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Spatial thinking in cartography teaching for schoolchildren

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ABSTRACT

We present data and analyses on school teaching practises that relate spatial thinking with the learning of maps from a cartographic education perspective. This study intends to support further research in the field of school cartography, given the increasing availability of digital cartographic resources in both the formal and the informal environments frequented by the individual. This increase in information demands a careful and critical reading of the cartographic data, although this requires a clear understanding of cartographic elements on the part of the individual. This reinforces the role of teachers in the classroom, given that they can contribute to the development of critical reasoning though the analysis of current geographic problems during learning activities in school cartography. The results presented here emphasize the importance of these contributions, but also demand substantial and consistent teacher training, in particular on the theories of spatial thinking.

Nous présentons des données et des analyses sur les pratiques d'enseignement scolaire qui relient la pensée spatiale à l'apprentissage des cartes dans une perspective d'éducation cartographique. Cette étude a pour objectif de poursuivre la recherche dans le domaine de la cartographie scolaire compte tenu de la disponibilité croissante des ressources cartographiques numériques dans les espaces formels et informels fréquentés par les individus. Cette augmentation de l'information exige une lecture attentive et critique des données cartographiques qui nécessite une bonne compréhension des éléments cartographiques de la part du lecteur. Cette réalité renforce le rôle des enseignants en classe dans la mesure où ils peuvent contribuer au développement du raisonnement critique au travers de l'analyse des problèmes géographiques contemporains lors des activités d'apprentissage en cours de cartographie. Les résultats présentés dans ce papier soulignent l'importance de leur contribution mais aussi rappellent le besoin en formation substantielle et cohérente des enseignants, notamment sur les théories de la pensée spatiale.

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1. Introduction

In this study, we present the partial results of a study of the relationship between spatial thinking and the teaching and learning processes in school cartography reports on the

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present. School cartography has been the subject of a number of studies in Brazil, such as those of Oliveira (1978), Simielli (1987, 1999), Almeida (2010), Vasconcelos (1993), and Martinelli (1998, 2017). Despite the consolidation of this field of research in Brazil, it is still necessary to reinforce its theoretical foundations, and develop an epistemic analysis, rather than an inventory of classroom experiences. There is a clear need to investigate themes such as spatial cognition and the epistemology of cartography, in order to promote the relevance of cartography for the formation of the citizen, to enable the understanding of an environmental disaster or extreme event, which requires more than the simple understanding of its location, but also a notion of its spatial relationships, such as its extension, density, area, and distribution.

While the theories that support research in the fields of cognitive psychology, spatial cognition, and neuropsychology have been expanding since the beginning of the twentieth century, these studies have only begun to become more mainstream in Brazil in the 1980s, through a number of studies based on genetic epistemology and, more recently, through the widespread adoption of the National Research Council (NRC, 2006) publication 'Learning to Think Spatially: GIS the a Support System in the K-12 Curriculum', which presents the concept of spatial thinking as a tool for the resolution of spatial problems. In this document, spatial thinking is presented as a type of thinking based on the construction of an amalgam of spatial concepts, instruments of spatial representation and cognition (NRC, 2006).

Studies of the capacity of the student to visualize and interpret places and their territorial configuration sup-ported the analysis of how learning activities stimulate the cognitive capacity of the student and their spatial concepts based on the use of representations. By using spatial concepts such as location, distance, and scale, the student is able to understand spatial representations, such as maps, graphs, and diagrams, and the application of these concepts to the resolution of problems, whether personal or academic, gives school Geography a meaning. This capacity is related to the development of cognition, from the simplest to the most complex level, for the understanding of territorial configurations. The ability to think spatially and apply this thinking to the stimulation of geographic reasoning with spatial concepts and cartography is still a challenge.

Since the publication of the NRC (2006), the debate has offered advances and reflections on the development of spatial thinking in the school environment. In Brazil, this document stimulated the reconsideration of education guidelines, the role of the teacher, in particular in Geography, and highlighted the value of school cartography.

