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Stimulating High School Student Creativity, Motivation, and Mathematics Performance with Classes Based on Creativity Techniques

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ABSTRACT

Background: Several countries and organisations highlight creativity when advocating an education connected to the current moment of scientific and technological progress we live, especially in the mathematics field. **Objectives**: We aim to answer the following questions: (a) Is senior high school students' creativity, motivation, and mathematics performance triad positively influenced by extracurricular mathematics classes based on creativity techniques? And (b) What are the different students' perceptions of mathematics based on the type of classes they received throughout the course (conventional classes and classes based on creativity techniques)? **Design**: To this end, we structured an experimental study to compare the results obtained from conventional classes to a control group and from classes based on creativity techniques to an experimental group. **Settings and participants**: The sample consisted of 41 senior high school students of a public school in the Federal District, Brazil, randomly selected after wide dissemination. **Data collection and analysis**: Initially, students underwent pre-tests (creativity in mathematics, motivation in mathematics, and performance in mathematics). Then, they participated in mathematics classes (conventional to the control group and based on creativity techniques to the experimental group). At the end of each class, they completed one step of the logbook. Finally, they were submitted to post-tests for direct comparison with the tests initially performed and participated in a conversation roundtable. Thus, the analysis included quantitative aspects of the results of the tests; and qualitative aspects of the study of the material written in the diaries and oral speeches during the conversation roundtable. **Results**: Although both groups increased their scores for the three variables investigated, statistically significant results were perceived only with the experimental group, which had all variables increased. We also found that the

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students recognised the classes based on creativity techniques as being good. **Conclusions**: This suggests that the class model investigated in this research may favour students' creative thinking ability and motivation, consequently increasing their performance in mathematics.

Keywords: Mathematics education; Creativity techniques; Creativity in mathematics; Motivation in mathematics; Performance in mathematics.

Estímulo à criatividade, à motivação e ao desempenho em matemática de estudantes do ensino médio a partir de aulas baseadas em técnicas de criatividade

RESUMO

Contexto: A criatividade tem sido destacada por diferentes países e organizações na defesa de uma educação conectada ao atual momento de progresso científico e tecnológico que vivemos e, em especial, quando analisamos a área da matemática. **Objetivos**: A partir desta pesquisa esperamos responder às seguintes perguntas: (a) a tríade criatividade, motivação e desempenho em matemática de estudantes do último ano do ensino médio é influenciada positivamente a partir de um curso extracurricular de matemática cujas aulas são baseadas em técnicas de criatividade? E (b) quais diferenças quanto às percepções dos estudantes em relação à matemática a partir do tipo de aulas que receberam ao longo do curso (aulas convencionais e aulas baseadas em técnicas de criatividade? **Design**: Para tanto, foi estruturada uma pesquisa experimental onde comparamos os resultados obtidos junto a aulas convencionais a um dado grupo controle e junto a aulas baseadas em técnicas de criatividade a um dado grupo experimental. **Ambiente e participantes**: A amostra foi composta por 41 estudantes do último ano do ensino médio de uma escola pública do Distrito Federal, Brasil, selecionados ao acaso a partir de ampla divulgação. **Coleta e análise de dados**: Inicialmente, os estudantes foram submetidos a pré-testes (criatividade em matemática, motivação em matemática e desempenho em matemática). Em seguida, participaram de aulas de matemática (convencionais ao grupo controle e baseadas em técnicas de criatividade ao grupo experimental), sendo que ao fim de cada encontro preencheram uma etapa do diário de bordo. Por fim, foram submetidos a pós-testes para comparação direta com os testes realizados inicialmente, bem como participaram de uma roda de conversa. Dessa forma, a análise contou com aspectos quantitativos no que se refere aos resultados dos testes; e com aspectos qualitativos no que se refere ao estudo do material escrito nos diários e das falas oralizadas durante a roda de conversa. **Resultados**: Embora ambos os grupos tenham alcançado elevação nos escores das três variáveis investigadas, resultados estatisticamente significativos foram percebidos apenas junto ao grupo experimental, o qual teve maior incremento em todas as variáveis. Além disso, encontramos aceitação por parte do alunado acerca das aulas baseadas em técnicas de criatividade. **Conclusões**: Isso permite sugerir que o modelo de aula investigado nesta pesquisa pode

favorecer tanto a capacidade de pensamento criativo como também a motivação e o consequente desempenho em matemática.

Palavras-chave: Educação matemática; Técnicas de criatividade; Criatividade em matemática; Motivação em Matemática; Desempenho em matemática.

INTRODUCTION

In some countries, the educational systems have been making great effort to stimulate their students' creativity, to shape citizens capable of dealing with the unknow in the professional, academic, and personal spheres. For example, entrepreneurs can leverage financial gains through creative actions, such as proposing new products or new marketing approaches, strengthening their business. If community leaders are creative, they can bring different ideas to enhance local or regional development or even gain the support of new collaborators. If children and young people are creative, they can apply the knowledge developed inside and outside school differently. Finally, creativity can strengthen the economy, social organisation, school and everyday life, among other contexts. And in a highly dynamic world, where updates are increasingly fast, creative thinking must be developed from early childhood. In this way, school education has a paramount influence in the process of creative thinking acquisition (Alencar & Fleith, 2003a; Amabile, 2012; Wechsler, 1998).

Various institutions defend that creativity is an essential skill for the 21st century, be it labour market and technological development institutions - such as the World Economic Forum (WEF, 2018)-, or those interested in broader school education - such as some educational guidelines in Australia, England, and Brazil (although the latter is still under construction). The Organisation for Economic Cooperation and Development (OECD), responsible for conducting the Programme for International Student Assessment (PISA), included in their 2021 test tasks to assess creative thinking – in other words, it is another global institution corroborating not just the need to shape more creative individuals in this century, but that this skill must be developed from school age.

Although the institutions have made an effort to insert activities that stimulate creativity in young people's education today, the issue is still not so observable when considering the specific fields of knowledge. In this research, we investigate creativity in the mathematics field.

Several studies by Fonseca (2019; 2015), Gontijo (2007), Haylock (1987), Kattou et al. (2013), Kwon, Park and Park (2006), Leikin and Pantazi

(2013), Lev-Zamir and Leikin (2013), Mann (2005), Nadjafikhaha and Yaftiam (2013), Pinheiro and Vale (2013), Sriraman (2004), and Valdés (2010), among others, defend promoting a mathematical education concerned with the development of creativity. Stimulating students' creative thinking is a way to prepare them to look for solutions to the new challenges that will arise in their lives, as it will contribute to the development of skills to solve problems from the knowledge already built, using different strategies in this process.

