

Development and production of an inclusive didactic resource for the introduction to the use of maps through 3D printing

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Abstract: The purpose of this paper is to present the development process and creation of an inclusive didactic resource for the introduction of basic concepts of map usage through 3D printing. The proposal seeks to deepen the discussion on the combination of technology with the studies of Tactile Cartography, adapting graphical representations to better meet the needs of visually impaired students. By uniting these elements, it aims to facilitate the learning and understanding of maps in an accessible and interactive way, promoting the dissemination of adapted didactic resources for the teaching of cartography.

Keywords: School cartography; Inclusive education; Tactile maps; 3D printing; Didactic resources;

1. Introduction

This study proposes the adaptation of a didactic resource aimed at introducing the use of maps to students with and without visual impairments. Preliminary data related to the development process of this resource, which is currently in the testing phase, are presented. The relevance of this research is highlighted, given the scarcity of studies that integrate 3D printing technology into Geography education, particularly within the context of inclusive education.

Cartography plays a crucial role in representing the Earth's surface, allowing for the understanding of different geographic and spatial aspects. According to Almeida (2003), for cartographers, the map is a representation of the Earth's surface, maintaining mathematically defined relationships of reduction, location, and projection on the plane. Franscicett (2002) defines cartography as a system that analyzes the coded representation of signs, using the map as its main instrument, with a high power of synthesis. This system allows for the reading and interpretation of spaces, near or far, through interrelated symbols. These symbols, represented on paper in a reduced form, provide valuable information to the reader for their orientation and understanding of the various spaces and their dimensions in the world. Passini (2012) states that the ability to read a map or chart, decode the symbols, and extract the contained information is essential for achieving autonomy. Almeida and Passini (2008, p. 15) highlight that “reading maps [...] means mastering this semiotic system, this cartographic language. And preparing students for this reading should involve methodological concerns as serious as teaching them to read and write, count, and perform mathematical calculations.” By introducing the student to the task of mapping, we provide the necessary paths for them to become conscious readers of cartographic language. However, the construction of this knowledge

requires teaching/learning methods and techniques that favor the student's understanding, as the learning of cartographic language does not happen in a single lesson.

Cartography, as a science primarily based on visual analysis to identify, relate, and understand phenomena, faces significant challenges in teaching people with visual impairments. Carmo (2009) states that most information about the surroundings is received through vision, and for visually impaired individuals, other senses become essential for interacting with the world. Therefore, it is crucial to adapt teaching methods to ensure that knowledge is accessible and assimilated by these students. Sena (2008) highlights that the understanding of maps, even adapted ones, does not occur immediately, requiring tactile training complemented by methodologies and didactic resources that demand less abstraction capacity.

In this context, Tactile Cartography emerges as a way to mitigate the challenges encountered. According to Carmo (2009), it can be defined as the science, art, and technique of converting visual information into documents usable by people with visual impairments. Carmo and Sena (2009) highlight that one of the main challenges related to disability is finding the best strategies for children, young people, and adults to learn the various disciplines throughout their educational journey, facilitating and supporting their future integration into society. The integration of Tactile Cartography concepts with new technologies offers opportunities to expand the production of didactic resources aimed at inclusive education. According to Santos and Reis (2015), planning actions that incorporate the pedagogical use of technologies can help reduce and even overcome the limitations faced by students with specific needs.

According to Morandini and Del Vecchio (2020), 3D printing, used in this work, has the capability to create physical objects based on the dimensions of height, width,

and depth from a digital model provided by a computer application.

In this context, the article presents the process of construction and evaluation of a prototype developed through rapid prototyping (3D printing) of the "City Game," a common activity in teaching orientation and location, especially in the early years and the sixth grade of elementary school. This game was adapted by Vasconcellos (1993) using artisanal techniques so that visually impaired students could work with these concepts, in addition to introducing the use of legends, different points of view of representation (projection), and geographic coordinates.

The objective of this work is to discuss new forms of adaptation for didactic resources and revisit the main concepts inherent to the use of maps.

2. MAIN CONCEPTS FOR THE USE OF MAPS

Almeida (2008) argues that a child can only understand what is within their reach, based on the mental structures they have already developed. For example, it is not effective to expect elementary school students to understand the cycles of the seasons based on the Earth's revolution. While the topic may arouse curiosity and fascination, it requires a level of abstract reasoning that may not be achieved, even with the teacher's efforts in enactments, team projects, and timely instructions. Often, these notions are not fully understood, and this may not be immediately noticeable to teachers, with the consequences emerging later.

Thus, methodological practices for the introduction to map usage should be designed with the goal of assisting in the construction of cartographic concepts, rather than functioning as a rigid guide with a specific deadline for completion. Almeida and Passini (2008), Castrogiovani et al. (2000), Almeida (2003, 2008), and Pissinati and Archela (2008) state that cartography should be used as an essential resource for understanding geography and reality, not just as content to be addressed at a specific moment.