1.1. The theoretical-methodological foundations

The theoretical fundaments of spatial thinking thus became an important input for research in school cartography and geographic education in the earliest school years (children of 6 years of age). This theoretical context is stimulated, in part, by the use of Remote Sensing and geoprocessing technology, which facilitates the acquisition of images, for example, and the construction, storage, publication, and divulgation of cartographic products. This perspective is fundamental to the analyses we present here, given that the basic structuring element of these different representations, such as thematic maps and geoprocessing, is geographic information.

These recent technological advances have greatly reduced the costs of producing and distributing maps, in particular through the internet, which has favored the free distribution of these materials. This scenario has resulted in a considerable increase in the number of users in search of digital alternatives for printed maps (Cartwright, 1999). The use of computer technology for cartography has enabled the combination of maps with other media, making them more dynamic and interactive (Canto, 2010). Geographic education has thus been obliged to accommodate learning processes that include the use of digital maps and satellite images, together with the discussion of spatial cognition.

In this context, one prominent author who has related spatial thinking to Geography is Phill Gersmehl (2008), whose research is supported by four cornerstones of Geography: location, condition, connection, and spatial reasoning. Gersmehl proposed, based on advances in the neurosciences, that distinct neural networks are employed in the different modes of spatial thinking. This proposal has become a fundamental reference in this field of research.

Gersmehl concluded that we solicit different cerebral connections during the use of a map, which may occur simultaneously. This author identified eight neurologically distinct modes of thought used to interpret the conditions and connections between places, which are related to different types of spatial representation. We highlight these modes here, given that they are intimately related to connections required for the development of geographic and cartographic in the school environment. These modes are spatial comparison, influence, groups (regions), transition, hierarchy spatial, analogy, patterns, and associations.

If we assume that spatial thinking is an amalgam of spatial cognition, concepts of spatial relationships, and representations, it is clear that it is made up of three fields of knowledge, which are potentialized through geographic reasoning, which depends on the categories and principles of Geography and their application in a geographic situation.

1.1.1. The spatial thinking

Therefore it is crucial to understand the variety of representations available, the processes of the cognitive development and the spacial concepts associated with the geographical principles, such as (location, dimensionality, extension, distribution, connection, continuity, proximity, separation, networks), and their different categories, and also to cognitive development.

Spatial thinking includes three fields of knowledge: representations, cognition and spatial concepts. The first field assumes the understanding of basic cartographical concepts the capacity to identify the type of map appropriate for each purpose, the most appropriate scale, and the visual variables that identify the phenomena. These aspects are decisive for students to critically analise their surroundings using models, sketches, satellite images, digital and thematic maps, and tactile maps, which involves both perception and the learning of spatial relations through the manipulation of a concrete object. The second field of knowledge here is the cognitive processes that we mobilize to understand and apply concepts, making decisions on the representation (e.g. scale), in order to solve problems using cartographic language, understanding the geographic perspective, and stimulating geographic reasoning.

The third field refers to the concepts of spatial principles (location, direction, orientation, distances, hierarchy, border, density, profile, gradient, among others) to make sense of geographic categories (landscape, territory, place, space and time).

Overall, then, spatial thinking it also contributes as a cognitive skill that can help teachers empower young people and improve the quality of Geography at school. From this perspective, Geography and Cartography are inseparable, stimulating spatial thinking and contributing to the autonomy and criticality of the students, which develops their geographic reasoning.

Studies of school cartography, which include conceptual understanding, map reading and use, mental maps, sketches, and interactive maps, all challenge us to understand geographic phenomena, with all their complexities, in both spatial and temporal contexts. This leads us to the analysis of didactic proposals, not only for teacher training, but also for the teaching of elementary school children with varying cognitive capabilities, types of map, charts, and other representations.