Moreover, investing in the development of creativity in the field of mathematics can contribute to reduce students' anxiety about this school discipline (Tobias, 2004), increase motivation to study in this area of knowledge (Fonseca; Gontijo; Zanetti, 2018; Gontijo, 2007), contribute to greater problem-solving capacity, among others. Certainly, creativity in mathematics also collaborates to rethink the classroom space, because creative thinking goes hand in hand with critical thinking (Lipman, 2003), leading to questions that can establish new ways of organising the pedagogical work, the class, and the other school areas.

To verify how the way of organising the pedagogical work with mathematics could favour the development of students' creativity in mathematics, we developed a research based on the following questions:

> 1. Is senior high school students' creativity, motivation, and mathematics performance triad positively influenced by extracurricular mathematics classes based on creativity techniques?
>
> 2. What are the different students' perceptions of mathematics based on the type of classes they received throughout the course (conventional classes and classes based on creativity techniques)?

These questions culminated in the construction of the following objective: to analyse the performance of two groups of senior high school students of a public school in the Federal District (Brazil) concerning creativity, motivation, and mathematics performance from two extracurricular mathematics courses that, despite dealing with the same subject, were operationalised from different methodological strategies (conventional classes - control group and classes based on creativity techniques - experimental group).

CREATIVITY IN MATHEMATICS

Although there is an increasing number of studies on creativity in mathematics, there is no single definition for this construct. Several researchers focused on this task, such as Ervynck (1991), Gontijo (2007), Haylock (1987), Kattou et al. (2013), Krutestkii (1976), Laycock (1970), Lee, Hwang, Seo (2003), Lev-Zamir and Leikin (2013), Livne and Milgran (2000, 2006), Mann (2005), and Sriraman (2005).

As an example of definitions, it is worth mentioning Laycock (1970), who defined mathematical creativity as an ability to analyse problems from different perspectives to generate multiple answers. Another definition was proposed by Ervynck (1991), who argued that creativity in mathematics does not develop “in a vacuum” (p. 42) but from a combination of known and unknown elements.

Aiken (1973) said that doing mathematics implies the need for creative thinking, although this can be obtained from knowledge and skills of innovative approaches and combining ideas in different ways to solve problems. This conception was corroborated years later by Leikin and Pantazi (2013) when they considered that relative creativity[1] is something important for the student to experience the daily life of a professional mathematician, keeping the appropriate proportions regarding the production of mathematical knowledge from their observations and analyses. Thus, allowing the student moments of research and discussion on mathematical objects and also time for the incubation of ideas will favour the emergence of insights that can lead them to a unique way of doing mathematics or presenting alternative ways to solve problems in this field of knowledge. The short time assigned for these phases during everyday school life is one of the barriers to installing an environment conducive to creativity in the classroom.

Haylock (1997) highlighted two aspects that seem essential in constructing a concept of creativity in mathematics and identifying a creative person in this area: the need for solid knowledge of mathematics and flexibility of thought. Other authors have also proposed conceptualisations for creativity in mathematics, and although they converge somehow, some aspects differ in

[1] The authors present “absolute creativity” and "relative creativity” differently. The first refers to great achievements, great accomplishments recognised by the community and that, therefore, have the potential to cause changes in the world. While the second is creativity in a smaller proportion, where the individual generates their own ideas, but even if they themselves find them new, they will not necessarily be new to others.

their formulations. For Gontijo (2007, p. 37), for example, creativity in mathematics is:

> the ability to present numerous suitable potential solutions to a problem situation, so that they focus on distinct aspects of the problem and/or differentiated ways of solving it, especially unusual forms (originality), both in situations that require the problem solving and problem posing and in situations that require the classification or organisation of objects and/or mathematical elements according to their properties and attributes, whether textually, numerically, graphically, or in the form of a sequence of actions.

And this is the conception of creativity adopted for the development of this research.

When mentioning creativity in mathematics, we should consider some elements of the general theory of creativity to carry out activities that favour its development and assess how far this creativity has been expanded. In this sense, three characteristics of creative thinking should be considered in the study of creativity in mathematics: fluency, flexibility, and originality. These are characterised by:

> the abundance of different ideas produced on the same subject (fluency), the ability to alter thinking or conceive different categories of answers (flexibility), and presenting infrequent or unusual answers (originality) (Gontijo, 2007, p. 37).

We highlight two approaches that we consider complementary to the approach used in the research, which are the concept of creativity mini-c, proposed by Beghetto and Kaufman (2007), to designate an original interpretation and experiences, actions, and events that are significant at the personal level, and the concept of relative creativity, proposed by Leikin and Pantazi (2013). These concepts show the existence of a level of intrapersonal creativity that can favour learning to the extent that the subject discovers new tools for himself, although these do not represent novelties for the general public.

Thus, creativity centred on the self-perception of each individual (relative or mini-c) may be associated with the conceptual development of mathematics, increasing the knowledge of the creator, who, in turn, tends to demonstrate their higher proficieny in mathematics, insofar as they internalise knowledge. This can also contribute to the increase of their motivation in mathematics, since the individual perceives him/herself as a protagonist in the process of doing mathematics in his/her own decision-making, conjecture elaboration, definition of strategies, etc.

MOTIVATION IN MATHEMATICS AND CREATIVITY IN MATHEMATICS

In different theoretical models that seek to explain the phenomenon of creativity, such as the Investment Theory of Creativity (Sternberg & Lubart, 1991), the Componential Model of Creativity (Amabile, 2012), and the Systems Perspective on Creativity (Csikszentmihalyi, 1999), a common element that characterises a creative person is the motivation that drives them in the production of innovative ideas and products.

According to Gontijo (2020), Fonseca, Gontijo, Zanetti, and Carvalho (2019), Grégoire (2016), and Kanhai and Singh (2017), among others, motivation in mathematics seems to be a necessary element for the subject to take risks in decision-making to present unusual ideas and thus engage in possibilities of building creative responses.

Regarding the importance of motivation in the creative process, we highlight the results of a program to stimulate creativity in the mathematics field developed by Petrovici and Havârneanu (2015). This program included the participation of students aged between 10 and 12 years from an urban school in Iasi, Romania. It was the development of an extracurricular activity that consisted of weekly workshops based on different types of problems carefully chosen for this purpose. The authors reported that the most significant difficulty for the development of students in this programme was the lack of motivation, since it was an extracurricular activity. However, all students performed positively in stimulating activities, which reinforced the notion that students motivated in mathematics may be more likely to manifest their doings in this area of knowledge. The authors argued that activities such as those carried out in their experiments serve mainly to stimulate extrinsic motivation, although the initial participation in the project proves the existence of intrinsic motivation as well. In this regard, this research is especially close to what was proposed by these authors.

