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Socio-critical mathematical thinking: Towards emancipation and the configuration of transformative learning environments

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Abstract

This study analyses the development of socio-critical mathematical thinking (SCMT) in primary and secondary school students through problem-solving tasks based on real-life contexts. From a socio-critical perspective of mathematics education, based on Paulo Freire's emancipatory pedagogy and Ole Skovsmose's critical mathematics education, an intervention was designed in two public institutions in Armenia, Colombia. The strategy consisted of students identifying topics of interest to them, writing an opinion piece and supporting it with reliable statistical data, promoting reflection and critical analysis of social, political, economic and environmental phenomena. Thirty-six students participated, of whom 83.3% expressed, in interviews and written assignments, a change in their perception of the role of mathematics. The results show a transition from decontextualised exercises to the formulation of projects with a socio-critical approach, strengthening argumentation and democratic participation. It is concluded that the incorporation of real contexts and critical data analysis favour ECM and contribute to the formation of critical citizens committed to their environment.

Keywords: socio-critical mathematical thinking, problem-solving, learning scenarios, emancipation in education, action research

INTRODUCTION

A recurring problem in education, especially in the classroom, is the disconnect between teaching and the student's reality, given that content is presented in isolation, without linking it to familiar contexts that allow students to identify and analyse problems in their environment. This lack of contextualisation promotes a passive attitude in students, who limit themselves to reproducing the knowledge transmitted by the teacher, without developing critical or creative skills. As Chevallard (2004) points out, this situation can lead to a monumentalisation of knowledge, presenting it as something static and alien to the student's experience. In the case of mathematics, it is essential to ask how we can use it as a tool to address the challenges of society and empower students to be agents of change.

In line with the above, contemporary society demands citizens who are capable of critically analysing the information they receive through the media and social networks. Empowerment through mathematics education is essential for developing this critical thinking, as by understanding concepts such as data, trends and probabilities, students acquire the tools necessary to evaluate information objectively and make informed decisions. In this way, mathematics education becomes a fundamental pillar for strengthening democracy by promoting active citizen participation and combating misinformation.

However, despite official guidelines in countries such as Colombia that promote meaningful and contextualised teaching (Ministerio de Educación Nacional de Colombia, 2006), traditional approaches still

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Contribution to the literature

- This article positions SCMT as a key bridge between mathematical knowledge and social realities.
- It offers a clear theoretical-methodological framework that supports both the understanding of mathematical concepts and their critical application in real-world contexts.
- Additionally, it provides teachers with evidence-based strategies to implement emancipatory pedagogies, fostering meaningful learning and active, democratic participation through mathematics education.

dominate classrooms. It is therefore essential that mathematics education in schools creates spaces for dialogue and reflection that promote the development of socio-critical mathematical thinking (SCMT) among students. This approach seeks not only to strengthen mathematical skills but also to empower students as agents of change.

Problem and Purpose of the Research

Based on the above, the purpose of this research is to develop SCMT for the emancipation and configuration of learning scenarios (LS) through problem-solving in primary and secondary school students in public educational institutions in the city of Armenia (Colombia). This approach allows us to identify how teachers and students carry out their mathematical practices in the classroom, to plan and characterise pedagogical actions that favour the development of a critical and reflective stance towards mathematical thinking.

Research Question

How does contextualised problem-solving influence the development of SCMT and the configuration of emancipatory LS in primary and secondary school students?

THEORETICAL FRAMEWORK

This study was based on a socio-critical perspective of mathematics education as seen from the emancipatory pedagogy proposed by Freire (2017), who describes education as a political act that allows students to interpret and transform their realities. This approach considers mathematics not as neutral knowledge, but as a form of literacy that empowers students with the ability to read the world critically (Castro, 2021; Valero et al., 2015). Therefore, education must engage with the social, economic, political and environmental realities experienced by students.

In Latin America, academics such as Guerrero (2008) have expanded on Freire's (2017) ideas to frame what is now called critical mathematics education (CME) (Skovsmose, 2014). This framework incorporates principles such as dialogic learning, emancipation, democratic competence, and the recognition of mathematics as a social construct. The author also highlights the importance of addressing the hidden power dynamics in mathematical and pedagogical practices, arguing that both students and teachers must adopt a critical stance towards their roles as political beings inside and outside educational spaces.