Castellar and de Paula (2020) presented a proposal for the more detailed analysis of the three elements of knowledge of spatial thinking, linked to the teaching of Cartography. For this, they first present the specific theoretical fundaments of each axis of spatial thinking. They then go on to discuss how spatial thinking promotes the development of spatial intelligence, which can be understood as the formation of a procedural content, in which ordinated actions, associated with learning strategies, are structured for the accomplishment of an objective:

> Without a doubt, spatial thinking is an amalgam, if we accept that the brain depends on the neural circuitry that is an amalgam of connections within an open system, to reproduce the connections among the functional structures and cerebral mechanisms that guarantee the transmission of the electrical pulses (synapses) that carry information. Spatial thinking is related to spatial concepts and representations. (Castellar and de Paula, p. 2)

This quote emphasizes the amplitude of spatial thinking, based on the stimulation of connections, functional structures, and mechanisms that can be systematized by many different school subjects. But by emphasizing spatial representations and concepts as fundamental components of this structure, the role of Geography is reinforced by the fact that this subject is responsible for the construction of part of these space-related concepts, and for introducing cartographic language into the school environment.

In this context, the connection between these fields of knowledge of spatial thinking, together with the epistemological statute of Geography, support a complex process of critical understanding of the world, which we understand as geographic reasoning. For geographic reasoning to occur in the school, it is important to construct a geographic situation that is appropriate for the intended analysis, which can be imagined as a bundle of events brought together in an attempt to glean a complete view of a phenomenon (Santos, 1997). This viewpoint encompasses the unique, the global space, and time.

For Castellar and de Paula (2020), 'geographic categories and principles, and the geographic situation, reveal the pedagogical potential of spatial thinking, which can be used as procedural content for geographic reasoning' (p. 308). In this case, geographic reasoning results from the relationships of the cognitive abilities, the ways of reading and interpreting phenomena through representations, which is a complex way of organizing the

arguments that account for the phenomenon being analyzed. The data collected in the present study will be used to evaluate the efficacy of these activities in the learning process in school cartography, considering the different fields of knowledge that contribute to the development of geographic reasoning. In this context, based on the theory and didactic pedagogical procedures, we present the partial results of a study of mental maps in 30 Brazilian children of 10–12 years of age.

2. The present study

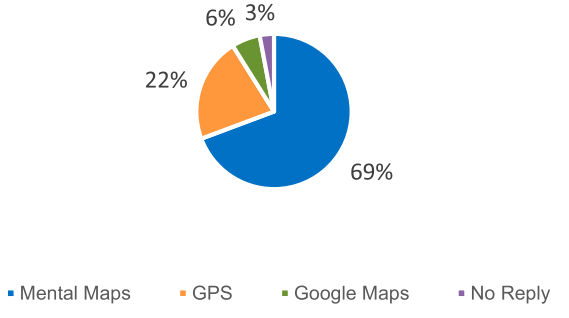
This paper reports on the present, ongoing study being conducted at a private school in Ribeirão Preto, a city 324 km north of the São Paulo state capital, in southeastern Brazil. This school is attended by students of middle to high socioeconomic classes.

At the beginning of 2020, prior to the COVID-19 pandemic, 30 students of 10–12 years of age – enrolled in the 6th year of elementary school – were encouraged to use their capacity for spatial thinking in a practical activity that was presented during Geography lessons, with the theme of cartography.

During each 50-minute Geography lesson, the students were encouraged to produce their own maps to represent the route from the school to their houses. This activity was part of the diagnostic evaluation, which was used to determine what cartographic knowledge the students already had, and to identify the causes of their specific difficulties for the assimilation of this knowledge.

This activity began with the following questions: Where do I live? Where is my place? How did I get here today? How can I show my route?

This initial discussion was an attempt to remind the students of the contents presented in the preceding school years, and to encourage them to recognize the usefulness of this knowledge for the understanding of their everyday lives. For analysis here, we focus on the latter question – How can I show my route? The answers were distributed as follows:



More than two-thirds (69%) of the students considered the production of a mental map to provide the best solution to this question. This was because they had experience of this activity in their previous years at school.

