Articles Section
2025, Volume 7, e2025012
Pages 1–12
10.33532/revemop.e2025012

revemop
ISSN 2596-0245

Hypothetical learning trajectories and mathematical modeling: enhancing critical education in Youth and Adult Education

Trajetórias Hipotéticas de Aprendizagem e Modelagem Matemática: Potencializando a Educação Crítica na EJA

Trayectorias hipotéticas de aprendizaje y modelización matemática: potenciando la educación crítica en la Educación de Jóvenes y Adultos

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Abstract
This article presents a reflection on the articulation between critical mathematics education (CME) and Youth and Adult Education (YAE), based on pedagogical experiences developed in a municipal school located on the outskirts of São Paulo. The research, qualitative in nature and grounded in action research, was conducted with YAE students and guided by the perspective of hypothetical learning trajectories (HLT) and mathematical modeling. The activities involved the investigation of everyday school and community problems, providing students with more contextualized and meaningful learning. The results indicate that the integration of CME, HLT, and mathematical modeling contributed to the development of critical thinking and the strengthening of student agency, revealing the power of a mathematics education committed to citizenship formation.
Keywords: Critical Mathematics Education. Mathematical Modeling. Youth and Adult Education. Hypothetical Learning Trajectories.

Resumo
Este artigo apresenta uma reflexão sobre a articulação entre a Educação Matemática Crítica (EMC) e a Educação de Jovens e Adultos (EJA), com base em experiências pedagógicas desenvolvidas em uma escola municipal da periferia de São Paulo. A pesquisa, de natureza qualitativa e fundamentada na pesquisa-ação, foi conduzida com estudantes da EJA e orientada pela perspectiva das Trajetórias Hipotéticas de Aprendizagem (THA) e pela Modelagem Matemática. As ações envolveram a investigação de problemas do cotidiano escolar e comunitário, proporcionando aos estudantes uma aprendizagem mais contextualizada e significativa. Os resultados revelam que a integração entre EMC, THA e Modelagem Matemática contribuiu para o desenvolvimento do pensamento crítico e para o fortalecimento do protagonismo dos estudantes, revelando a importância de uma educação matemática comprometida com a formação cidadã.
Palavras-chave: Educação Matemática Crítica. Modelagem Matemática. EJA. Trajetórias Hipotéticas de Aprendizagem.

Resumen
Este artículo presenta una reflexión sobre la articulación entre la Educación Matemática Crítica (EMC) y la Educación de Jóvenes y Adultos (EJA), con base en experiencias pedagógicas desarrolladas en una escuela municipal de la periferia de São Paulo. La investigación, de naturaleza cualitativa y fundamentada en la investigación-acción, fue realizada con estudiantes de la EJA y orientada por la perspectiva de las Trayectorias Hipotéticas de Aprendizaje (THA) y la Modelización Matemática. Las actividades involucraron la investigación de problemas cotidianos de la escuela y la comunidad, proporcionando a los estudiantes un aprendizaje más contextualizado y significativo. Los resultados indican que la integración entre la EMC, las THA y la Modelización Matemática contribuyó al desarrollo del pensamiento crítico y al fortalecimiento del protagonismo estudiantil, revelando la importancia de una educación matemática comprometida con la formación ciudadana.
Palabras clave: Educación Matemática Crítica. Modelización Matemática. Educación de Jóvenes y Adultos. Trayectorias Hipotéticas de Aprendizaje.

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1. Introduction

Youth and Adult Education (YAE) is a modality that historically presents itself as a reparative policy, aimed at subjects whose school trajectories were interrupted by processes of social, economic, and cultural exclusion (CNE/CEB, 2000; Arroyo, 2005). In Brazil, despite being legally recognized as rights, YAE still occupies a marginal place in the educational system, with a high dropout rate and fragmented public policies, which reveal a structural disregard for these subjects (Arroyo, 2005; Mesquita and Lessa, 2021).

YAE students, often rendered invisible by the school's statistics and hegemonic narratives, bring experiences marked by multiple forms of resistance. They are workers, mothers, migrants, people who face long daily hours and yet maintain the desire to study and build new life projects. However, when they arrive at school, they find a model that often reproduces the exclusionary logics that previously kept them away from the educational process.