In line with the above, Alvis (2019) promotes, in his doctoral thesis, development of mathematical competence in problem formulation and solving through a competence model centred on a socio-cultural view of learning', a competence-based model focused on socio-cultural learning, where mathematics teaching includes the analysis of social and political phenomena. Alvis (2019) emphasises the role of mathematics in promoting critical and reflective thinking, especially through competence in problem formulation and solving.

Mancera et al. (2016) further emphasise this approach by developing socio-critical modelling environments in classrooms, where mathematics becomes a tool for analysing and debating political, economic and environmental issues. These environments promote the classroom as a democratic space that encourages student participation and reflection on real-world issues.

These theoretical contributions, and others, show a common concern: the absence of spaces in the classroom that promote critical analysis and problem-solving from real contexts that are close to the student. This disconnects limits students' ability to engage with the socio-political and environmental dimensions of mathematics.

Based on the research question and the background, the study sought to conduct a semantic analysis of 'SCMT' starting from the concept of 'thinking' as a human faculty that allows individuals to make sense of their world. Jara (2012) defines thinking as reflection, reflexivity and appropriation, capacities linked to the historical, social and political experiences of individuals. Similarly, Paul and Elder (2003) describe critical thinking as a disciplined process of analysing one's own reasoning to improve the quality of thinking in response to problems and information.

Finally, Skovsmose (1994) conceptualises CME as the development of three types of knowledge: mathematical, technological and reflective (as shown in **Figure 1**). This triad supports mathematical literacy aimed at enabling citizens to judge, analyse and act critically in the face of social injustices. For Skovsmose (1994), being critical means engaging with issues that

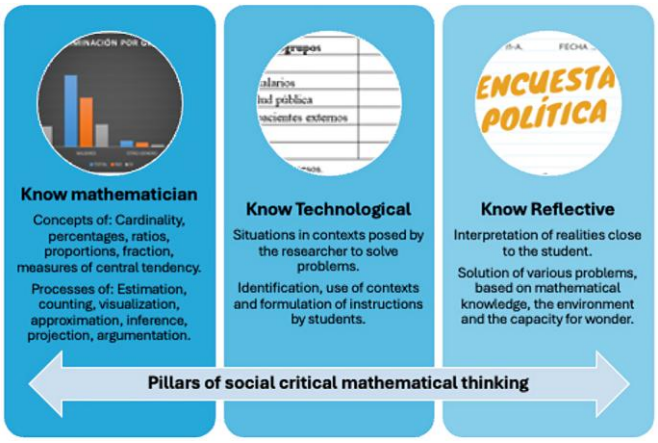

Figure 1. CME (Source: Authors' own elaboration)

affect individuals and communities and responding with informed actions.

On this basis, this study defines 'SCMT' as:

> "The ability of students to interpret information from real-life contexts for use in mathematical thinking and to recognise that this thinking responds to social, political, economic, cultural and environmental interests, enabling them to critically address and solve these problems, taking a position and acquiring, from mathematics, arguments that open up new possibilities, breaking the political neutrality that exists in mathematics teaching in schools, based on the connection between mathematical knowledge and the responsibility of educating democratic and political beings" (Erazo et al., 2022).

This implies that students use mathematics to interpret everyday situations and the media they consume (e.g., news or social media), while becoming aware of how mathematical knowledge can serve or challenge power structures. In line with Skovsmose and Valero (2009), SCMT involves reconfiguring learning environments so that students are no longer passive recipients but become active participants capable of using mathematics to promote democracy and social justice.

In line with the above, the development of SCMT requires the configuration of *LS*, understood as contextual situations from the student's everyday life, which are analysed from a mathematical, technological and reflective perspective. In this way, students can make informed and participatory decisions in the policies of which they are a part, promoting true democracy, as proposed by Skovsmose and Valero (2009). Thus, students adopt a critical stance in such situations, ceasing to be passive individuals and becoming active agents in their context.