As mentioned above, digital maps have become increasingly common in both the formal and informal environments experienced by the individual. Here, almost one third (28%) of the students considered digital maps to be the appropriate resource for the resolution of the problem, even though, when asked to justify their response, most of the students did not know how to use the digital tools they had suggested. One

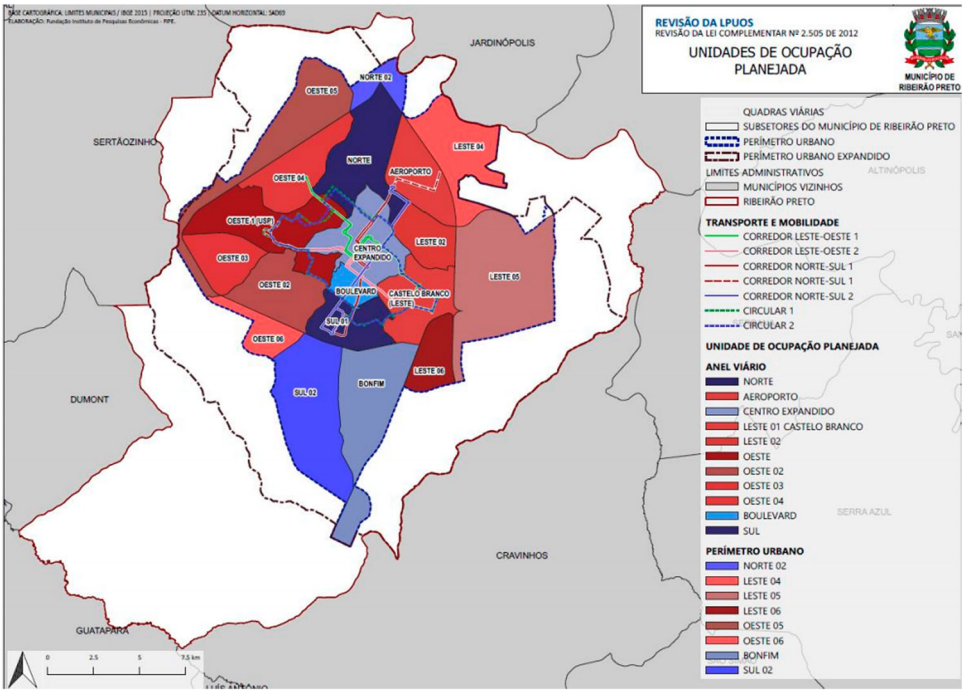


Figure 1. Zoning of the city of Ribeirão Preto in 2019.

student did not answer the question. In this specific case, we noted that the student had had little or no contact with maps in the preceding school years.

For this activity, we worked the contents related to spatial localization, while involves the concept of location, that is, by indicating the location of the school and the zoning of the municipality of Ribeirão Preto. Using their tablets or smartphones, the students attempted to identify the zone in which they live, and the zone in which the school is located. At this point, it was necessary to revise the contents of cartographic orientation to provide basic guidelines for the nomenclature of the different zones of this municipality (Figure 1).

The responses of the students indicated that they had difficulty defining the zones occupied by the city using a compass rose, and that this location tool is rarely or never used, in practise, by the students. The students were able to identify the cardinal and colateral points, but had great difficulty using these elements.

Given this, we decided that the use of mental maps would be an adequate strategy to stimulate the understanding of geographic contents by the students. Mental maps are representations that demonstrate elements of the perception, culture, and the imagination of the students in all years of elementary school. These maps allow us to explore the places lived by the individual, and their perceived and conceived spaces. We can use these maps to evaluate the identity and the relationships that the students construct with the place in which they live, as well as the geographic elements that make up these places.

Mental maps are cartographic representations due to their fundamental emphasis on characteristics of location, conditions, and spatial arrangements. When producing a map, the student experiences the work of the cartographer, who has to insert reference points, organize the legend, and establish relationships of distance and orientation. To do this, we:

> […] evaluate the drawing of the lived space, such as a mental map, to understand part of this process of development and the learning strategy which, in addition to stimulating the cognitive development of the student, permits the understanding of the function of cartographic representation and spatial concepts, while also developing the spatial thinking abilities that are essential for the student to understand any representation of the world. (Castellar & Juliasz, 2017, p. 164)

Based on the observations presented in the theoretical lessons, and their own reflections during the discussion of theories and their everyday lives, the students were challenged to construct a mental map. This content was related to spatial concepts and their organization when proposing trajectory between home and school.

