School Cartography and Spatial Thinking of Brazilian Students at the end of Junior High School

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Abstract: *This paper was written under the assumption that the main purpose of keeping Geography in the K-12 curriculum is to foster the development of a particular kind of reasoning that can be called geographical. To achieve this goal, we strongly believe in the importance of School Cartography and the development of student's Spatial Thinking. This mode of thinking has been consistently defined as a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning. Using such a framework we have administered the STAT (Spatial Thinking Ability Test) to 268 students of six different Brazilian schools in the state of Rio de Janeiro, all of them finishing their 9th grade. The results help us to diagnose how well Geography teaching in Brazilian schools is achieving the goal mentioned above. It may also help guide future strategies to overcome the pedagogical problems regarding the development of Spatial Thinking using Cartography and Geography in school.*

Keywords*: Spatial thinking; school cartography; geographic education; assessment of spatial thinking.*

A cartografia escolar e o pensamento espacial dos estudantes ao final do fundamental brasileiro

Resumo*: Este texto foi elaborado a partir do pressuposto de que o propósito maior do ensino da Geografia na escola básica é o de fomentar o desenvolvimento de uma modalidade de pensamento ou raciocínio que pode ser adjetivado de geográfico. Para esse fim, defende-se a centralidade da Cartografia Escolar e do desenvolvimento do pensamento espacial discente. Essa modalidade de pensamento tem sido definida como a fusão de três elementos: conceitos espaciais, instrumentos de representação e processos de raciocínio. A partir desse referencial teórico aplicamos um teste de habilidades do pensamento espacial predominantemente associado à cartografia e que foi desenvolvido por dois geógrafos, um estadunidense e um coreano. O teste foi aplicado a 268 alunos do nono ano do ensino fundamental de seis escolas diferentes do Rio de Janeiro. Os resultados ajudam a diagnosticar em que medida a educação geográfica nacional está dando conta da finalidade supracitada e permite orientar o desenvolvimento de futuras estratégias pedagógicas que visem a superar os problemas identificados.*

Palavras-chave*: Pensamento espacial; cartografia escolar; educação geográfica; avaliação do pensamento espacial.*

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Objectives and theoretical framework

This text is based on the conviction, shared by many researchers in the area, that the general objective of geographic education is to contribute to the development of a type of thinking or reasoning that is eminently geographical in character, and which is inseparable from the foundations of scientific geography. School cartography and the development of spatial, or more explicitly for our purposes, geospatial thinking, are inserted within this macro objective. We define the concept of geospatial thinking along the lines established by authors such as Huynh and Sharp (2013), who understand it as the application of spatial thinking to problems and contexts that require geographical information.

We therefore make it clear that the development of spatial thinking and of competencies associated to graphical language in general and to cartographical language in particular do not constitute an end, from the perspective of geographic education, but rather, are parts of the broader process of developing geographical literacy, or in other words, of the process of construction of a way of thinking that is geographically founded, through which learners can interpret reality.

In other words, the core task of geographic education is to teach learners to think geographically. To think spatially and learn to master cartographic language are, in our field of interest, essential means towards this end and not the end within themselves. Based on the works of authors such as Bednarz and Kemp (2011) and Castellar and Vilhena (2010), we understand that these two sets of competences are indispensable for developing spatial literacy, which is inherent to geographical analysis. Our focus, therefore, will be on the importance of spatial thinking as one of the theoretical methodological foundations for developing cartographic literacy within the setting of Geography teaching in primary and secondary school. To help synthesize the key idea of what constitutes geographical thinking, we cite Reginald Golledge, who wrote: “In sum, geographical thinking and reasoning provides the basis for understanding - or rationalising - about why special effects exist and not just discovering what they are.” (GOLLEDGE, 2002, p.6).

We are aware of the enormous difficulty involved in defining precisely what constitutes geographical thinking, comparable to trying to define geographical science itself. The obstacles start with the founding scientific paradigms of attempts to reach a definition and extend with everything we still need to learn about cognitive processes, despite the advances provided by Neuroscience.