In the context of mathematics teaching, these barriers seem to become even more evident. For YAE students, subjects often stand out as major challenges because they are associated with past experiences of failure, punishment, and devaluation. The traditional approach, unrelated to the real context, only reinforces the idea that mathematics is something inaccessible and far removed from people's experiences. From this perspective, there is a risk of perpetuating technical mathematics, restricted to memorizing algorithms and insensitive to students' prior knowledge and legitimate ways of understanding and interpreting the world.

Critical mathematics education (CME), as proposed by Skovsmose (2001, 2010), emerges exactly in this context as a transformative alternative. More than teaching content, CME seeks to train critical thinkers who can analyze, question, and transform their reality through mathematical knowledge. It assumes that all mathematical practice is embedded in social, cultural, and political contexts. Therefore, its teaching needs to take into account the meanings that mathematics assumes in people's lives.

However, implementing strategies that promote this debate in YAE classes, which bring together diverse experiences, requires sensitive and adaptable teacher planning. In this sense, the hypothetical learning trajectories (HLT) (Simon, 1995) can be seen as an essential element in building a teaching cycle that allows observation of students' learning paths.

The experience that gave rise to this text occurred in a municipal school on the outskirts of the northern zone of São Paulo, in a YAE class, during the professional master's degree in science and mathematics teaching. As a teacher-researcher at this school and with a strong connection to the community, we developed a didactic proposal aimed at meaningful learning. We investigated real problems faced by students, such as garbage, urban infrastructure, and collectivity in the school environment.

This article, therefore, focuses on an aspect of the research that does not cover the entire dissertation, prioritizing the practical articulation between the three theoretical pillars. To this end, this study seeks to answer the following research question: How can the articulation between critical mathematics education, mathematical modeling, and hypothetical learning trajectories strengthen the protagonism of YAE students in solving problem situations in everyday school life?

The introduction presents the text as organized into a literature review, which contextualizes the theoretical foundations; a methodological section, which details the procedures adopted in the research; the analysis and discussion of the results; and, finally, some considerations.

2. Literature review

2.1. Youth and Adult Education: contexts and challenges

Youth and Adult Education (YAE) is a space that highlights the need for pedagogical practices that value dialogue, respect for the subjects' experiences, and the promotion of citizenship. The theoretical foundation for this view is in Freire (1987), who defends problem-posing education.

In this sense, pedagogical practices must originate in students' reality, validating their knowledge as legitimate and providing opportunities for listening, dialogue, and transformation, focusing on critical reading of society and overcoming social injustices (Freire, 1987). Therefore, Freire says that awareness is a process that has everything to do with forming subjects who can act on the world rather than just adapting to it.

These obstacles intensify when it comes to teaching mathematics. Subjects are often associated with memorizing algorithms and past experiences of failure, which can fuel a cycle of insecurity and exclusion. According to the survey of academic production in the area conducted by Braga, Pereira, and Rôças (2022), research on YAE in mathematics remains poorly integrated across several fronts related to the theme. This result highlights the relevance and opportunity of investigations, such as this one, that seek to establish a clear connection between theoretical frameworks (such as CME and HLT) and specific pedagogical practices (such as mathematical modeling), to transcend traditional teaching in favor of appropriate approaches for YAE students.

2.2. Critical mathematics education: principles and implications

In the field of mathematics education, Skovsmose (2001) suggests critical mathematics education (CME), which challenges the notion that mathematics is neutral and sees it as a social practice. According to the author, mathematics teaching is a political act that can lead to emancipation or oppression, depending on how it is carried out.

Skovsmose (2012) therefore emphasizes the need for mathematical literacy that allows both understanding and intervention in a world characterized by mathematical aspects and relationships. Thus, the author argues that mathematical literacy should be understood as "the ability to interpret a world structured by numbers and figures, and the ability to act in this world" (Skovsmose, 2012, p. 19).

In this sense, instead of passing on ready-made, decontextualized content, CME proposes that knowledge be collectively built from real and meaningful situations. According to Skovsmose (2001), mathematics education must deal with three important types of mathematical knowledge: mathematical knowledge, technological knowledge, and reflective knowledge in order to form citizens.

Mathematical knowledge involves mathematical skills, including the understanding of algorithms and formulas, as well as the reproduction of proofs and demonstrations; technological knowledge refers to the application of mathematics and mathematical models; and, finally, reflective knowledge concerns the ability to reflect and evaluate the use of mathematics.