As free representations, the use of mental maps enables us to analyze the importance of these depictions in the construction of spatial concepts and geographic principles, as well as the identification of which cartographic elements contribute to the understanding of the student. In this context, the present study was based on the analysis of the images, through the assessment of four items: I – distribution of the elements; II – the symbology and the elements of the landscape used in the map; III – cartographic elements (e.g. construction of the legend, orientation, title, scale), and IV – the presentation of other aspects or details (messages, urban contrasts, social aspects, environmental problems, etc.). We verified which of these items were relevant to the fields of concept, representation and spatial cognition.

3. Results

Based on the mental representations presented by the students, we analyzed how they perceive and interpret the places of their everyday experiences, which symbolic elements they use, and how they construct their social relationships with the space in which they live. As they participate in the activity and the questions raised in the classroom, cartography begins to make sense to the students, when they consider the legend, proportions, how to understand the route on the drawing. The mental map permits that the student understands the map as a *social construct*. When drawing the map, the student needs to think about space, select prominent elements that should be highlighted and others that should be suppressed, thereby experiencing the social context of the production of a map.

During this activity, the students begin to perceive the importance of the symbols in the legend, in terms of their color, shape, and size, thus understanding that the map is a language that expresses geographic information on places. This type of activity also highlights the value teaching using maps, and through maps, which makes cartography and geography inseparable.

The students also perceived that their maps are not exact copies of reality, but rather an approximation that uses a selection of the information available on real places. This

perception potencializes a critical reading of reality, given that, when producing and reading the map, comparing it with reality, and conversing with classmates, the student learns the process of the construction of mental map and how the elements present in their everyday life are interpreted.

In terms of spatial thinking, in the field of representation, this activity provided insights into the viewpoint assumed by the student when producing the map. While this question was assumed to have been resolved in students of this age, the viewpoint proved to be a major problem in this activity, and approximately 70% of the students used both frontal and vertical viewpoints simultaneously.

This way of perceiving the world is related to the spatial perspective of the students. Although they had experienced the construction of maps during their preceding school years, the idea that a map is a language which represents a vertical viewpoint of the elements of a landscape was not well developed. We perceived that maps are used rarely, if ever, to work on the geographic content, which means that the student is poorly equipped to resolve problems or interpret spatial phenomena. This reinforces the conclusion that the curriculum of the pedagogical training of the early elementary school teachers should include disciplines that cover both Geography and Cartography more systematically. This would help ensure the development of spatial thinking as early as possible, to guarantee the autonomy of the student for the production and interpretation of maps.

> The use of symbols, signs, and colors was related to the visual variables. These choices permit reflections on the spatial relationships that the symbols represent. In other words, the student understands that the symbol was not chosen at random, that it has a specific objective, and a function on the map. This symbolic representational thinking on the mental map stimulates spatial thinking through learning situations that use symbols and signs, that is, visual variables. (Castellar & Juliasz, 2017, p. 166)

The activity with mental maps also allowed us to recognize how the students perceive the city, based on the size of the mapped area, the distances, and the directions of the trajectory. The comprehension of location, distance, and scale also allows the student to understand digital or interactive maps, by using technology, which gives the maps a social function and contributes to the reading of reality. The concepts of scale, distance, direction, and orientation are used to this end, given that the map 'must fit on a page', as one of the students put it.

The distance between places is part of the cognitive process of spatial relationships represented by a map. The process of comparing distances on a map and in real life articulates the concepts of conditions and the connections between the points on the map. The activity using mental maps to represent places and trajectories mobilized abilities, such as the so-called spatial transition (Gersmehl, 2008).

As the fundamental principle of Geography is the location of objects and phenomena, when the student designs a map, this activity permits them to think about the location of objects within a given space, which is frequented by the mapmaker. This process develops the spatial notions that correspond to the concepts of location, neighborhood, condition, and connection. It also permits the mobilization of the cognitive field of spatial thinking, by formulating a hierarchy among the objects represented on the map, highlighting those judged to be important during the trajectory, and excluding the objects