Throughout the epistemological history of geography, many authors have sought to define the parameters of this geographical thinking or reasoning. To mention just one relevant example, one of the most important names in the history of the science, Carl Sauer, speaking at the opening Conference of the 52nd Annual Meeting of the Association of American Geographers, in 1956, used a metaphor that helps to define the theme of this text, that of people with a certain geographical bent, or rather, who are inclined to thinking geographically:

> May a preselective bent toward geography be recognized before it asserts itself as deliberate election? The first, let me say most primitive and persistent trait, is liking maps and thinking by means of them. We are empty -handed without them in lecture room, in study, in the field. Show me a geographer who does not need them constantly and want them about him, and I shall have my doubts as to whether he has made the right choice of life. (SAUER, 1956)

To cite an example of an important recent Brazilian geographer who agrees with this line of thought regarding the singularity of geographical thinking, we would also quote Paulo César da Costa Gomes, who wrote:

> What is geography? It is a way of thinking. That is what it is about. This text is a daring attempt to demonstrate that, beyond those aspects that we normal associate with Geography, it is also an original and potent way of organizing thinking. (GOMES, 2017, p.13)

We do not intend, within the scope and purposes of this paper, to go deeply into the discussion about what constitutes Geography and geographical thinking. We simply wish to affirm that, in our opinion and in that of various other authors, some of whom are quoted within these pages, the set of skills and competencies that are related to thinking geographically include the capacity to think spatially and to operate with graphical and notably cartographical representations. Consequently, we understand that the development of this pair of interrelated competencies should be considered one of the core objectives, or even the backbone of geography teaching in primary and secondary school. At least, if our objective is to build a more singular contribution through geography for our future citizens, always in close dialogue with the other fields of knowledge that make up the schooling process.

Taking this perspective as our starting point, we began to question the efficiency of geography teaching in schools when it comes to developing these two competences, notably with respect to spatial thinking, which is little known and not usually discussed in a systemic manner.

To try to ensure coherence and seeking appropriate theoretical foundations to support this point of view, we have adopted the theoretical field known as spatial thinking as the primary foundation for our investigation. Spatial thinking is a field of interdisciplinary studies that spans the areas of interest of several subject areas, particularly those of cognitive psychology, Mathematics and Geography, but also involving many others. The core to the definition of spatial thinking can be found in a document that has become the standard for discussion on this theme, the U.S. National Research Council (NRC) report, published in 2006. In the introduction to the document, we can find a definition that has become the benchmark for this field of research and which consolidated understanding regarding the three cognitive pillars of spatial thinking: “Spatial thinking—one form of thinking—is based on a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning.” (NRC, 2006, ix).

While we can’t dwell for long on the discussion of what constitutes spatial thinking in this text (for a discussion of the theme in Portuguese, please see DUARTE, 2017), we should clarify that spatial thinking is not in any way a concept that is exclusive to geography. It is present in all areas of our everyday lives. When we walk down a busy street we use our most basic and intuitive spatial thinking skills to avoid bumping into other people. We also use this type of cognition to decide on the best route between two points in a city, to distinguish between the shapes of the letter “A” and the letter “H”, to identify the symbols used on road signs, to organize the furniture in a room and to play sports. The list of examples is endless.

Likewise, in a more systematically-acquired manner, we use and develop spatial thinking in our geometry lessons, when studying mechanics in physics, in artistic or geometrical drawing classes, and in our physical education activities. However, we are among the many authors who understand that there exists a powerful and singular intersection between spatial thinking and geography (which we defined previously as geospatial thinking) and this intersection contributes strongly to the capacity of the students to read/interact with the world as citizens and professionals.

Methodology

Taking this theoretical framework as a reference, we propose to apply a diagnostic assessment to students finishing the ninth grade of their K-12 education. With this, we aim to demonstrate the need to rethink teaching practices in relation to map-work and to spatial thinking in elementary school, using the results of a Spatial Thinking Ability Test (STAT) that was applied. The STAT was developed by two geographers, an American, Robert Bednarz, and a South Korean, Jongwon Lee (2012), to whom we asked for authorization to use the instrument. The test was developed specifically to evaluate the spatial thinking of students according to the definitions and parameters of this mode of thinking and focusing on that spatial thinking which involves graphic representations. It consists of 16 questions, 8 of which require the use of maps, 4 of which assess the logic of cartographic language but without the use of maps, and 4 classic questions taken from spatial skill tests in the area of psychometry, using geometric figures.