To put this into practice, Skovsmose (2011) suggests creating investigation scenarios, which are open-ended problem situations from real life, in which students are encouraged to use mathematics to understand and act in their context. This perspective is directly related to the idea of awareness proposed by Freire (1987) and seeks to strengthen students' protagonism.

2.3. Mathematical modeling in YAE

This critical view aligns with the fundamentals of mathematical modeling, which are not merely a didactic instrument but also a way to explore and understand everyday phenomena through mathematics (Barbosa, 2020; Loyola, 2019). Therefore, it is necessary to characterize it as an approach in which students themselves identify, define, and explore a relevant and significant problem situation for their context.

Loyola (2020; 2019) states that mathematical modeling should be seen as a way of interpreting and reframing reality, making the student a protagonist in the search for answers to everyday problems. In YAE's context, this practice becomes even more relevant, as much of the students' prior knowledge, experiences, and social demands are used to develop a critical understanding of the society in which they are inserted.

In addition, within CME's scope, mathematical modeling enables the articulation of mathematical knowledge with the critique of reality. As Barbosa (2004) points out, mathematical modeling enriches the perception of the phenomena being modeled, enabling subjects to question, analyze, and make informed decisions. It is a practice that goes beyond technical knowledge and advances towards citizenship and protagonism.

We cannot overlook the most recent contributions to modeling in critical contexts, which also support the formative character of modeling in YAE. According to Silva and Barbosa (2020), when modeling is based on real social issues, it enables students to mobilize mathematical knowledge and develop a critical discourse, particularly in contexts of social vulnerability.

2.4. Hypothetical learning trajectories: planning, conceptual fields, and meaningful learning

In the context of an education aimed at emancipation, as occurs in YAE, teachers' planning cannot do without tools that articulate pedagogical intentionality with the flexibility necessary to serve students. For this, the concept of hypothetical learning trajectories (HLTs) is fundamental.

According to Simon (1995), an HLT goes beyond a lesson plan; it is a conjecture that the teacher builds, articulating three main elements: a learning objective, a sequence of tasks designed for students to achieve this objective, and a learning hypothesis, which is a prediction about the reasoning, strategies, and difficulties that students may face.

We consider that the dynamic and cyclical nature of HLTs prevents rigid planning, enabling a planning that is always in motion, being continuously validated and restructured during the learning process, according to the interactions and productions of the students (Simon, 1995; Traldi and Ribeiro, 2025). Within YAE's context, in which previous experiences and knowledge are diverse, this flexibility is essential for education to really be a dialogue, and not something that is imposed, respecting the time and path of each subject, avoiding comparisons that standardize, and promoting a more attentive listening to the processes of knowledge construction.

In the course of our research, to sustain the initial proposal of the teacher-researcher and ensure a consistent pedagogical basis, it was indispensable to resort to the theory of conceptual fields, developed by Vergnaud (1997). According to this author, knowledge is not organized in isolated concepts, but in broad "conceptual fields", i.e., sets of problem situations, whose understanding and resolution require an interconnected network of concepts, theorems, and operative schemes.

Take, for example, the multiplicative conceptual field, which served as a theoretical-mathematical basis for the analysis of results. It is not only the algorithm of multiplication; there is a universe of other cases that go beyond this, including questions of proportion, combinatorial questions, and questions of rectangular configuration.

Based on the knowledge of the structure of this field, the teacher-researcher could elaborate an HLT with diverse tasks that addressed interconnected concepts, allowing students to build and/or reinforce more flexible and adaptable thought schemes. This allowed the teacher-researcher to both formulate hypotheses about learning and question whether a student was solving a proportionality problem using additive logic or was already applying a multiplicative scheme.

3. Methodological paths

3.1. Approach and design

The research adopts a qualitative approach and is based on action research (Tripp, 2005), combining pedagogical intervention and the production of scientific knowledge in a cyclical and reflective way. Action research is recognized as adequate for contexts in which the researcher acts directly in the investigated scenario, planning, executing, and evaluating teaching practices with the objective of solving real and relevant problems, especially in scenarios of social vulnerability and educational diversity.

The research was developed in a municipal school located on the outskirts of the northern zone of São Paulo, a context marked by significant socioeconomic vulnerability. The participating class consisted of 25 students from the final stage of YAE, aged between 18 and 65 years, most of whom were women who reconciled their studies with informal work and family responsibilities. His school trajectories were marked by interruptions and failures, especially in mathematics. To preserve their identities, the names used are pseudonyms.