With a clear understanding of the concepts that structure this research, participating students were asked to reflect on what they consider to be the biggest problem in the world today. Based on this reflection, they were guided to select one of these problems and write an opinion piece (they were provided with the necessary foundations to construct this type of text). The opinion piece had to be supported by data taken from a mathematical model, tables or statistical graphs obtained from reliable sources, which allowed us to gather evidence on the process of mathematical knowledge acquisition in real contexts. This task will be described in greater depth in later sections, which detail both the methodological strategy used and the process of information collection and analysis.

In conclusion, SCMT is an educational perspective that recognises mathematics not as a neutral and abstract discipline, but as a cultural and political activity integrated into real LS, which seeks to foster critical and social awareness among students and empower them to question, analyse and transform their realities through mathematical reasoning. Likewise, in this research, the principles of SCMT are applied through the design and implementation of problem-solving tasks based on real and socially relevant contexts (e.g., environmental, economic or community issues). These tasks are introduced in primary and secondary public schools in Armenia, Colombia, with the aim of fostering a socio-critical mathematical mindset, where students are encouraged to engage in reflection, debate and collective action, guided by questions such as: What is the problem? Who does it affect? What mathematical tools can help us understand or respond to it?

METHODOLOGY

This research is framed within a critical social paradigm (Alvarado & García, 2008, p. 189). This is because it is not limited to an empirical or merely interpretative approach but offers important contributions to social change within the communities themselves, with the aim of transforming the structure of social relations. Furthermore, from a methodological perspective, this research is based on a qualitative approach, as this emphasises understanding and deepening phenomena, exploring them from the perspective of participants in a natural environment and in relation to the context, as it seeks to understand, act and transform reality with designs that are not modelled a priori and that allow flexibility within the research (Ñaupas & Valdivia, 2018, p.378). The study was approached from a critical methodology, as this allows attention to be focused on situations in the real context, such as the educational institution and the surrounding social and economic context. Given the characteristics of this research, it is appropriate to work with the action research (AR) method, since, according to Kemmis and Carr (1988, cited by Latorre, 2009), it is seen as a form of self-reflective inquiry, promoted by participants in social situations with the aim of improving the rationality and justice of their social and educational practices, as well

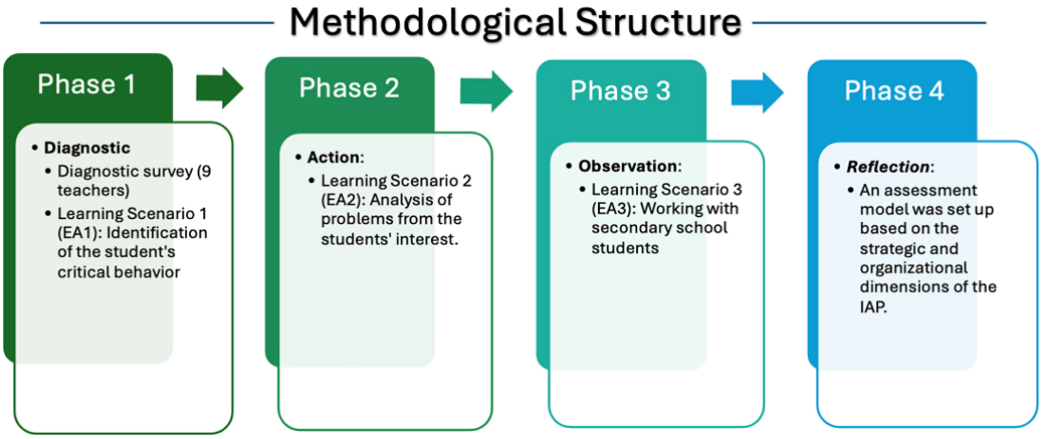

Figure 2. Methodological structure of the research (Source: Authors' own elaboration)