The test was applied to 268 students in their 9th grade in six Rio de Janeiro schools: 1 private upper-middle class school in the southern Zone of Rio de Janeiro (84 students), The State University school – CAp-UERJ (59), a large public state school (CIEP) from the Duque de Caxias city system (48) and three schools from the Rio de Janeiro city system (77). The results obtained were compared with those obtained with the application of the same test in a U.S. high school (LEE e BEDNARZ, 2012) and in three Rwandan high schools (TOMASZEWSKI et al., 2015).

The schools in which the tests were applied, all of them within the state of Rio De Janeiro, can't be considered a truly representative sample for Brazilian 9th grade students, since they are generally considered among the best schools in the states. One of the city schools in the survey was ranked second-best in the state in 2013 and the other two are placed in the top 30%. In that same year, the University school (Cap – UERJ) achieved the third best ranking in the state, while the private school is considered a centre of excellence with outstanding results in the state university admission tests. It is clear, therefore, that the standard of academic performance of the respondents is considerably higher than the average for students in the state and the country as a whole. Nevertheless, the results allow us to reach some important conclusions concerning the degree to which students have developed their spatial thinking as it relates to geography by the end of their 9th grade.

General overview of comparative international cases

In this section, we will analyse the results taken from 3 international cases to which we have access to data regarding the application of the test, considering just the overall percentages of correct answers, for each group of schools. The results presented in Figure 1 express the proportion of questions that were correctly answered among the 16 that make up the Spatial Thinking Ability Test (STAT).

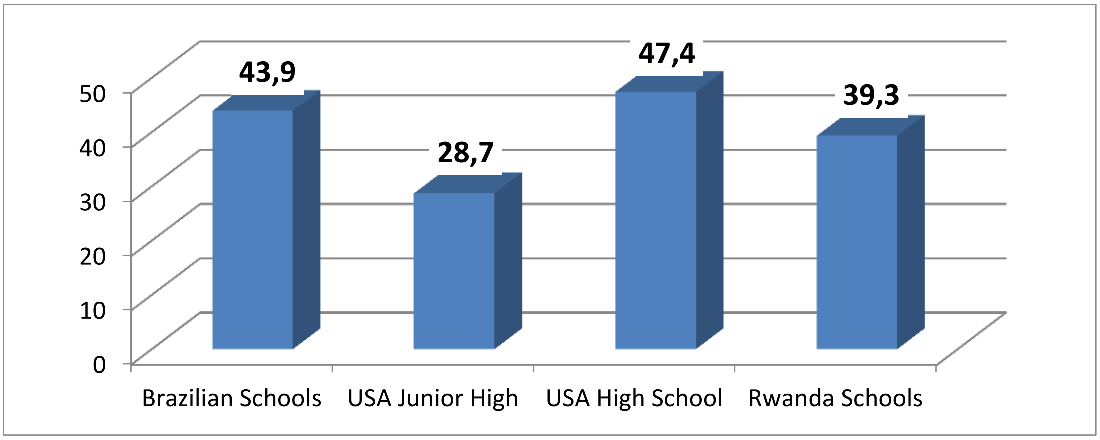

Figure 1: Percentage of Correct Answers to the STAT questions.

Fonte: Duarte (2016).

One of the findings that stands out is that none of the groups of students managed to get more than half of the questions right. In the best average, that of the U.S. high school, students managed to get an average of 7.6 questions correct out of sixteen. In the worst average, of the junior high school, students only managed to answer 4.6 items successfully. That means that for every correct answer, they got three wrong.

The literature relating to the elaboration and application of the test does not provide parameters as to what might be considered an excellent performance in the test, nor even as to what might be the minimum acceptable performance for students in each age group. However, it seems clear to us that average results below a 50% success rate cannot be considered excellent. Within the comparative analysis with Brazil, we should remember that the North American data to which we have access is the most fragile, because it refers exclusively to one specific school in the state of Ohio. Meanwhile, it comes as no surprise that the average performance for the Brazilian Schools was significantly better than that observed for the students from a U.S. Junior High School (in the majority of North American states, the junior high years are roughly equivalent to Brazil's 6th, 7th and 8th grades, while their high school years cover what we call our secondary schools), considering that these students are slightly younger (and consequently have developed their abstract thinking to a lesser degree) and have had less years in school. Within this age group, one or two years less in school can make a considerable difference, especially with regard to various aspects of spatial thinking.