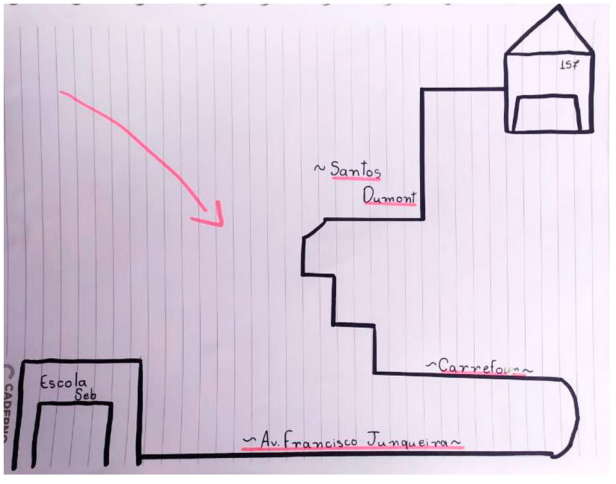


Figure 2. Mental map produced by student 'A'.

that are lower down in the hierarchy. We will discuss these general findings in more specific detail below.

3.1. Analysis of the mental maps of the students

For a more detailed analysis, let us first consider the mental map of student A (Figure 2). From a more general cartographic perspective, it is interesting to note that the student has used a frontal viewpoint for the origin and endpoint of the trajectory, but a vertical viewpoint to represent the trajectory itself. As mentioned above, while we expected the students to have advanced beyond this level, given their age, most of the students used a mixed viewpoint (vertical and frontal), which they justified by saying that, by showing the façades of the chosen reference points, they were facilitating the identification of these objects by the readers of their maps.

This student overlooked a number of different types of information along the trajectory, deciding instead to represent only the reference points that facilitate the recognition of the route. However, the selected points were not marked with symbols, but rather, with names.

There is no reference to any of the other basic elements on the map, which may reflect a very poor initial cartographic formation. In terms of the elements of spatial thinking, however, when this student verbalized the process of the development of her map, it was possible to confirm that she had assimilated the concepts of location, distance, condition, and connection, which mobilize specific abilities.

The location is the starting point, from which the student arranges places and objects on the map. During this process, the ability of the student to determine the hierarchy of the elements that would be included in the map, in order to define the trajectory.

This student clearly worked with the concept of distance, given that the longest lines on the map represent the greatest trajectory times. The verbalization of this student also consisted of reflections on what was close and far away, which part of the trajectory took longer to travel, and so on. This allowed the student to use their ability to recognize the

Figure 3. Mental map produced by student 'B'.

influence of space, by identifying and creating references to determine the position of a place or object.

Finally, the concept of connection was expressed by the analysis of how the objects are linked, identifying the position of an object in relation to a second object. This allows the student to identify the order of the objects by selecting the way in which the elements are represented.

The second mental map (Figure 3) was produced by student B. An initial cartographic analysis of this map shows that the vertical viewpoint was employed to represent both the roadway elements and the buildings found along the trajectory.

This student also opted to name these features on the map, rather than using a legend. Once again, the map has no orientation.

Although the activity used here did not aim to evaluate the cartographic rigor of the map production, it is important to note that the Cartography learnt in school appears to be completely unconnected with the actual production of the map, even considering that it was a mental map. We did not expect the students in this age range to use coordinates or scales, that is, more robust content, but we did imagine that they might at least use the sun as an auxiliary resource for the orientation of the final product. This is because this content was revisited in the activity on the urban zones of the municipality of Ribeirão Preto. Given these results, we perceived that orientation and the compass rose would have to be explained, not as a revision of the contents of the previous school year, but rather, as a new content to be presented during this activity.

These same considerations would also apply to the question of the vertical viewpoint of the map. Following these initial considerations on the qualities and drawbacks of the mental maps, we analyzed which spatial thinking concepts, irrespective of the cartographic problems, were present in the representations.

Like student A, student B began the map based on the location, selection, and distribution of the objects. However, in contrast with the former case (student A lives near the school), the distance traveled by student B is much greater.

Student B included abstract categories of elements that are part of the landscape and the environment, such as the trajectories and the reference points, which have a hierarchical relationship that determines their inclusion on the map. In particular, we note the presence of an irregular occupation (the colored squares) along the trajectory, which may be an important element for the mobilization of the notion of transition and spatial influence.