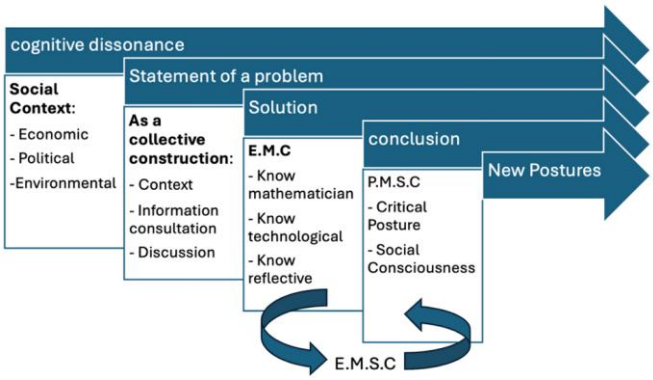

Figure 3. Structure for the development of socio-critical mathematical thinking (Source: Authors' own elaboration)

as empowering those practices and the situations in which they take place. Thus, AR is shown to be an instrument that generates social change and educational knowledge about social and/or educational reality, providing autonomy and empowering those who carry it out (cited in Pérez Serrano & Nieto Martín, 1992, p. 182-188).

The study was carried out in four phases (**Figure 2**). In the first phase, nine practising teachers with more than five years' experience in teaching mathematics were initially selected. These teachers shared their perceptions of the relationship between mathematics teaching in school and the social, political and environmental phenomena close to the students. Next, the critical thinking of a group of 11th grade students from a public school was identified through the design and implementation of an LS1 related to the environment and the economy, which involved mathematical processes such as proportionality and unit conversion, among others. This information was essential for the development of the data collection instrument, which was implemented in the second phase.

For the second phase, discussions were generated, in the classroom that allowed the exchange of ideas between students and the teacher, who posed destabilizing questions that generated cognitive dissonance in the students, as a starting point for said discussion. For Ovejero (1993), cognitive dissonance refers to the internal disharmony of the system of ideas, beliefs and emotions of an individual, who has two thoughts that are in conflict at the same time, or by a behaviour that conflicts with their beliefs. That is, the term refers to the perception of incompatibility of two simultaneous cognitions, all of which can impact their attitudes. By generating disharmony, they pose problems that may come initially from the teacher and then from the students and that require mathematical knowledge, the use of technological knowledge, to individually and collectively achieve reflective knowledge with these elements, in accordance with the development of the critical and socio-critical theory that has been developed in this work. It is important to note that this sample was different from the one selected in the first stage.

By having these elements, it is expected that the student will take a critical position in the face of a social situation and be able to argue it from mathematics (using socio-critical mathematics education–EMSC as a bridge), that is, the development of a SCMT that should ultimately generate new questions for the emergence of new problems in context. The above is shown in **Figure 3**.

The research was conducted using a non-probabilistic sample of approximately 60 11th grade students aged 15 to 18 from a public school in the city of Armenia, Colombia. 24 of these students participated in phase 1 and 36 in phase 2. As well as the intervention with around 9 secondary education mathematics teachers. The selection of these teachers was made through an invitation to all mathematics teachers in secondary education in the municipality of Armenia with the endorsement of the municipal education secretary of the same city, which makes this a representative sample of the total number of teachers in the municipality and the department.

To address the objectives set out in this research, two main sources of data were considered: on the one hand, a reflection workshop with secondary school mathematics teachers from public schools. Another