Another example that highlights the importance of motivation in mathematics for creative production in this area is the research developed by Gontijo (2020) with 100 Brazilian senior high school students from a private school. The author sought to understand the relationships of creativity in mathematics and motivation in mathematics, among other factors. By applying specific instruments, such as the mathematics motivation scale and the mathematical creativity test, the author found positive and significant correlations between the two variables under discussion.

It is worth noting that Gontijo (2007) describes motivation in mathematics as a list of habits, which include

> studying mathematics frequently; dedicating time to studies; solving problems; creating study groups to solve mathematics exercises; researching information about mathematics and mathematicians' lives; being persistent in problem solving; developing problems to apply acquired knowledge; explaining physical phenomena from mathematical knowledge; doing homework (solve exercises at home); relating well to the mathematics teacher; participating in classes with questions and formulation of examples, and cooperating with colleagues in mathematics learning. (p. 138)

And based on this concept, in this investigation, we understand motivation in mathematics as the subject's willingness to undertake habits to the extent that he/she studies mathematics alone or in a group; that he/she thinks and reflects on mathematics and its different applications and in various contexts; and that he/she does mathematics either inside or outside school.

PERFORMANCE IN MATHEMATICS AND CREATIVITY IN MATHEMATICS

We can say that proficiency refers to a measure that "represents a student's specific latent trait (aptitude)[2]." And, thus, proficiency can be measured in different areas of knowledge. For this research, proficiency in mathematics taken as the ability to demonstrate the learning of mathematical concepts and to apply them to solve different types of problems. And, in this research, proficiency was determined from the students' performance in mathematics tests.

Although some research focuses only on creativity in mathematics, many researchers have considered investigating this theme associated with

[2]Available at: <http://www.portalavaliacao.caedufjf.net/pagina-exemplo/medidas-de-proficiencia/>. Accessed on: November 10 2019.

mathematics learning (performance). Grégoire (2016), for example, explicitly highlights that motivation and expertise (knowledge, performance) are elements of creativity in the mathematics field.

Regarding the relationship between creativity in mathematics and performance in this area of knowledge, Bahar and Marker (2011) found positive and significant correlations, as well as Mann (2005) and Walia (2012). The conclusions reached by the authors are close to what this research intends, expanding the list of works that have been structured to investigate the correlations between creativity, motivation, and mathematics performance.

As an example of research that examined the relationship between creativity in mathematics and knowledge in mathematics, we cite the work by Walia (2012), who investigated this relationship in students from the Kurukshetra school in India (school stage equivalent to the Brazilian 8th grade), involving a sample of 99 male students and 81 female students randomly selected. The researcher found a positive and significant correlation between the two variables under analysis.

Another study that investigated the relationship between creativity in mathematics and knowledge in mathematics was conducted by Kattou et al. (2013). The authors collected data from 359 students of the 4th, 5th, and 6th grades in Nicosia, Cyprus. After applying mathematical skills tests and mathematical creativity tests, a positive and significant correlation was found between the two variables. From a factorial analysis, the study also suggested that creativity in mathematics is a subcomponent of mathematical skills. In this case, reinforcing a direct link between creativity and mathematics skills.

Thus, taking into account that creativity is a desired characteristic in citizens today and that it helps in doing mathematics, the use of creativity development techniques becomes an important element to be included in the organisation of pedagogical work with students, in view of the emphasis they give to the generation of new ideas to solve different problems – which is the focus of this research.

METHODOLOGY

This investigation followed the assumptions of experimental research (Gil, 2008; Creswell, 2010), given the objective of comparing the performance of two distinct groups of students regarding creativity, motivation, and performance in mathematics. To this end, we set off from two different models of classes, one developed through a more conventional approach (control class) and another based on classes with creativity techniques, that is, classes that aimed to value the elaboration of conjectures and heuristics in the application of strategies to find different solutions to problems (experimental class).

INSTRUMENTS

Mathematics Motivation Scale

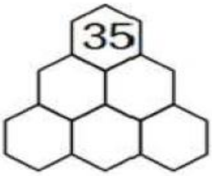
The Scale of Motivation in Mathematics (Escala de Motivação em Matemática – EMM, in the Portuguese acronym) proposed by Gontijo (2007) was designed to measure the high school students' levels of motivation in mathematics. According to the author, knowing about the student's motivation is "an important step to establish teaching strategies that promote learning in this area" (p. 135) and stimulate the academic and creative improvement of the subject. The EMM consists of 28 items, which have positive (+) and negative (-) perceptions of mathematics and that the respondents must choose one of the options for each item: 1 (never), 2 (rarely), 3 (sometimes), 4 (frequently), and 5 (always). Below, some examples of items:

> I calculate the time it will take from home to the destination I intend.
>
> I perceive the presence of mathematics in the activities I develop outside of school.
>
> I try to solve the same mathematical problem in different ways.
>
> I get frustrated when I can't solve a math problem.

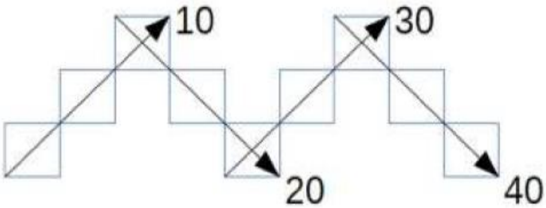
Creative Performance Test in the Mathematics Field

The Creative Performance Test in the Mathematics Field (Teste de Desempenho Criativo no Campo da Matemática – TDCCM)- (Fonseca, 2015; Fonseca, 2020) is an instrument that allows identifying latent traits of creativity expressed through fluency, flexibility, and originality of thought, manifested from the written record of solutions to open problems. The TDCCM has two versions, A and B, with five items each, which were structured as possibilities to be used as pre- and post-test, because although they are independent, they have similar objectives and degrees of difficulty due to the parallelism between their items. Below, a couple of examples (item 1 of both versions of the test):

Look at this number pyramid. All the cells must contain one number. Each number in the pyramid can be computed by performing always the same operation with the two numbers that appear underneath it. Fill in the pyramid, by keeping on the top the number 35. Try to find as many solutions as possible.



Observe the illustration below. All cells must be populated with a number. Numbers should not be repeated. To fill in the cells below it is necessary to consider that the first diagonal should result in 10, the second in 20, the third in 30 and the last in 40, not cumulatively. You can choose to use any mathematical operation to be performed between the cells to obtain diagonal results, such as +, -, x, ÷, etc..., however, you must use a single mathematical operation for each proposed solution. Find as many solutions as possible.



Mathematics Performance Test

The Mathematics Performance Test (Teste de Desempenho em Matemática - TDMat), versions A and B, were compiled by Fonseca (2019), from the selection of items already validated and used in large-scale official assessments such as ENEM. The purpose of the math performance test was to record students' performance in mathematics tests before and after the extracurricular course.