One other element that mobilizes concepts and spatial ability, and is found on both maps A and B, is the streets. As mentioned above, these lines (streets) impose an order and spatial sequence of the objects in space, and also permit the establishment of spatial notions, such as neighborhood. This student also employed the concept of connection to link the reference points, which are ordered in accordance with the visual memory of his trajectory.

Given their creativity in the production of their maps, the students experienced the work of the cartographer and the importance of the elements present on the map. Even so, the students still present deficiencies in many aspects of their Cartography, which generate insecurities during the production of the cartographic representations. These doubts were raised in questions such as 'will it fit?' 'Do I start at the school or my house?' and statements like 'I can't do it' and 'I can only do it using Google Maps', which reflect a preoccupying scenario in terms of the potential for learning from and through maps.

On the positive side, in addition to mobilizing the development of logical reasoning for functions such as the capacity to select, group, and classify, the activity also enabled the students to reflect on these spatial relationships, which they attempted to demonstrate in their drawings. The group of students were able to recognize their living space, locate objects, move through space from memory to represent it on paper, as well as identifying directions. These are the elementary contents of spatial thinking, which should be developed in the students through the teaching of Cartography.

4. Final considerations

In the present study, we evaluated the importance and use of mental maps and the development of cartographic literacy in the early years of Brazilian elementary education. The results highlighted the importance of classroom activities that stimulate the students to read and draw maps, and also showed that mental maps allow these children to recognize their living places, and stimulate cognition and spatial thinking, and, as a consequence, geographic reasoning. The results of this study also reinforce the idea that Geography has an important social function, by providing knowledge that permits the understanding of the real world, the lived space, and roles, and the relationships between society and nature, as well as using maps as the language to represent phenomena and places.

The present study is part of a larger project on the use of maps that aims to assess the functional spatial-thinking structures found in young school-age children and also contribute to their understanding of geographic contents. Spatial thinking, which includes geographic contents and concepts, and their representations, also involves reasoning, defined by the abilities developed to understand the structure and function of a space and describe its organization and relationship with other spaces, that is, to analyze the order, relationship, and the pattern of spatial objects.

For this type of analysis, the students must be stimulated to think spatially, thereby developing their geographic reasoning. The correct use of geographic concepts mobilizes spatial thinking, and by applying procedures of research and analysis to process the geographic information, the students can recognize many of the phenomena that surround them, such as inequalities and the exploitation of natural resources. Geography serves to delimit, structure, and revalidate this cognitive domain based on the geographic situation (Santos, 1996; Silveira, 2010).

We thus believe that a learning activity based on a geographic situation which involves the construction of a mental map, for example, can initiate a methodological sequence in the classroom. By stimulating the thought processes of the student through the analysis of their inhabited space, which stimulates their ability and willingness to read conventional cartographic representations of varying levels of complexity.

The teacher that employs activities of this type in the classroom will be able to understand how the child conceives and represents the observed space. For this, it is important that the teacher, whether pedagog or specifically of Geography, learns cartography, to be able to teach and interpret the results of the students' efforts, supervising the practical activities in the classroom.

Mental maps are an important cognitive tool that mobilize spatial thinking. By proposing that the students conduct spatial analyses using maps, they understood the concept of location, which enabled them to develop their understanding of Geography through the question 'why things are where they are' (Lacoste, 1973; Martins, 2007). The students also considered the concepts of direction and distance, reflected on the elements used in representations, such as symbols and trajectories, which stimulate the spatial cognition of the map maker and user, thereby establishing an incipient, critical reflection on space.

By highlighting urban problems, such as potholes in the street, polluted streams, and rivers lacking riparian vegetation, as reference points, the student begins relate connections and spatial analogies, and begins to perceive their lived space, which provokes a change in posture that implies the application of geographic reasoning.

The results of the present study reinforce the hypothesis that schoolchildren are able to develop spatial thinking – including concepts, abilities, and spatial representations – and that concrete geographic situations can contribute to the development of geographic reasoning, based on the production of their own maps and their contact with an ample sample of cartographic representations.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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