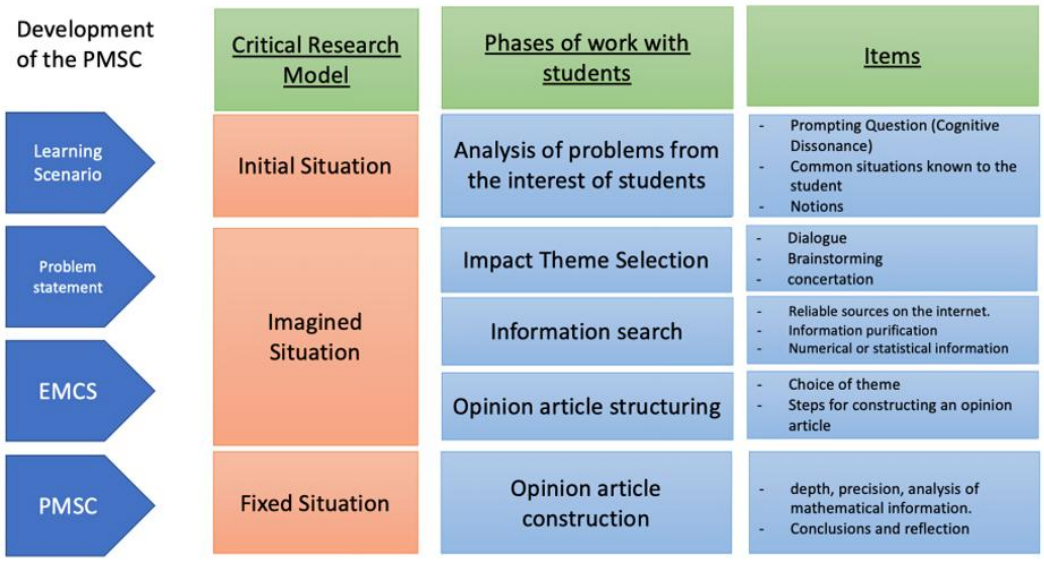

Figure 4. Triangulation (Source: Authors' own elaboration)

source is the textual productions of the students, understood as opinion articles in transversality with the area of Spanish language and analysis of environmental situations in transversality with the area of natural sciences. In the institutional work scenario of the workshop for teachers, the data are made up of the interactions between teachers and between teachers and the teacher-researcher when they generate critical processes (reflection, debate, building consensus, implementation of actions, etc.) as well as on curricular documents of national and institutional order and other curricular aspects of their practice, in relation to the approach with which the development of SCMT is assumed and promoted, the implications and training needs to assume the transformations of their practice. In this article, only the work, in real contexts, with students is analysed.

Phase three aimed at observing the socio-critical behaviour of students in the development of problem formulation and resolution. Various tasks were analysed using a matrix of previously established descriptors and those that emerged from the information obtained from the questionnaires, semi-structured interviews, and group discussions. Finally, in phase 4, the categories and descriptors used for the critical analysis of the data were described, developing a situational and personal theory of the entire process. Below is a brief description of one of the learning spaces that were developed during research phase two and the relationship between it and the theories presented.

Analysis of Problems From the Students' Interest

During virtual education, implemented due to the confinement caused by the COVID-19 pandemic, 11th grade students carried out an analysis of situations of interest to them, in collaboration with the Spanish language area, where they learned to write opinion articles. They were asked to research a topic of social, political or environmental impact and to do so, they had to consult reliable sources, collect data to support their thesis and, using various mathematical tools, analyse the information to reach conclusions based on that analysis. The purpose was to sensitize students about the problems that affect today's world from their own interests and that they could see in mathematics a powerful tool for understanding different phenomena and taking a critical position in the face of situations that affect them as citizens and political beings about to start an academic or working life (Skovsmose & Valero, 2009; Valero, 2018). **Figure 4** shows the triangulation between the SCMT, the critical inquiry model for mathematics teaching and the phases of AR.

Below are the results that emerge from the application of socio-critical approaches to the field of mathematics, with the aim of understanding and questioning the social structures and inequalities reflected in the teaching and learning of this discipline, as well as a data analysis, which examines how socio-critical principles can challenge traditional conceptions and promote more inclusive and emancipatory mathematical thinking. The results obtained in this study have the potential to inform and transform educational practices in the field of mathematics, promoting a more critical and reflective vision of this discipline.

RESULTS

By recognizing that socio-cultural theories in mathematics education conceive mathematical knowledge as a product of social and cultural interaction (Marrero, 2021), this research aligns with the perspective that knowledge develops in specific, historically situated and socially constructed contexts. In this way, thinking and knowledge emerge from individuals' participation in particular social situations, where ideas and concepts

Table 1. Opinion article topics (student work)

Issue	Qualification
Environment	The Malpelo sanctuary is in danger.
Economy	Consumerism, the greatest predator of humanity
Health	ITS is the best client for sex workers.
Environment	The dangers of "black gold"
Health	Pregnancy in teenagers
Environment	Our lung burning
Environment	The Amazon disappears beyond the news.
Pandemic	Quarantine is not for the poor
Environment	Colombia oil spills.
Violence	Is being a social leader in Colombia synonymous with death?
Health-poverty	Malnutrition in La Guajira
Health	Abortion, can we? Understand each other?
Corruption-politics	Odebrecht in Colombia: A road full of potholes
Violence-discrimination	The worst thing about being human is being inhuman.
Environment	The deplorable reality of pollinating animals

are inevitably influenced by the activities and socio-cultural contexts in which they originate.

