SE: System of equations of the 1st degree. Rep: Representation; PLAN: Planning; EXEC: Execution; MONIT: Monitoring; MA: Addition method; MS: Substitution method; SF: Final Solution; ☑: Correct; X: Incorrect; NF: Did not do

Source: The authors.

Figura 2 – Difficulties of students A09 and A25 in activity 9-c



Source: The authors

they did not notice this fact, recording it as the value found in their final answer. Because of this, the group presented difficulties both in the execution stage and in the monitoring stage of the proposed problem.

Similar results occurred in the studies by Lima e Abreu (2025), when working with the content of quadratic equations, and Roberts e Le Roux (2019) and Luz e Proença (2025), in the teaching of systems of equations, in which they pointed out students' difficulties in operating with algebraic symbols and performing arithmetic operations. These studies indicated the need for the teacher to help their students, such as by revisiting numerical forms to help them understand the procedures involved. In our study, the difficulties in Stage 4 were not overcome by some groups, which may stem from something in the previous Stage 3, such that there should be work to review difficulties at the end of that Stage 3. Therefore, this is something our study should follow up on in future teaching proposals.

6. Conclusion

This research aimed to reveal *the potentialities and challenges in the development of a teaching proposal via problem solving for the learning of systems of 1st degree equations by eighth-grade elementary school students.* To achieve the proposed objective, we made use of Proença (2021)'s proposal of teaching organization via problem solving, based on four stages: use of the problem as a starting point, formation of the concept, definition of the content, and application to new problems.

Regarding stage 1, *Use of the Problem as a Starting Point*, we observed that all 15 groups surveyed correctly solved the proposed problem. However, they adopted a trial-and-error strategy, indicating the need to develop the demand to **solve problems and model situations** of algebraic thinking. Regarding stage 2, *Formation of the Concept*, we found that the participants were able to correctly point out characteristics of examples and non-examples of the content studied, leading to an understanding of the mathematical form of systems of 1st degree equations, as well as of a mental construct coherent with the mathematical concept. Thus, we could observe an evolution of the demands to **represent** and **reason** in algebraic thinking.

Stage 3, *Definition of the Content*, in turn, showed that most students were successful in using the substitution and addition resolution methods for systems of 1st degree equations, indicating that they were able to establish relationships between the formal aspects of this content and the conceptual formation of stage 2. However, some groups made mistakes in algebraic calculations, indicating difficulties in applying **procedural knowledge** and in the **reasoning** demand of algebraic thinking.

Finally, in stage 4, *Application to New Problems*, we found that most of the participating groups correctly wrote the system of 1st degree equations equivalent to the proposed problems, adopting the algebraic resolution strategy (substitution method and/or addition method) as the path to be followed in search of the answer to the mathematical situation presented. This indicates an evolution of the demands to **represent** and **reason** in algebraic thinking, in contrast to what we saw in stage 1. However, as occurred in stage 3, we again had some groups with difficulties in algebraic calculations and in evaluating the final answer to the proposed problems. These results showed difficulties yet to be overcome in the use of **procedural knowledge** in the execution stage and in the attitude of reviewing this knowledge in the monitoring stage of problem solving.

However, we can point out that we achieved our objective, since, in developing the teaching proposal, our research revealed both potentialities and challenges. Regarding the potentialities, it was possible to foster advances in the comprehension, understanding, and construction of the concept of systems of 1st degree equations and the algorithmic processes involved. Thus, this culminated in the advancement of the conceptual and procedural knowledge of the students surveyed. In this sense, we had indications of the construction of the demands of algebraic thinking that are important for school development in the discipline of mathematics.

Regarding the challenges, already in Stage 1, the students did not mobilize algebraic strategies related to the use of 1st degree equations, which were previously studied content. Another challenge was that, even though procedural knowledge had been addressed in Stage 3, some groups had difficulties with this knowledge in operating with the equations in the system of equations. Still with regard to the students, another challenge was that, in Stage 4, the mobilization of procedural knowledge and the monitoring of the resolution followed did not occur as expected on the part of some groups. Thus, the demands of algebraic thinking to reason still need to be developed. Finally, we understand that the development of the teaching proposal poses challenges in two respects: we could have asked the students to try to propose an algebraic strategy at the end of Stage 1, which would have helped us understand in depth whether their knowledge of the use of equations was in fact not well formed; and we could have reviewed, with greater emphasis, from the groups that had difficulties, the errors in performing algebraic calculations and the absence of monitoring of their resolutions.

Regarding the scientific research carried out in this pedagogical context, we can point out a contribution in relation to studies that used the problem as a starting point, which is the focus on conceptual formation. Proença (2021)'s proposal of teaching organization via problem solving allows us to investigate how students build knowledge of the concept of a 1st degree linear equation, and not only procedural knowledge (as is done in the traditional way of teaching), in order to then analyze the use of this knowledge in contextualized situations. Thus, both from a pedagogical and a scientific research perspective, our study shows a contribution to the evolution and development of the mathematical concept addressed within the scope of problem solving and the development of algebraic thinking.

Finally, future studies could take these challenges faced by students and teaching into account in order to organize teaching proposals via problem solving in the view of Proença (2018, 2021), one of which would be to seek to understand whether students know how to use prior knowledge such as 1st degree equations. Another important aspect would be to incorporate a post-test type assessment some time later to measure students' understanding. If this is done, we can help improve students' performance on large-scale tests such as Prova Brasil and state tests, as well as the PISA test.

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Not applicable / These research data have not been published in the data repository; however, the authors are committed to sharing them if the reader is interested.

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