Round of Conversation

According to Melo and Cruz (2014), this is a method of collecting participants' impressions from the group discussion about something. In practical terms, it is a collection instrument in which the researcher can, based on a script and a climate of freedom among the participants, promote a conversation to record opinions, feelings, desires, i.e., what is in their thinking and that cannot be captured by tests, scales, and inventories. Therefore, a round of conversation was held at the end of the extracurricular course with each group.

The conversation was recorded to facilitate registering the participants' speeches for further analysis from the reliable transcription of what had been verbalised on that occasion.

Logbook

To complement the rounds of conversation regarding the capture of qualitative data from the groups participating in the research, the logbook allowed each subject to express their perceptions, reflections, and feelings individually, in writing, in forms made available for this purpose. This instrument contained four questions: (a) describe the activities performed; (b) indicate your doubts and/or questions; (c) make an assessment of the class; and (d) how did you feel in this class?

Porlán and Martín (2004) define the logbook as a methodological apparatus that allows each student to have their individuality to register their impressions about the activities experienced without the influence of the group's opinions, as it may occur in the round of conversation. Also, the logbook can be configured as an important element for the researcher to become aware of the acceptance criticisms between the two pedagogical methods compared.

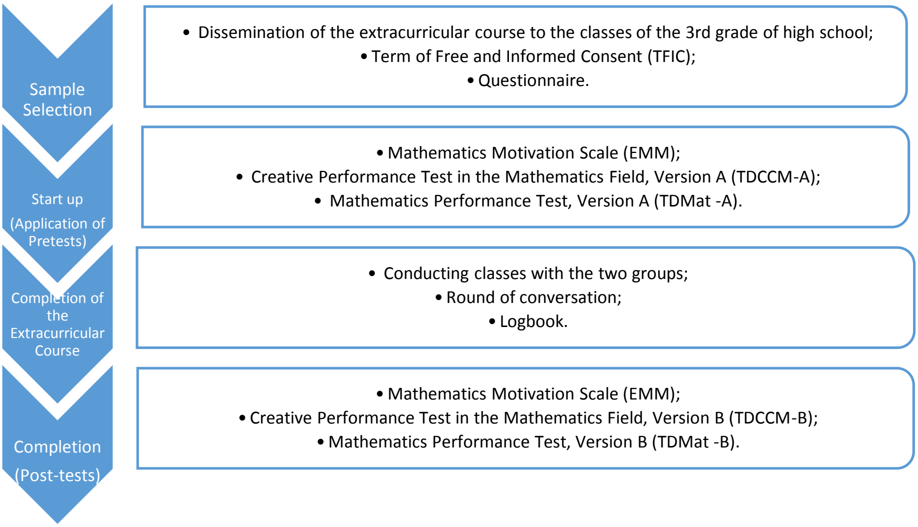
Sample Survey and Data Collection

To explain the methodological approach adopted regarding the sample survey and data collection in the fieldwork, the following flow of steps were strictly followed along with the respective descriptions (Figure 1).

In summary, these phases had as their core an "extracurricular course", planned from a selection of mathematics contents. This course was offered to two groups, the first was submitted to conventional classes (control group); while the second received classes based on creativity techniques, thus stimulating the space for discussions, insertion of motivational elements, and resolution of open problems (experimental group).

Figure 1

Description of research phases



The research was approved by the Ethics Committee/ University of Brasilia (process No. 91925918.3.0000.5540; opinion No. 2.877.638). The school was selected through the convenience criterion, which, in turn, authorised the research as soon as the planning was presented. This is a public institution in the Federal District, Brazil, located in an area occupied by low-income population.

Regarding the first phase – sample survey, the extra-class mathematics course was disclosed to all students of the third grade of high school. All those who expressed interest were included in the sample, being randomly divided into two groups. The classes of the course occurred in the opposite shift of the regular classes, in a total of eight meetings lasting 1h40min each.

Forty-one students participated in the research: 20 students composed the control group; and 21, the experimental group. The average age of the participants was 16.90 (SD = 0.81), with a minimum age of 15 years and a maximum of 18. The extracurricular course was presented as part of a research, and for this reason, due clarification was provided and signatures were collected in the Informed Consent Form (ICF), which were prepared in two versions: (a) for students; and (b) for parents or guardians. On this occasion, the questionnaire was also applied to raise some additional information of interest to the research.

In the second phase – application of diagnostic instruments (pre-tests) - the instruments selected were applied to: (a) better understand the profile of entrants in relation to how they relate to mathematics (motivation - EMM), and the level of performance in mathematics concerning elementary content of this discipline (TDMat, version A); and (b) identify the level of mathematical creativity of students in mathematics (TDCCM, version A) to support comparisons with the instruments applied after completion of the course, in order to verify the contrast of the results of the groups.

By continuing to the third phase – completion of the course - the researcher effectively acted in the classroom according to the dynamics provided for in the teaching plan prepared for each group. For the control group, the classes were based on conventional mathematics questions related to the content studied, without major adaptations, while for the experimental group, the same content was worked based on creativity techniques, thus stimulating the debate and the search for different questions and solutions, valuing, therefore, fluency, flexibility, and originality of thought. The meetings of the experimental group, in turn, always started from an open questioning that allowed, therefore, the adoption of multiple response paths and/or many different answers. The dynamics of the classes followed a common structure, composed of (a) Warming up; (b) Approach to the task; (c) Development of the task; (d) Construction of concept/definition; and (e) Systematisation, as presented by Gontijo, Zanetti, and Fonseca (2019).

In Table 1, it is shown a comparison between the planning of a meeting for the control group and the experimental group. It is noteworthy that both were designed for application in a class lasting 1h40min and with the objective of reviewing surgical techniques and procedures to solve numerical expressions and equations of the 1st degree.

Finally, in the last meetings, the fourth and last phase of the field research – application of diagnostic instruments (post-tests) - was carried out, which consisted, just as in the second phase, in the application of the instruments (EMM, TDMat – version B and MCTMF - version B) to students of both groups, in order to obtain new information about their motivational perceptions of mathematics, performance after a differentiated work between the classes, and the scores presented in the specific creativity test.

Table 1

Experimental and Control plans

	Experimental group	**Control group**
Materials	a. Printed material to carry out the activity (Puzzles). b. Whiteboard and whiteboard marker for collective generation of ideas (Brainstorming). c. White sheet and pen for individual/collaborative idea generation (Brainwriting).	a. Whiteboard and whiteboard marker for teacher use. b. Miscellaneous exercises and problems.
Teaching-Learning Strategies	**a. Warming up:** Addition Puzzle (In groups of 4 or 5 students for mutual resolution construction). Find the number formed by $\bigcirc\square\triangle$, given: $\begin{array}{r} \bigcirc\square\triangle \\ +\ \bigcirc\square\triangle \\ \bigcirc\square\triangle \\ \hline \triangle\triangle\triangle \end{array}$ **b. Approach to the task:** **I.** Did all groups think the same way to solve this puzzle? Are we going to share how each group solved it? **II.** Is there anything common between solving this puzzle and solving a numerical expression and/or first-degree equations? **c. Task development:** **I.** Brainstorming creativity technique: What should we consider to solve a numerical expression? **II. Brainwriting creativity technique[3]:** What are the steps/ modes/procedures to solve a first-degree equation?	Lecture with conceptual explanation, presentation of examples, and resolution of textbook exercises.