In response to the LS, **Table 1** presents the opinion topics proposed by the 11th grade students who participated in this research. These topics were discussed, and each team, made up of two or three students, adopted one of them to design and construct an opinion piece based on mathematical, technological, and reflective knowledge. Each piece was then analyzed using the categories to determine the scope of SCMT.

Below is a selected article for analysis considering the semi-structured interview, the form of organization of activities as an LS according to the proposal of Skovsmose (1994) and its respective analysis according to descriptors and coders created for this research.

Opinion Article: Our Lungs on Fire[1]

The article, because of the LS, shows the students' concern about the forest fires that occurred in the Amazon rainforest in 2020. Furthermore, it is observed how, by interpreting a bar chart consulted on a reliable web portal, they built a quadratic regression model and, due to the fitting error, determined that this was not the appropriate model for said analysis (as shown in **Figure 5**), so they opted for an exponential model that allowed for a lower fitting error. This demonstrates the ability to argue as a process that refers to the why of what the student does when presenting reasoning to justify a mathematical procedure. To do this, we start by identifying a situation to arrive at reasoning and analytical judgments based on mathematical knowledge.

Figure 5 combines three graphical representations described below: graph 1 shows the rate of deforestation in the Brazilian Amazon, taken from the datawrapper.de website; graph 2 presents a scatter plot created by the students with data from the period 2000-2020; and graph 3 illustrates an attempt to fit this data set to a linear regression model.

A semi-structured interview was conducted with the students who wrote the opinion piece. Analysis of this interview (participants E15, E6, and E2) shows that they managed to use mathematics not as an end, but as a powerful language for understanding, quantifying and projecting a real problem: the loss of territory in the Amazon. Starting from an initial motivation linked to environmental and social concerns, and through a process of independent research, the three agreed on the selection of the topic due to its global and local relevance. The process involved searching for information from reliable sources, organising and visualising data using digital tools, and attempting mathematical modelling through regressions, facing methodological challenges and failures that they resolved by adjusting their approach.

The numerical result achieved (the estimate of 14,300 square kilometres of forest loss) was not an end point, but rather the argument that validated their concern and strengthened their call to action. This value became a supporting element for proposing environmental care measures and awareness campaigns both in the school community and in the surrounding area. The process allowed the students to move from personal motivation to the formulation of conclusions with scientific, ethical, and social implications, recognising the importance of environmental education as a driver of change and the need to inform and raise awareness among their peers about an issue that, although geographically distant, has direct consequences on everyone's lives.

The above characteristics, seen from the descriptors designed in the light of critical mathematics and SCMT, show that the group of students understand the concepts and procedures required to address the problem, and apply this knowledge to build and discern the relevance of using a mathematical model. They used the