Within the same line of thinking, the performance of U.S high school students, which is slightly better than that of their Brazilian counterparts, also comes as no surprise, particularly when we remember that their national average reflects the participation of students who are largely well above the average educational levels in Brazil, given the academic profiles of the schools in question.

In the case of the Rwandan schools, the average results which were not so different from those in Brazil (7 correct answers out of 16 for the Brazilian schools and 6.3 for the Rwandan students), which gives us some cause for reflection. In the first place, it should be mentioned that the universe of respondents from the African country is far more significant than in the case of the United States, not only because it covers three institutions (as opposed to just one), but also because of the diversity of these institutions and the expressive number of students that participated in the survey. In addition, even if we consider that some of the Rwandan respondents represent elite segments of the country's population (at least in the case of one of the institutions, GSO-B) we shouldn't lose sight of the fact that the country is one of the poorest in a very poor continent and that the nation in question was dilacerated by a devastating Civil War just two decades ago. It should also be noted that the results published by Tomaszewski et al (2014) refer to the initial diagnosis of the students who, since then, have been taking part in a program implemented by the authors to foster the development of spatial thinking, including the use of Geographical Information Systems (GIS). As such, when the same students take the test again at the end of their high school years, the results are expected to be considerably higher.

In light of this situation and considering that the Brazilian results are inflated by the high quality of an expressive proportion of the respondents in our sample group, it seems clear to us that our national performance leaves a lot to be desired. Nevertheless, we must make it clear that although we are using our logic and common sense, we can't support these points with any scientific studies (which as yet do not exist) regarding desirable performance profiles in tests of this type or based on a broader pool of data involving the application of this or another instrument for the diagnosis of spatial thinking.

The graph in Figure 2 shows how well each of the Brazilian schools performed individually as compared to the general average for Brazil and for the other two countries.

As an analysis of the graph makes clear, there is a considerable gap between the performances of the students of the CAp – UERJ and the Liceu Franco-Brasileiro schools as compared to those of the other Brazilian schools. Both institutions achieved 50% averages, performing better than all the other groups, including the high school group in the United States. On the other hand, the average for the Duque de Caxias state school group, whose students only answered one third of the questions correctly, was only slightly better than that of the U.S junior high students, the youngest group in the survey.

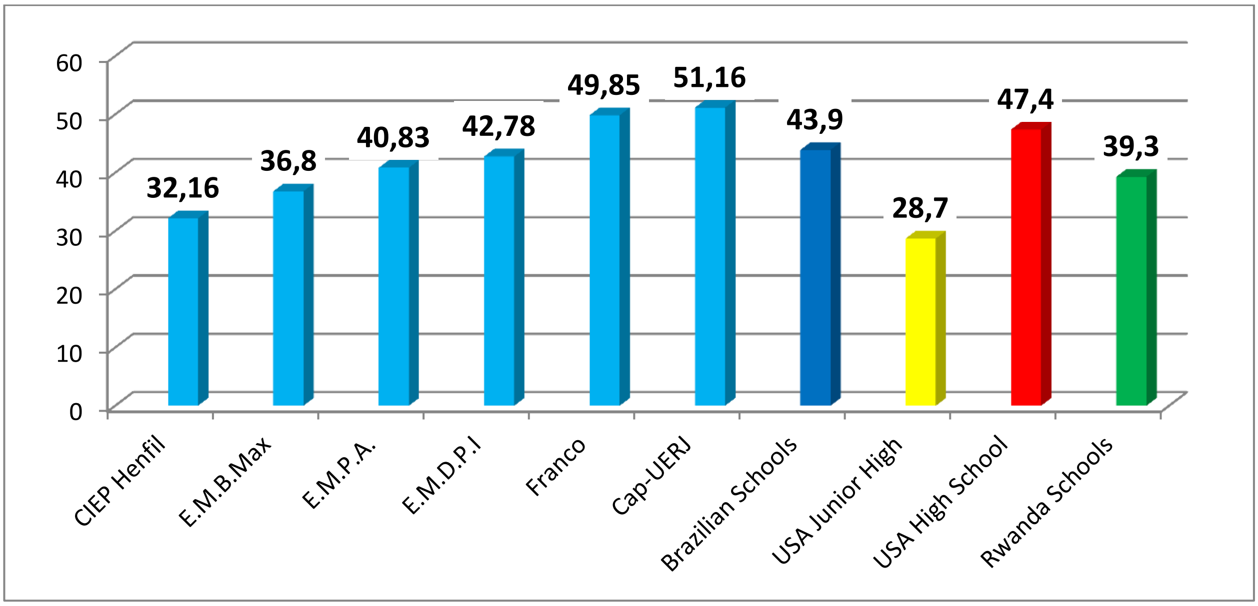

Figure 2: Overall percentages of correct answers to the STAT questions.
Fonte: Duarte (2016).