The first author of this article worked as a teacher-researcher in a school on the outskirts of São Paulo, characterized by social vulnerability, urban occupations, lack of basic sanitation, poor public transport, and a lack of public facilities. Despite the challenges, the school is recognized by the community as a space for welcome, dialogue, and resistance.

3.2. Data production procedures

Data production took place with the help of three main instruments, enabling triangulation and a multifaceted perspective of the phenomenon studied:

i) Field diary of the teacher-researcher: systematic and reflective notes, prepared at the end of each meeting, about what happened in the classroom and outside it, interactions in class, relevant speeches of the students, questions, advances, difficulties, obstacles, and their impressions about the development of the tasks.

ii) Student records: consisting of a selection of writings and materials produced according to the activities performed, including drafts of calculations, tables, sketches, posters, and the final versions of the projects prepared in group.

iii) Audio records and transcriptions: recordings and transcriptions of the conversation circles and the final socializations of the projects, to faithfully capture the dialogues and the collective construction of meanings.

3.3. Development of investigative practice

The collaborative research was based on the articulation between mathematical modeling and hypothetical learning trajectories (HLTs), constituting a joint process of knowledge construction between the teacher and his students. The following steps are the materialization of the action research cycles.

a) HLT problematization and planning stage: in initial conversation circles, students recognized real problems in their daily school life and in the community, especially the accumulation of garbage and the irregular disposal of waste. Based on this problem, raised by the students, the teacher-researcher elaborated a first hypothetical learning trajectory. This HLT has already set, as an objective, the mobilization of concepts from the multiplicative field and measures, and has organized a sequence of tasks that included: surveying the problem, carrying out measurements, performing calculations, producing materials, and implementing the intervention. Possible obstacles were also identified in advance, including difficulties with the concept of proportionality.

b) Development and research stage: this stage served as the central cycle of action and observation.

- Action: students, in groups, actively participated in mathematical modeling. They focused on the problem, defined variables (number of rooms, size of bins, amount of cardboard, and adhesive tape), observed and measured to collect data, and began building their mathematical models (calculations and scale drawings).
- Note: The teacher acted as a mediator, following the students' strategies and recording in the field diary how learning compared to the planned HLT. The students' doubts and reasoning guided the necessary mediations with the groups.

c) Reflection and replanning step: the observation records of the previous step were analyzed to identify specific learning needs and recurrent or particular difficulties. HLT was redesigned from this analysis; that is, the tasks were adjusted, additional resources were offered, or there were specific and differentiated mediations for specific groups or students, all to maintain the responsiveness of the teaching process.

4. Protagonism and meaningful learning in mathematics in YAE

The interpretative analysis (Erickson, 1986) of the data reveals that the proposed articulation enabled a narrative in which mathematical concepts emerged naturally, from a project that originated from the daily experience of the school community.

The research scenario (Skovsmose, 2001) was established by the students after rounds of conversation and revolved around the accumulation of garbage, the lack of appropriate dumpsters, and the improper disposal of waste in the neighborhood. Thus, it was decided to create educational posters and carry out an awareness campaign. It is in this genuine and socially pertinent context that mathematical concepts, rather than being an obstacle, become necessary tools for action.

The first task was to plan the making of the posters. When faced with the teacher-researcher's question: "Well, considering that you decided to make 15 posters, how many cards do you think will be needed?", the students were thrown into the heart of the multiplicative conceptual field (Vergnaud, 1997).

Ana's answer, "*Each poster board can make two posters. Then, with eight cardstock sheets, we get 16 pieces, which is enough for 15 posters*", was not a mere calculation. His reasoning reveals an operative scheme, which articulates the notion of proportionality (1:2 ratio between poster board and posters) with excess estimation, that is, a strategy of managing resources, avoiding waste, and ensuring the success of the task, evidencing a practical knowledge that was valued and taken as a starting point for formalization.

Another group, when deepening the discussion on optimization, questioned whether 7.5 cardstock would be theoretically sufficient, prompting a conversation about the discrete nature of objects, the exact calculation, and the practical feasibility of material acquisition.