[3] The Brainwriting used in this workshop is carried out from dynamics called by "1001 ideas". The class is divided into groups of four or five participants, arranged in small circles. Each participant is allowed one minute to produce three ideas regarding the initial questioning. Closing time, the leaves circulate clockwise. Participants have

	d. Construction of the concept/ definition: The review of how to solve numerical expressions and first-degree equations will occur during the execution of the creativity techniques mentioned in the previous activity.	
Systematisation	The systematisation of the ideas generated in the application of the Brainstorming and Brainwriting techniques is carried out collectively, to enable students to analyse the ideas presented and argue whether these are appropriate to solve numerical expressions and/or first degree equations. Moreover, they may express doubts that were not clarified during the collective production. In this phase, textbook activities were also done.	
Prospections/ Finalisation	Using the Braindrawing creativity technique, each participant will be encouraged to go to the board and draw an image and/or scheme to represent a first-degree equation. After the presentation/exhibition of the drawings, a collective reading will be carried out to systematise the meanings of each one of them.	Moment intended to correct activities and answer various questions.

Procedures for implementing the instruments

The questionnaire and the ICF were given to students who showed interest in participating in the research still in the dissemination phase by the school. These documents were collected at the beginning of the activities of the first day of class of the extracurricular course.

In the first class, the participants of the research were invited to complete the EMM and the TDCCM-A. In the second meeting, besides starting the moment of classes, both for the control group and for the experimental group, the participants answered the TDMat -A.

one more minute to read colleagues' ideas and generate three more ideas. At the end of time, the sheets circulate clockwise again and so the procedure is repeated until the sheet returns to the initial author.
After this phase, each participant is allowed one minute to circulate the three best ideas that are on their sheet. The participant passes the sheet on and circulates the three best ideas of the new sheet, and so on until the sheet returns to the initial author. The same idea can be circulated more than once if more than one person thinks they are one of the best ideas. Finally, the group talk about the ideas selected on their respective sheets and vote for the top three in the group.
In the present case, the three ideas that best represent the procedure for solving a first-degree equation, as if they could synthesise the resolution procedure in three steps.

At the end of each class, starting from the third, students were invited to complete the logbook. As mentioned earlier, this instrument asked some questions to encourage them to write about the activity of the day.

In the last meetings, the students underwent the second version of the TDMat and TDCCM. On this occasion, the round of conversation was held and fully recorded in audio.

Data analysis procedures

Regarding qualitative data, the software for qualitative data analysis and mixed methods MAXQDA was used to categorise the written records captured in the research, as well as the transcriptions that were made from the rounds of conversation proposed during the extracurricular course.

The Statistical Package for the Social Sciences (SPSS) was used for quantitative data. Based on the Mann-Whitney and Wilcoxon tests, this software was used to investigate the differences between the groups' averages regarding creativity, motivation, and mathematics performance measures, as well as the correlations between the indicators of these variables.

Regarding the Mann-Whitney and Wilcoxon tests, these are non-parametric statistical tests that fulfil the same role as the parametric student t-test, however, they are used to compare two groups when their parametric equivalent (student t-test) cannot be used, either because it is a non-normal distribution or because it has a small sample, as occurred in this research. The difference between the two tests adopted in this research lies in the fact that while the Mann Whitney U test is used for unpaired samples (e.g., control group X experimental group), the Wilcoxon test is the alternative for paired samples (e.g., pre-test control group X post-test control group) (Field, 2013). In both tests, $p < 0.05$ indicates significant differences in the comparison between the groups under analysis.

Another statistical test used in the research was the Spearman's rank-order correlation. This is a test to assess the association between the variables studied, or rather, between the crosses EMM (+) X TDMat-A; EMM (+) X TDCCM-A; EMM (-) X TDMat-A; EMM (-) X TDCCM-A; TDMat-A X TDCCM-A for the first application; and EMM (+) X TDMat-B; EMM (+) X TDCCM-B; EMM (-) X TDMat-B; EMM (-) X TDCCM-B; TDMat-B X TDCCM-B for the second application.

It is worth mentioning that qualitative and quantitative approaches were used to design a triangulation of results. Thus, findings from the quantitative analysis were analysed together with the findings obtained from the qualitative analysis to complement each other. This article presents the quantitative results that were generated from the qualitative analysis of the instruments used.

RESULTS AND ANALYSES

The results are presented from each variable analysed through the applications of the tests mentioned above.

Creativity in Mathematics

Table 2 presents the results of the mean and standard deviation obtained by each group from the application of the TDCCM, versions A and B.

Table 2

Mean and Standard Deviation of TDCCM - A and B, in both groups

		Median	Mean	Standard Deviation
TDCCM-A	Control	156.05	138.92	89.46
	Experimental	168.29	128.13	86.22
TDCCM-B	Control	104.95	280.06	388.60
	Experimental	701.71	503.82	313.96

When performing the statistical analysis of the data by the Mann-Whitney test, it was possible to perceive that the initial separation of the groups into control and experimental had no effect on the creativity scores in mathematics from the application of the TDCCM-A ($p = 0.416$), which allows us to infer that the students of both groups presented a similar performance in relation to this variable. This did not occur at the end of the intervention, when the test revealed a significant difference between the students because they belonged to the control group or the experimental group ($p = 0.003$), with advantages for the experimental group.

From this, we can say that although the groups initially presented equivalent results, this situation did not remain at the end of the intervention.

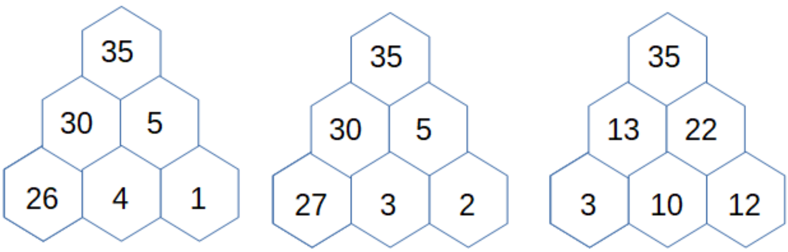
The means obtained by group B (experimental group) were higher and the standard deviation was reduced. This shows that classes based on creativity techniques that were proposed during the intervention contributed to a better performance of students in version B of the TDCCM.