Some comparisons between the Brazilian and the International results, by question groups

When choosing to use the STAT as a diagnostic instrument, one of the methodological aspects that weighed most in the decision was the fact that Lee and Bednarz firmly anchored their criteria for selecting and organizing the questions in the test on the most relevant research that existed in the field regarding the parameters for assessing spatial thinking. With respect to spatial thinking skills and modes, in particular, they based their work on the research of Phil Gersmehl and Reginald Golledge, two highly-regarded authors in the field of spatial thinking. As a result, the authors identified eight modes of spatial thinking around which they built up and grouped the questions for the test.

I – Comprehending orientation and direction.

II – Comparing map information to graphic information.

III – Choosing the best location based on several spatial factors.

IV – Imagining a slope profile based on a topographic map.

V – Correlating spatially distributed phenomena.

VI – Mentally visualizing 3-D images based on 2-D information.

VII – Overlaying and dissolving maps.

VIII – Comprehending geographic features represented as point, line, or polygon.

We should also point out the STAT was revised by a team of U.S. University professors, participants in the *Teacher's Guide to Modern Geography (TGMG)* project for the development of teaching materials, organized by the Association of American Geographers, including professor Phil Gersmehl. In addition, the authors used various statistical instruments to verify the validity of the STAT.

Given the limits of the scope of this text, we are unable to present and comment the test results for all the question groups. Instead, we will analyse just two groups that will help us to outline the level of development of spatial thinking in the 9th grade students.

In order to carry out an overall analysis of the performance of the students in the eight types of spatial thinking covered in the test, we will start by analysing the graph in figure 3.