This first moment did not happen without challenges, which, foreseen in the HLT, became learning opportunities. Pedro's question, "I did not understand this relationship of repetition very well. Why do we need to multiply 2 by 8?" makes it clear that he did not understand multiplication as the action of repeating equal parts.

The mediation of the professor-researcher, who articulated the operation to the action of 'repeating the process of dividing the cardstock sheets', made it possible for Pedro to reach a more meaningful understanding, stating: "*Now I begin to see the connection. We are multiplying to repeat the process of dividing the cardstock sheets*". This episode illustrates meaningful learning in action, in which a formal concept is anchored in a concrete operation, breaking with decontextualized mechanics.

The project progressed to the step of calculating the materials and investigating the problem itself, in which the consolidation of concepts and the diversity of reasoning were evidenced. To find out how much duct tape he would need, Erika did a two-step multiplication: "*Five pieces of 20 cm per poster give 100 cm. Then, 100 cm times 15 posters give 1500 cm*".

Her strategy shows that she understands the operation structurally and applies it to solve a problem in parts. To conclude, she reflects on the fact that "*multiplication is a faster way to add several times*", which corroborates the idea that understanding the concept is a valuable and ef-

fective tool, going beyond simple memorization. On the other hand, Lucia's strategy, which made successive additions, was also validated. The acceptance of different records of semiotic representation (Duval, 2003) is critical in YAE, since it respects life stories and contributes to the construction of self-esteem (Mesquita and Lessa, 2021).

At the same time, other groups also mobilized mathematical knowledge contextually. While measuring the cardstock sheets (66 x 48 cm) and the sulfite sheets (30 x 21 cm) to plan the collage, they found the concepts of area and reason. Raquel said, "*We are multiplying half of the cardstock sheet by the size of the sulfite sheet to know how many sheets will be needed. Would it be like making 'small sets'?*"

The spontaneous expression "small sets" is an intuitive and significant approximation of the concept of Cartesian grouping and product, demonstrating the passage from concrete manipulation to mathematical abstraction. This thought, which Vergnaud (1997) would call a scheme under construction for situations of rectangular configuration, shows how a more elaborate mathematical thought originates from practical need.

In addition to the numbers, research on the issue of garbage mobilized students to draw on other knowledge, articulating mathematics with an interdisciplinary and critical view. They investigated and debated how long various materials take to decompose in nature, using numerical data to examine the effects of consumption and disposal on the environment.

Critical knowledge, according to Skovsmose (2001), is one in which mathematics is used to make an ethical reflection and to become aware. The articulation between numerical data and their socio-environmental repercussions is an example of this critical knowledge.

One of the most significant results of this course was the empowerment of students, both in solving tasks and making decisions, arguing, and reflecting critically on the process and the results obtained. This empowerment was reflected in observable changes, such as greater class attendance, increased inter-group collaboration, and, above all, an appreciation of one's own knowledge. One of the students said: "*This time, we didn't just talk about the problem... we did something. And when we see that it works, it makes us want to continue studying*". This speech summarizes this change from a passive attitude to that of a transformation agent.

Another student summarized how the subject gained a new meaning: "*I never imagined that I would make accounts to help the school. Now I see what this thing we learn is for.*" This speech shows how mathematics is no longer seen as an end in itself, but is increasingly understood, within a perspective of critical mathematics education, as an essential instrument for interpretation and performance in society.

The final socialization of the projects with the school community sealed this process. By detailing their models and choices, students put reflective and critical knowledge into practice (Skovsmose, 2001). Pedro's speech, "*Now we can associate the multiplicative concepts of repetition of additions, distributivity, and proportionality in our calculations*", demonstrates that he has already appropriated the mathematical vocabulary and can use it to reflect and communicate his thinking.

Another student summarized the resignification of the subject: "*I never imagined that I would make accounts to help the school. Now I see what this thing we learn is for.*" This speech highlights the overcoming of the vision of mathematics as an end, repositioning it as an instrument of symbolic power that students can mobilize to understand and change the dynamics of their living spaces.

5. Some considerations

The objective of this article was to understand how the articulation between critical mathematics education, mathematical modeling, and hypothetical learning trajectories can enhance the protagonism of Youth and Adult Education students. The analysis indicates that this articulation was pertinent to fostering meaningful learning and students' protagonism, as can be seen in the change in posture, their involvement, and their own speeches.