[1] Full opinion article at: https://goo.su/z6r8mUs

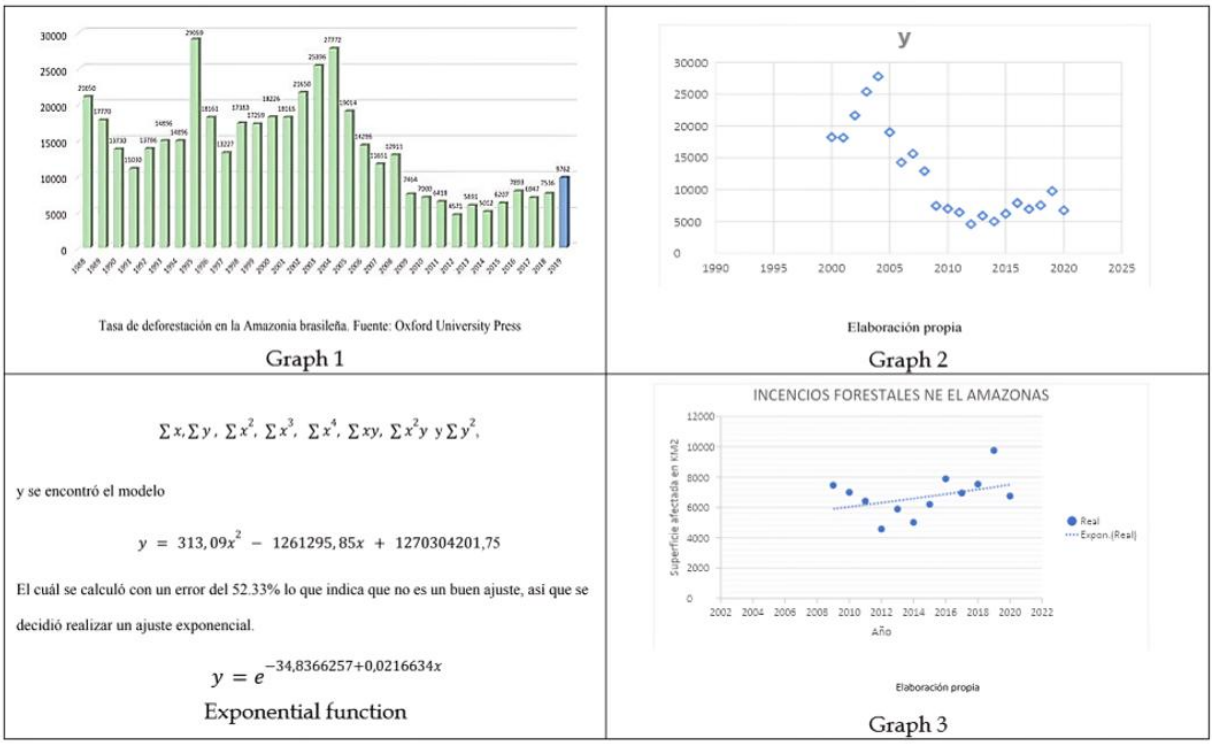

Figure 5. Mathematical analysis–Opinion article (Source: Field study)

Table 2. LS 2 (EA2)–A lung on fire

		Forms of organization of student activities	
		Exercise paradigm	Research scenarios
Transfer type	Mathematics	Quadratic regression model exponential fitting	Find the parameters of a parabola or exponential trend of a phenomenon to best fit a series of data
	Semi-reality	Construct a graph that best fits the situation given, considering the smallest adjustment error	Growth trend of deforestation rate in the Brazilian Amazon
	Real-life situations	How much of the Amazon rainforest will disappear by 2050 if historical trends continue?	What are the global effects of the devastating wildfires in the Amazon rainforest in 2020? What actions are the countries that preserve this lung of the world considering mitigating the environmental impact? What actions can we take to help preserve life on the planet from home?

appropriate technology to obtain these models, which allowed reflection on the use of mathematics and the social, environmental and ethical effects derived from it. Finally, the authors of the opinion article interpreted, from a real and current situation, information for the use of social and critical mathematical thinking, where they raise reflections on the role of society, regarding its interest in the environment and climate change.

With the results found and the analysis of the semi-structured interview, a critical position is shown regarding this environmental problem, in accordance with the objective of the proposed activity.

DISCUSSION

The results obtained show significant progress in the level of critical and reflective participation of the students. In the early stages, the productions focused on textbook exercises and decontextualised problems; however, at the end of the process, there was a clear transition towards context-specific problems and cooperative work in solving mathematical tasks. This change is reflected in **Table 2**, where the tasks progressed from the exercise paradigm, through semi-reality, to real-life situations, in accordance with the model proposed by Skovsmose (1994).