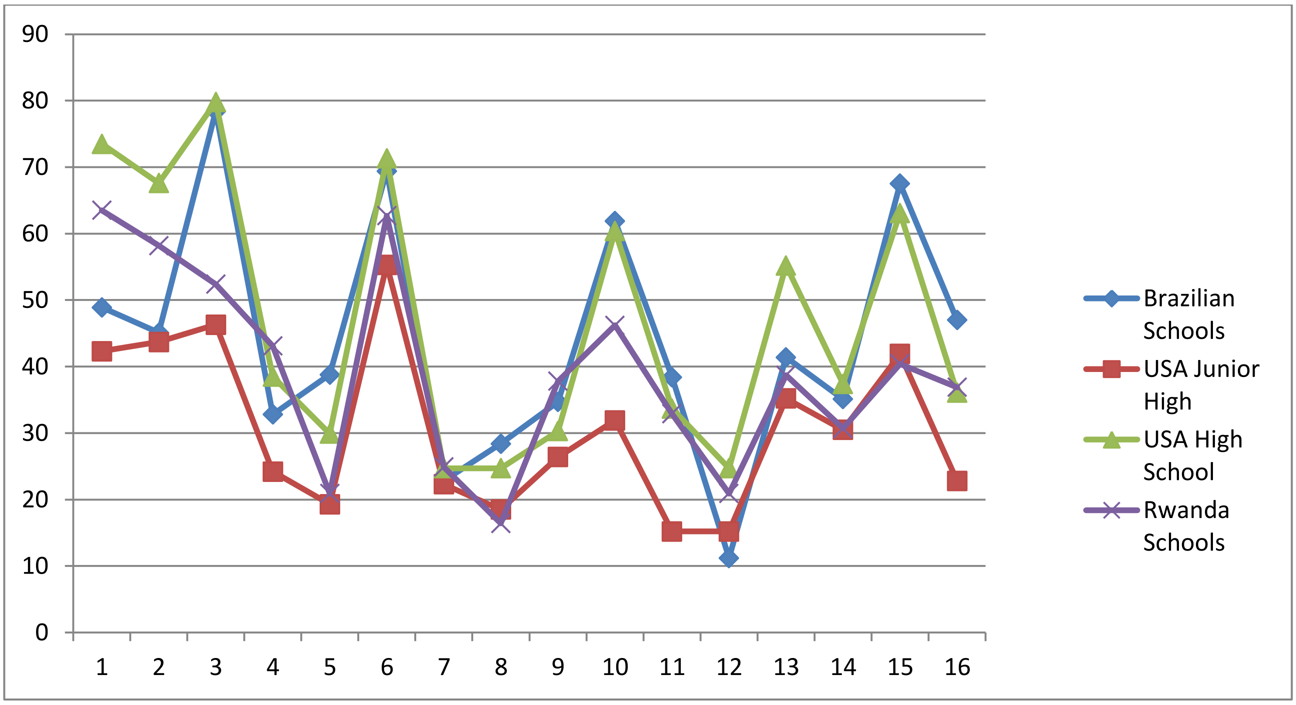

Figure 3: Percentage of correct answers for each question in the STAT by school groups.
Fonte: Duarte (2016).

The first general point that can be made based on an analysis of the graph is that there is a reasonable similarity between the peaks and troughs for the four school groups under study. While the height and depth of the peaks and troughs are not always equal, it is clear that almost all of the questions were easier or more difficult for all the students in the three countries studied, despite the differences in their overall performances. A quick glance reveals that the youngest students in the research, those from the junior high school, had the poorest performance, while the Brazilian students and the American high school students enjoyed the best results. The students from Rwanda occupied an intermediate position between the two groups.

However, we are most deeply interested in investigating the differences in performance with regard to the different groups of questions, according to the type of spatial thinking that they evaluate. The graph in Figure 4 shows the performance of the students in the first two questions of the test, which assessed students' understanding of orientation and direction, using the cardinal points. Both questions were based on a simple grid of streets, representing the urban plan for a fraction of a hypothetical town, in which travelling instructions were given that tested the two skills mentioned. These are considered relatively trivial primary school level activities.

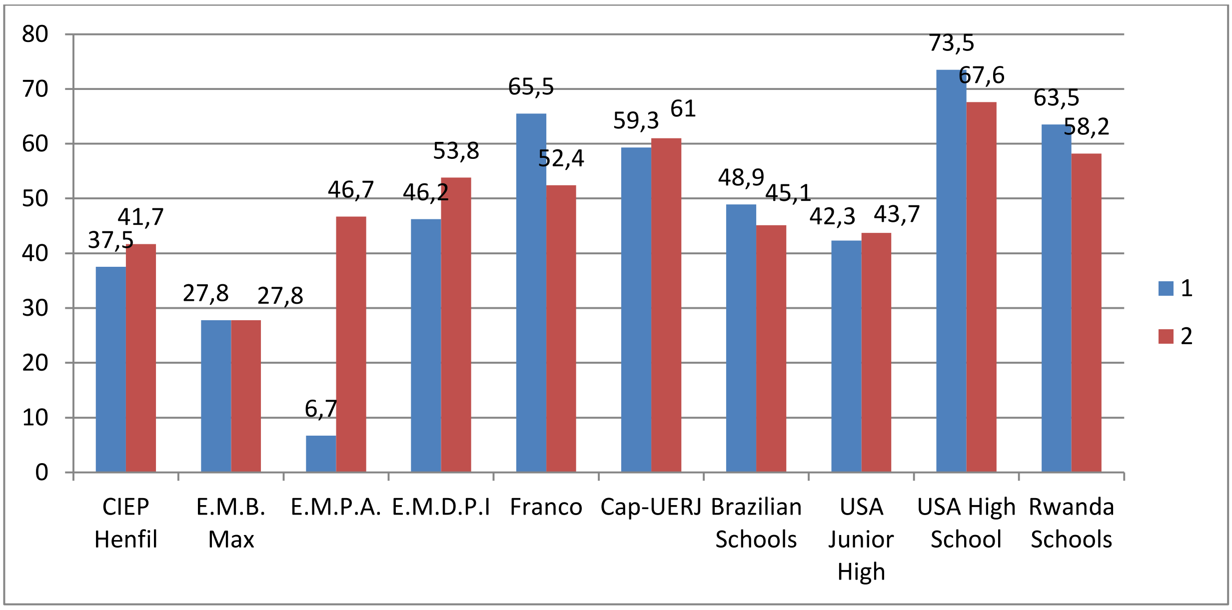

Figure 4: Percentages of correct answers from Group I of the STAT by question.
Fonte: Duarte (2016).