Then, the results obtained before and after the intragroup intervention were compared, i.e., from the paired samples, to verify whether the change in the results between versions A and B were in fact, significant. From the Wilcoxon test, the results showed no significant difference between the data obtained from the control group ($p = 0.76$), although the opposite occurred with the experimental group ($p < 0.001$).

To exemplify better how the nature of the answers changed from the intervention, we will take as example solutions presented in item 1 of the TDCCM, presented in the previous section. In version A, both for the control group and for the experimental group, the responses were similar, such as in Figure 2.

Figure 2

Examples of TDCCM-A answers

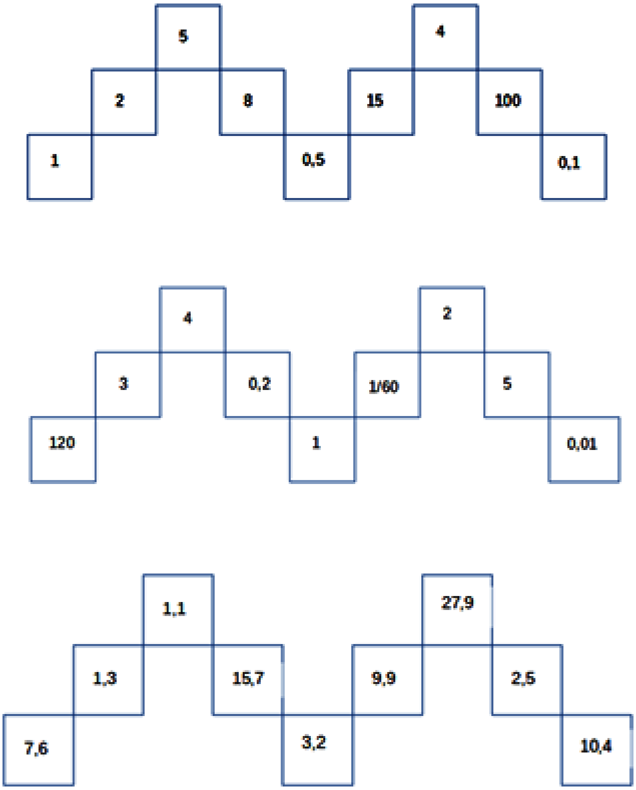


We can say that the students revealed: low fluency, since they presented only two or three solutions at the time; low flexibility, since the answers were practically obtained only with whole numbers (with very few exceptions among some participants); and low originality, since the answers did not differ in structure from each other.

However, when the answers to the item of version B, that is, post-intervention, were analysed, the students' productions were different. The following examples illustrate what the numerical data in table 2 indicate, i.e., that the experimental group scored higher in creativity. This happened because the students gave more answers (fluency), had more flexibility (they used not only numbers of different sets but also different operators), and were more original (by using more resources in their answers, they produced some uncommon results as to the group they belonged). We present below some solutions using multiplication, division, and addition, respectively. For the addition, only rational numbers were used.

Figure 3

Examples of TDCCM-B answers



Similar behaviour was identified in the other items of the test. While in version A the two groups answered similarly, in version B, the experimental group's aswers obtained higher scores in terms of fluency, flexibility, and originality.

Motivation in Mathematics

Table 3 presents a summary of the results extracted from the application of the motivation scale:

Table 3

Mathematics motivation scale scores

		Pre-intervention			Post-intervention		
		Median	**Mean**	**Standard Deviation**	**Median**	**Mean**	**Standard Deviation**
Control	**Positive aspects**	74.00	70.43	23.33	75.00	69.43	32.24
	Negative aspects	11.00	11.71	3.95	12.00	11.43	3.87
Experimental	**Positive aspects**	74.00	68.14	20.09	77.00	76.00	18.72
	Negative aspects	17.00	11.29	3.86	16.00	14.71	4.07

The change obtained in the control group did not result in a statistically significant difference, both with regard to positive and negative aspects in relation to mathematics ($p = 0.61$ for positive aspects; and $p = 0.67$ for negative aspects). However, a significant difference was found for the experimental group, which both increased its positive perceptions in relation to mathematics ($p = 0.01$) and decreased its negative perceptions in relation to this area of knowledge ($p = 0.03$), which was expected. Then, Figures 4, 5, 6, and 7 present the visual distribution of the answers from the EMM of both groups before and after the intervention. Recalling that 1 represents "never"; 2, "rarely"; 3, "sometimes"; 4, "frequently"; and 5, "always".