The shared experience shows that mathematical modeling, when grounded in problem situations from the school community's experience, overcomes its merely instrumental character. It constitutes a critical mathematical literacy tool (Barbosa, 2004), enabling students to go beyond the application of formulas and develop the ability to analyze and question their reality through mathematics critically.

The research on garbage at school, which resulted in posters and suggestions for actions that led to fundamental changes, made it possible for students to view notions of the multiplicative field, measures, and proportionality as proper instruments for action, not just as content to be learned.

In a complementary way, the HLT proved essential for teacher planning that is sensitive and responsive. Anticipating paths and obstacles, the HLT enabled the teacher-researcher to act not as a transmitter of knowledge but as a mediator who adjusts the route of the teaching and learning process in real time as the students' answers and reasoning emerged. This flexibility proved particularly appropriate for YAE, since it considered the different rhythms and trajectories of life, and received error as an integral part of the learning process.

The articulation of these perspectives, supported by the principles of critical mathematics education (Skovsmose, 2001), enabled the creation of a genuine research scenario (Skovsmose, 2000), in which technical, reflective, and critical mathematical knowledge could be mobilized in an integrated way.

Students exercised technical competence, the ability to reflect on their choices, and the ability to analyze the social impact of their actions when planning, calculating resources, and sharing their projects. The phrase "*Now I see what this learning is for*" represents the achievement of learning that confers meaning and dignity, being a fundamental principle for an inclusive mathematics education in YAE (Mesquita; Lessa, 2021).

It is important to emphasize that this study was conducted in a single context, which does not allow generalizations. However, the results indicate promising paths. As developments, we propose analyzing the same articulation in different YAE contexts, in addition to conducting research

on the training of teachers to work with this perspective, providing them with the necessary theoretical and practical support.

Finally, this study reiterates the feasibility and the need to develop a mathematical education in YAE that, by distancing itself from the mere transmission of content, is dedicated to the formation of critical subjects, protagonists in their own learning processes and able to use mathematical knowledge as a tool of symbolic power, which they can mobilize to understand and transform the dynamics of their life environments.

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Appendix – Editorial Details

Editorial History
Received: 26/02/2025.
Accepted: 23/07/2025.
Published: 25/10/2025.

How to cite – ABNT
CAMILO, Felippe; RIBEIRO, Rogério Marques. Hypothetical learning trajectories and mathematical modeling: enhancing critical education in Youth and Adult Education. **REVEMOP**, Ouro Preto/MG, Brazil, v. 7, e2025012, 2025. https://doi.org/10.33532/revemop.e2025012

How to cite – APA
Camilo, F., & Ribeiro, R. M. (2025). Hypothetical learning trajectories and mathematical modeling: enhancing critical education in Youth and Adult Education. *REVEMOP*, 7, e2025012. https://doi.org/10.33532/revemop.e2025012

Funding
Not applicable

Conflicts of Interest
The authors declare that there is no conflict of interest of a personal, commercial, academic, political, or financial nature regarding this article.

Contribuição dos Autores
Resumo/Abstract/Resumen: Felippe Camilo, Rogério Marques Ribeiro; **Introduction or First considerations:** Felippe Camilo, Rogério Marques Ribeiro; **Theoretical framework:** Felippe Camilo, Rogério Marques Ribeiro; **Methodology:** Felippe Camilo, Rogério Marques Ribeiro; **Data analysis:** Felippe Camilo, Rogério Marques Ribeiro; **Discussion of results:** Felippe Camilo, Rogério Marques Ribeiro; **Conclusion or Final considerations:** Felippe Camilo, Rogério Marques Ribeiro; **References:** Felippe Camilo, Rogério Marques Ribeiro; **Manuscript review:** Felippe Camilo, Rogério Marques Ribeiro; **Approval of the final published version:** Felippe Camilo, Rogério Marques Ribeiro.
CRediT – Contributor Role Taxonomy – https://credit.niso.org/.

Data Availability
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.

Review Process
Double-blind peer review

Reviewers
Two *ad hoc* reviewers evaluated this article and did not authorize the disclosure of their names.

Translation / Proofreading
This article was funded by the Minas Gerais State Research Support Foundation (Fundação de Amparo à Pesquisa do Estado de Minas Gerais–FAPEMIG), Project APQ-04960-23, Notice N. 008/2023–Support program for scientific and technological publications.