As an analysis of the graph reveals, the Brazilian schools performed weakly in this group compared to those of the other countries. On average, the Brazilian students performed only slightly better than the youngest participants in the survey and their results were much worse than those of the Rwandan students and the U.S. high school students. The Brazilian students got less than 50% of the answers correct, while their counterparts in the two groups averaged at more than 60% or 70%.

Moreover, this average Brazilian performance would have been even worse if the results hadn't been 'pulled' up by the students from the two centres of excellence covered by the survey, CAp-UERJ and the Liceu Franco-Brasileiro school. The average percentage of correct answers of the students of these two institutions were closer to those found in Rwanda and in the US high school. Nevertheless, it remained below international averages for those students with roughly equivalent ages / years of schooling. The other four institutions, all municipal, achieved similar percentages to those obtained by the youngest and least schooled students, from the American Junior High school.

This performance is particularly disappointing if we consider that it refers to one of the most simple dimensions of spatial thinking, and one which is among the most frequently taught in Brazilian schools (orientation with the use of cardinal and collateral points). As pointed out earlier, these two exercises are quite simple and are commonly-seen in Brazilian textbooks. Schools should be teaching this type of activity in the first segments of primary education. The results indicate that this simple and everyday dimension of spatial thinking needs to receive greater attention from school geography professionals, who should intensify activities of this genre, including and especially in out-of-class situations, such as in field studies. In these situations, the students can build up solid orientation skills using their own bodies as a reference point together with the location references of other students.

One of the possible explanations for this lower-than-expected performance lies in the type of orientation exercises that we normally find in our national textbooks. In most cases, the activities propose that the students position a compass centred on a Brazilian city or state and that they identify the direction in which another town or state lies. We rarely find activities in which the students need to cover an orientation route in which at each location the referential under consideration is changed, generating a sequence of astronomical directions. This is what the students are asked to do in questions one and two of the STAT, which may have been a negative factor for the Brazilian students. This fact leads us to recommend that the authors of geography textbooks pay close attention to the quality and the quantity of questions / activities that involve the modality of spatial orientation, and that these textbooks need to include throughout the primary school years an increasing number of exercises that involve the constant 'decentering' of the students.

By the same token, it may signal to educational managers that this theme should be included/ reinforced in further development courses for geography teachers.

The sixth modality of spatial thinking (the second to be analysed here) is one of the most difficult in the STAT, judging by the results obtained. Based on the visualisation of an image featuring the two-dimensional representation of contour lines, but using a shadowing technique to give it a three-dimensional aspect (from a vertical perspective), the students must demonstrate the capacity to identify the corresponding three-dimensional representation of this same relief from a frontal perspective, starting from a point of view shown on the page.

This exercise requires, firstly, that the respondents have a relatively advanced capacity for spatial decentralization (PIAGET and INHELDER, 1956). They must be able, using their imagination, to place themselves in a specific point of view on the map in order to be able to recognize the corresponding three-dimensional representation observed from this perspective. In addition, the spatial area visualized has quite a diversified relief, which makes the task of recognizing the representation more difficult. It is therefore a typical type of exercise designed to assess the student's capacity for spatial visualization, requiring the use of spatial concepts such as direction, spatial forms, gradients, profiles and reliefs, as well as types of reasoning that involve observing, identifying, distinguishing and imagining (JO and BEDNARZ, 2009). We understand that the work of mathematics teachers in K-12 education, dealing with topics associated to geometric solids, may contribute positively to this competence of spatial thinking.