Figure 4

Distribution of the EMM answers - Control Before Intervention

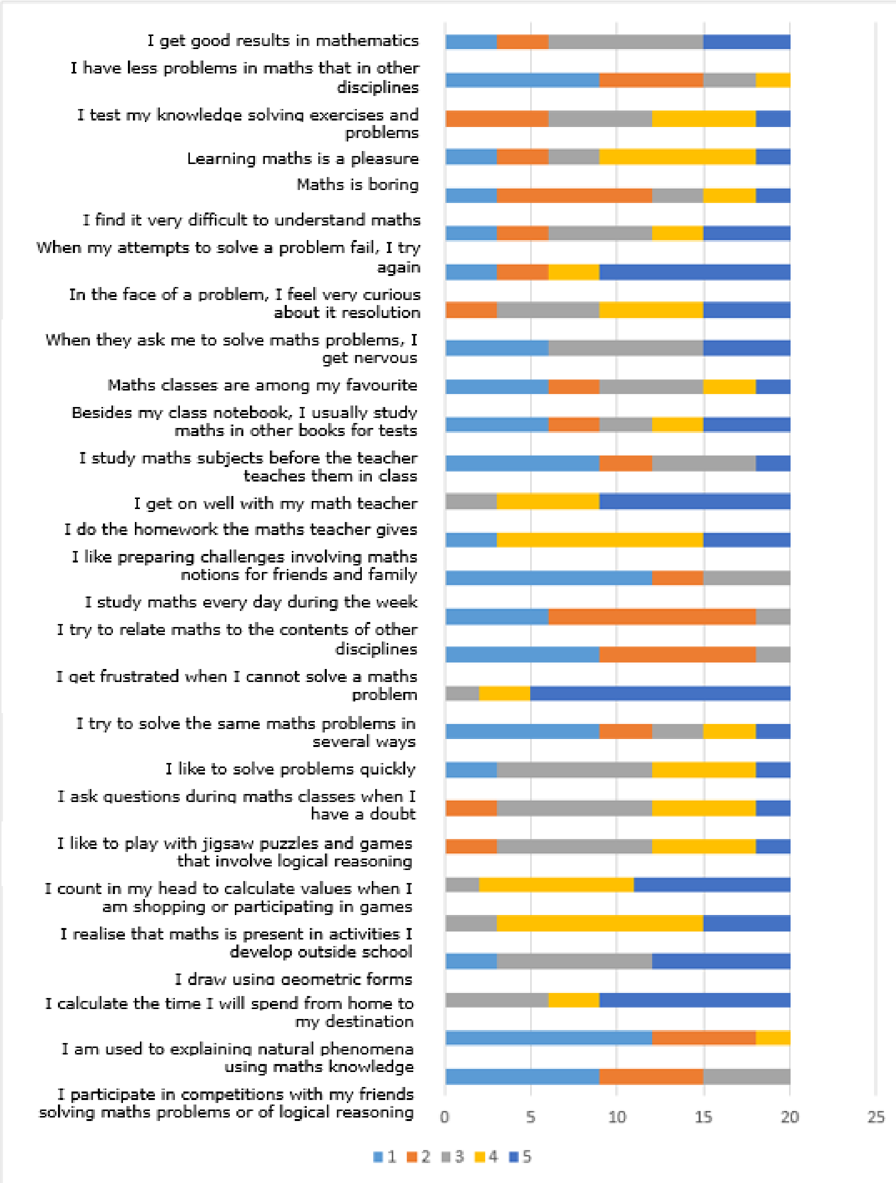


Figure 5

Distribution of the EMM answers - Control After Intervention

Figure 6

Distribution of the EMM answers – Experimental Before Intervention

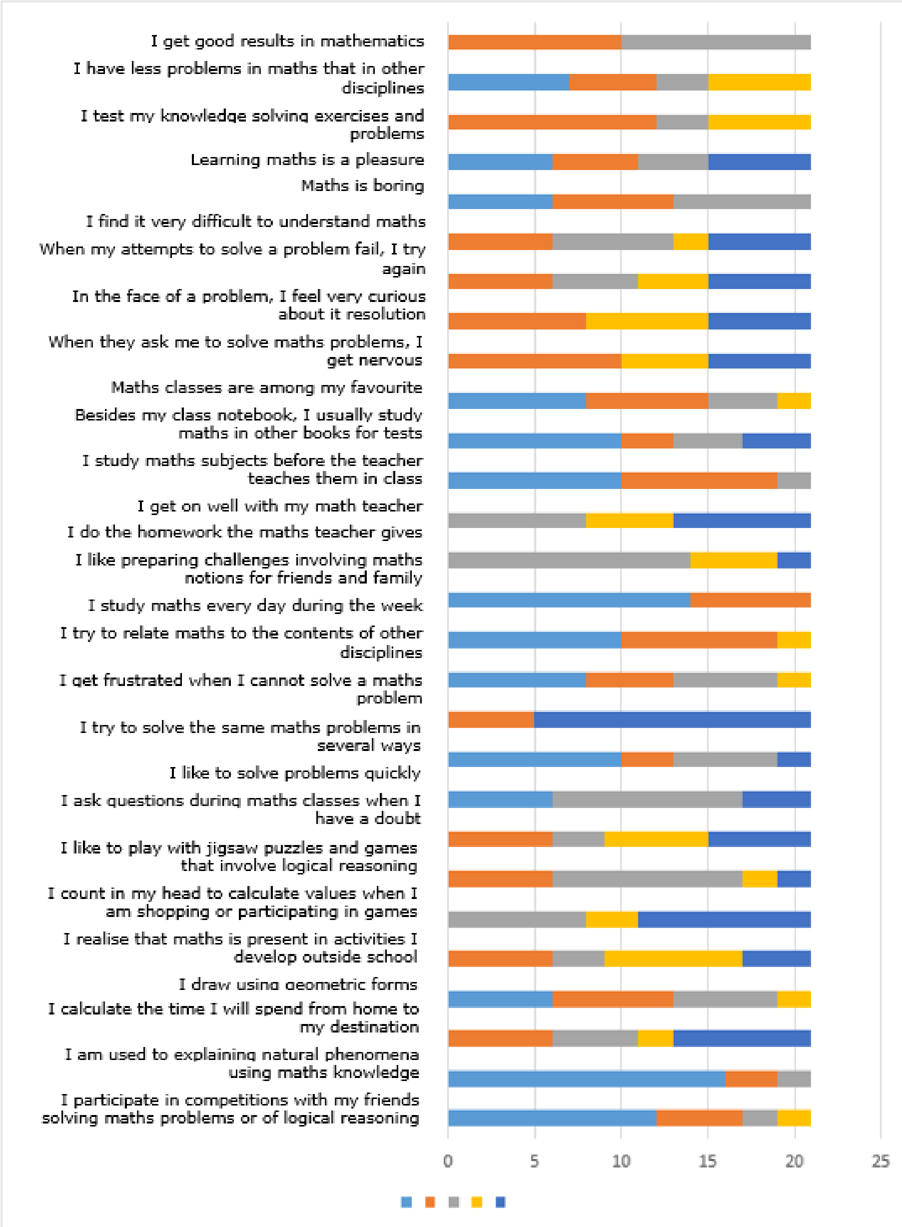


Figure 7

Distribution of the EMM answers – Experimental After Intervention

Observing the distributions of the scale application before the intervention, we noticed that there was an increase regarding the students' relationship with mathematics in both groups. However, in the experimental group, some changes were more pronounced, which explains the significant differences indicated in table 3.

Performance in Mathematics

In terms of mathematics performance, the groups also presented similar results initially, since most students left many questions unanswered, and extremely low results prevailed in the Mathematics Performance Test - TDMat, with an average = 2.14 points (SD = 2.43) being the minimum score = 0.00 and the maximum = 6.87 in the first application, on a scale from 0 to 10. This reinforces how high school graduates' proficiency in mathematics is lower than expected (Brasil, s.d.; IPM, 2016; OECD, 2019).

The difference found in the evolution of scores by the two groups is summarised in Table 4:

Table 4

Mean and Standard Deviation of TDMat – A and B, in both groups

		Median	Mean	Standard Deviation	Minimum score	Maximum score
TDMat - A	Control	2.50	2.30	2.56	0.00	6.87
	Experimental	1.25	1.95	2.50	0.00	6.25
TDMat - B	Control	4.50	4.28	3.19	0.00	8.13
	Experimental	2.81	3.33	1.75	1.25	8.50

According to Table 4, both in the application of the TDMat A and TDMat B of the control group, the minimum score was 0.00, although the maximum score was increased between version A and version B of the instrument. However, the experimental group not only increased the maximum score, but no student scored 0.00 in version 2 of this instrument. Moreover, the reduction of the standard deviation also shows that the group achieved a more cohesive set of scores than before. The Wilcoxon test shows a significant difference for the experimental group ($p = 0.04$), while this does not occur for the control group ($p = 0.07$).