Thirty-six students participated in the main activity, 16 of whom wrote an opinion piece using real statistical data on environmental issues. A representative example is the article 'Our lungs on fire,' which analysed, based on reliable sources, a graph documenting the loss of forest cover in the Amazon due to forest fires. This work integrated data interpretation, the construction of a quadratic regression model, and an exponential

adjustment to project the estimated impact by 2050 if no government measures are taken. The analysis of the semi-structured interviews complements these findings: 30 students (83.3%) expressed a change in perception about the role of mathematics, recognising it as a key tool for understanding social, political, economic and environmental phenomena. This figure supports the assertion that designing tasks framed in real-life situations enhances students' ability to relate mathematical knowledge to socially relevant issues. Likewise, the transition from tasks based on environmental situations associated with mathematical concepts to projects involving socio-critical questions allowed students to develop evidence-based arguments and adopt an informed stance regarding their context. When they participated in critical and socially relevant mathematical practices, this promoted not only a deeper understanding of the concepts, but also a reflective attitude towards mathematical knowledge.

Finally, these findings suggest that a democratising curriculum enables students to move from being passive recipients of content established in national programmes or guidelines to becoming reflective and cooperative agents in the construction of learning environments. In this process, mathematics is no longer conceived as neutral knowledge but is positioned as a means of analysing, questioning and transforming reality, in line with the principles of SCMT.

CONCLUSIONS

The prevalence of students' own exploration of their social environment, over the coercion of activities drawn solely from the textbooks used in Colombian public educational institutions, issued by the Ministry of National Education, was a fundamental decision in the mobilisation of the PMSC. It was not a question of identifying the level of competence observed in algorithmic or procedural tasks, comparing them with other students or institutions, or granting privileges to those who are good at mathematics. Rather, it was about supporting the social and political subject in the teaching and learning process to consolidate a socio-critical mathematical competence that places citizen participation at the centre, at its heart, as its priority, having identified a socially risky practice that concerns and involves their social needs.

The main limitations of this study relate to its scope, duration, and implementation conditions. The research was conducted exclusively in public institutions in the city of Armenia (Colombia), which limits the generalization of the results to other educational contexts, furthermore, data collection was based mainly on interviews, observations and written work, which means that the findings depend largely on the students' ability to express their ideas and on the researcher's interpretation. Finally, external factors such as previous experiences with mathematics, family context or personal interest in environmental issues were not controlled for and may have influenced the level of participation and reflection achieved.

However, In the process of constructing the research, it was possible to conclude that in collective participation around problems that affect the community surrounding the student and in the area of mobilization of SCMT, teachers take distance, in their classroom practices, from the situations that the student experiences in his daily life or from those that at least affect him as an active part of society and as a political being. On the contrary, students are motivated by the development of mathematical concepts and procedures around these situations, so that they achieve autonomy and responsibility to carry out processes in different manifestations to clarify and act against practices of political, economic, environmental, health, among others, risk. From this perspective, students favored understanding and simplification from reading the world through dialogic strategies but especially valued the use of strategies from the development of the PMSC to extend participation outside of school, organize to act in the face of the naturalization of social facts, become sensitive to their own needs or those of others.

In conclusion, the work carried out allowed us to glimpse the meanings that secondary school students, mostly from stratum II and III, from commune 2 of the city of Armenia in Colombia, give to their social context, analyzed through mathematical tools, where the socio-critical action of young people could be observed in issues such as the environment, health, education, among others, with free participation, which sought at all times to raise awareness about the role of the student as a political being and his role in the social processes of his own community. These tasks allowed the configuration of an assessment model from the reflections of the actors involved, for the development of SCMT.

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Ethical statement: The authors stated that this study did not require formal ethics approval. Participants were students enrolled in a public educational institution who voluntarily answered an anonymous questionnaire and participated in interviews. No physical procedures were performed, nor were sensitive personal data collected. The students' mathematics teacher monitored and carried out the procedures described above. The authors also confirm that informed consent was obtained, and confidentiality was guaranteed.

AI statement: The authors stated that no artificial intelligence tools were used in the design, collection, analysis, or interpretation of the data for this research. AI-based tools were only used to facilitate minor editing and formatting of the text, under the full supervision and responsibility of the authors.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: The data supporting the findings and conclusions of this study are available from the corresponding author upon reasonable request.

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