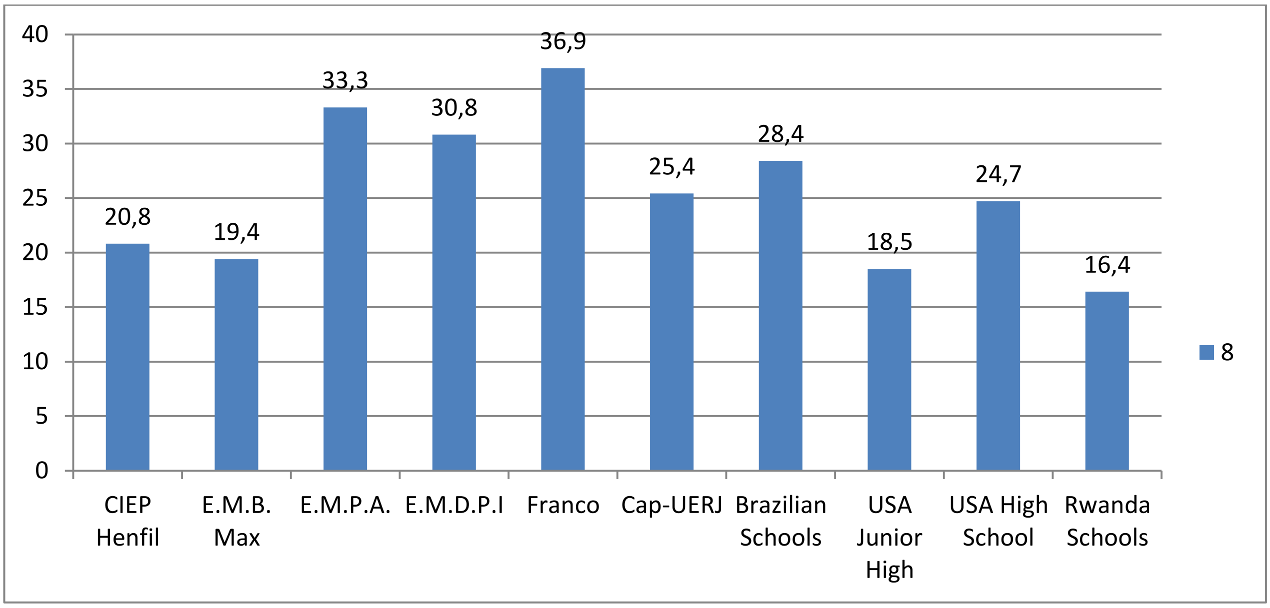

Figure 5: Percentages of correct answers to questions in Group VI of the STAT (Question 8).
Fonte: Duarte (2016).

Of all the students in the four settings considered in this research, the Brazilian students managed to achieve the highest proportion of correct answers to the Group VI questions, averaging at 28.4%. The highest scores were those of the students from the Colégio Franco-Brasileiro and the Pedro Aleixo and Dom Pedro 1 municipal schools. However, even in the cases of these institutions, just one third of the students were capable of finding the correct three-dimensional representation.

Although the Brazilian results are better than those of the other countries it should be emphasized that the scores were still considerably low, which indicates the need to develop this aspect of spatial thinking through a range of teaching strategies, but which should necessarily involve cartographic representations. After all, the success rates vary from an extremely low average of about 1 student in every five, in the case of the Henfil state school (CIEP) and the Burle Marx Municipal school, to a rate of one in every three students in the case of the Colégio Franco-Brasileiro and the Pedro Aleixo municipal school. We recognize that this type of spatial visualization requires high levels of proficiency in this field of intelligence, which just confirms the importance of incorporating activities of this type in the geography teaching materials for schools from the 6th to the 9th grades of K-12 education. In particular, we understand that geography textbooks in this segment should include a large number of exercises similar to this question. We believe this for at least two reasons: the already mentioned omnipresence of this teaching resource in Brazilian schools and the graphic quality of these works, which allows for the use of coloured images and good resolution. All that would be required is that at the end of each unit an activity with similar characteristics to those featured in the Group VI questions of the STAT should be inserted. In this way, Brazilian students, with regular exposure to this type of exercise, would be capable of developing this spatial thinking skill. Simpler exercises could be used to start this process such as, for example, presenting an oblique perspective of the land and asking for the corresponding two-dimensional representation.

It is worth emphasizing that this national “failure” is also reflected internationally, given that the averages of the American and Rwandan students also range from 1 successful student in every six who took the exam (in Rwanda) and one in every 4 in the case of the U.S high school students.

Final Considerations

The results of the application of the STAT clearly demonstrate that much has to be rethought in terms of teaching practices relating to the process of developing competences in the field of cartography. Particularly if we consider the importance of developing mental processes associated to the use of spatial representations in general and of maps in particular as tools that allow students to solve problems and understand contexts that involve geographical contents.

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