A possible explanation for so low results is that the mathematical content approached during the intervention was not necessarily the same content that students were studying in their regular classes, i.e., it may be because part of the day was already committed to the extracurricular course and the other part was dedicated to the studies of that “mathematics” necessary for school approval. The content seen was basic mathematics that all students of that school grade should master reasonably.

Also, the number of items without any type of answer reduced in the resolution of version B of the test (second application). In the first application, the students in the control group handed the test back without answering about 8 out of a total of 15 items, while in the experimental group this occurred with 10 items. In the second application, the control group reduced the number of blanks to about 6 (reduction of 2 compared to the first test) while the experimental group reduced to 6 (reduction of 4 compared to the first test). This suggests that in the second application the students in the experimental group were more willing to solve the questions, although they did not know immediately how to solve them or had not found the correct solutions – revealing that they may have developed a typical posture of a problem solver (Schoenfeld, 2013). The Wilcoxon test shows that this reduction was significant for the experimental group ($p = 0.039$), while this did not occur for the control group ($p = 0.223$).

Acceptance of pedagogical strategy adopted

Some speeches from the experimental group allow us to infer the students’ acceptance of the class method that was offered during the research. They also demonstrated better indicators of creativity, motivation, and mathematics performance. Students also reported feeling comfortable during classes - which, in a way, corresponds to a validation of the pedagogical strategy adopted in this research.

Table 5 presents some of the answers obtained from the students in relation to some classes of the extra-class course, separated by groups that belonged to:

It is possible to identify speeches that represent the experimental group’s sense of security, comfort, and enthusiasm; but that represent monotony on the part of the control group. In addition, statements collected in the logbook and in the round of conversation led to the structuring of two messages: (a) classes based on creativity techniques contribute to students feeling both freer to do mathematics and more motivated, which reflects better mathematics performance by allowing themselves to risk more; and (b) conventional classes of the extra-class course were good, but nothing different from what they are already used to at school. Therefore, they did not see anything that contributed to a change in attitudes towards mathematics.

Table 5

Some students' reports about the intervention

Theme	Group	Reports
Cylinders	Control	• Calm. • Well • Nostalgic. • Interested but sleepy.
	Experimental	• Well satisfied with the resolutions and activities developed in the group. • I was very interested in the explanation. • Comfortable, it was possible to clarify some doubts about the calculations. • I felt more intelligent.
Anagrams	Control	• Well. • Very well.
	Experimental	• Very well. • Calm.
Arithmetic Mean	Control	• Apathetic, but I feel I understand now what I had forgotten. • I felt comfortable. • I felt anxious and a little pressured by myself to finish the questions in a reasonable time and not to make mistakes.
	Experimental	• Thoughtful. • Well. • Energetic.
Fractions/MMC	Controle	• Very crazy. • Sleepy and bored. • Anxious.
	Experimental	• Well, challenged by the challenges proposed. • Nervous at first because I did not remember anything, but I eventually remembered. • Comfortable. • Made me put my head to work and think more. • The class was great fun. • Encouraged to observe, evaluate and solve problems, expanding into personal life.

CONCLUSIONS

Generate many, many ideas in mathematics; do mathematics; mathematicise; posing and solving mathematical problems. These tasks, once, were not part of the dynamics of studying mathematics. The changes, resulting from technological innovations and advances in knowledge production, are demanding new skills, especially creative thinking, imbued with motivation and knowledge.

Let us consider the first research question: “Is creativity, motivation, and mathematics performance triad of senior high school students positively influenced by extracurricular mathematics classes based on creativity techniques?” The findings showed that mathematics classes based on creativity techniques are useful to improve the creativity-motivation-performance triad in mathematics, showing that the approach used is favourable to mathematics learning and teaching, which considers, in turn, the changes predicted for the - already present - future world.

About the second question: “What are the different students’ perceptions of mathematics based on the type of classes they received throughout the course (conventional classes and classes based on creativity techniques)?”, the findings suggest acceptance of the work dynamics adopted with the experimental group, showing that they were happy with the experience.

As limitations of this study, we point out the sample size, for two reasons: (a) because it prevents a quantitative analysis from parametric tests; and (b) because it distances itself from the reality of a regular classroom, considering that, in general, these have twice the number of students who participated in each group in the research. The small sample size also hindered the generalisation of the results and the statistical study regarding the correlations between the variables. However, despite these limitations, it should be noted that the correlational results must still be made more flexible, since the qualitative analysis allowed us to understand the association between those variables.

It is still a small discussion compared to the entire group of schools in the Federal District, Brazil, but it allows us to suggest that this reinvention of pedagogical practice should be replicated other times. It is certainly delicate to suggest that all teachers could undertake classes in the way presented in this research when considering the high workload of many or the high number of students they have in each class. However, the research points to a path. And understanding that creativity is something that needs to be stimulated during basic education, this is already an important synthesis. Problem solving (whether open or closed) can transform the class into moments of stimulating creativity in mathematics. After all, much of the wealth of this type of class is in the pedagogical practice adopted, so that a problem can only be corrected or can be configured as a driving force to nourish the generation with many ideas, ideas from different perspectives, and original ideas.

As possibilities for further research on the phenomenon of creativity, there is a list of alternatives, such as investigating (a) the association between critical thinking and creative thinking, since it is expected that the individual can judge and choose from the many ideas generated those that best apply to their needs; (b) from a longitudinal perspective, analysing the personal and professional choices of subjects with high and low creativity in mathematics; (c) how anxiety in mathematics can influence creativity, motivation, and mathematics performance, as well as investigating how the improvement of these three variables can combat anxiety in mathematics; (d) whether the self-concept about mathematics influences the results in tests of creativity, motivation, and mathematics performance; or (e) how creative thinking is present in activities related to creativity, motivation, and mathematics performance.

Further investigations should be carried out in different schools, regions, and with a greater number of students. This is a pioneering study that can nurture other investigations and can gradually stimulate the creation of new classes/workshops to stimulate creativity, motivation, and performance in mathematics. Moreover, this research also allows us to understand elements that should be considered in the development of didactic materials with that purpose, such as books, games, etc. In fact, a next step for this investigation is to expand the road maps of the classes used with the experimental group to give rise to materials to support the basic education teacher.

The improvement of mathematics teaching today demands the creation of multiple pedagogical practices that work properly despite the different educational contexts throughout the country. Therefore, the challenge now is to be creative with mathematics teaching to stimulate those variables, despite all the difficulties found in the current educational system.

AUTHORSHIP CONTRIBUTION STATEMENT

MGF and CHG conceived the idea. MGF prepared the instruments, collected the data, and performed the analyses under CHG's supervision. Both participated in the construction of the text actively.

DATA AVAILABILITY STATEMENT

The data supporting this article are under the custody of MGF and may be made available at the request of other interested parties for a period of five years.

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