To achieve this objective, Simielli (2007) suggests working on notions such as: oblique and vertical vision, three-dimensional and two-dimensional images, cartographic alphabet (point, line, and area), construction of the notion of legend, proportion and scale, as well as laterality/references and orientation.

2.1 Oblique Vision and Vertical Vision

Simielli (2007) states that everyday vision is generally oblique, meaning lateral, and does not allow for vertical analysis of a space. Vertical vision requires a level of abstraction to be understood. Romano (2007) explains that, to represent in two dimensions what is seen in three dimensions, it is essential to understand vertical vision, which encompasses length, width, and height, always from top to bottom.

Simielli (2007) also says that oblique vision is the perception of an object or place when looking from above

and slightly to the side. Romano (2007) defines vertical vision as the perspective where the view is perpendicular to the plane of the observed object.

2.2 From Three-Dimensional Image to Two-Dimensional

Pissinati and Archela (2008) state that, since the map is a two-dimensional representation of reality seen from above, and most people are not used to observing the world this way, this is one of the reasons that explain the difficulty in understanding the map. As the real plane is three-dimensional (with height, width, and length), the map, being two-dimensional, suppresses the height dimension.

The use of models is important because, being a three-dimensional product, it allows students to visualize different topographic shapes and altitudes. The model facilitates the correlation of various information, enriching the learning process. The focus will be on the transition from the concrete and three-dimensional space, as observed in reality, to the flat space of the paper (Simielli, 2007).

2.3 Cartographic Symbols: Point, Line, Area, and the Construction of the Legend

Symbology, or graphic semiology, consists of three basic elements: point, line, and area.

- **Point:** Represents position (locality or location). Used to represent phenomena of various natures, such as physical, socioeconomic, urban, political, military, religious aspects, among others.
- **Line:** Represents only direction. Used to represent linear phenomena, such as highways, rivers, and railways, as well as continuous phenomena, such as temperature, inflation rate, and rainfall.
- **Area (or zone):** Represents width and length. Can be represented by textures or colors, used for phenomena that occupy a spatial extent, such as climate zones, land use areas, and administrative regions.

Garcia and Garavelo (2006) state that the legend is the summary explanation of the meaning of the symbology used in the graphic representation. It provides the interpretation of the symbols and colors used on the map, allowing readers to understand the represented information.

2.4 Proportion and Scale

The construction of the concept of scale, which is the relationship between map measurements and real-world measurements, requires the child to understand the notion of proportion. The child needs to understand that an object or area can be represented in different sizes and that the choice of the map size depends on the level of detail of the information to be portrayed. Almeida and Passini (2008) state that the map is a proportional reduction of reality, and the scale defines how many times the real space has been reduced. The determination of the scale is one of the most important aspects in map-making, as it allows for a representation of reality with different levels of detail (Garcia and Garavelo, 2006).

2.5 Localization, Laterality, and Orientation

Geographical references for orientation are defined based on the movements of the Earth. Spatial orientation requires the student to have mastery of the notions of laterality and references. Without these concepts, mastering spatial orientation becomes difficult. To achieve this mastery, it is necessary to work with topological relations (neighborhood, separation, order, involvement, and continuity), projective relations (perspective, left/right, up/down, front/back), and Euclidean relations (proportions and distances, lines, angles, and measurements). Understanding these relations requires a great capacity for abstraction to correlate the Earth's rotation with the apparent movement of the Sun and the succession of days and nights (Almeida and Passini, 2008).

2.6 Geographic Coordinate System

The use of a coordinate system is fundamental for the construction of space at a psychological level, as it is the main point of abstraction. This system helps in the organization and understanding of space, allowing for a more precise and structured representation of reality (Almeida and Passini, 2008). Geographic coordinates are numerical values that define the position of a point on the Earth's surface. Latitude is measured in relation to the Equator, which serves as the point of origin for latitudes. Longitude is measured in relation to the Prime Meridian, which is the reference line for longitudes. These coordinates help to precisely locate any point on the globe.

3. 3D Printing in the Creation of Adapted Resources

According to Seely (2004), digital manufacturing involves design and production with the help of computers. Volpato et al. (2007) highlight that rapid prototyping, like 3D printing, is easy to automate, eliminating the need for molds and tools and reducing operator intervention. Huang et al. (2013) describe the FDM method, used in this work, as a process that deposits thin layers of thermoplastic on a platform. When the material comes into contact with the cooler platform, it hardens quickly, forming the piece.

Mello (2017) states that this technology has many applications, from education to the automotive and aerospace sectors, as well as transforming diagnostics and procedures in the healthcare field.

In education, the 3D printer enhances teaching. Blikstein (2013) says that the produced objects are of high quality and can be used in real and functional tests. Slawkovsky (2012) notes that representing objects in 3D is not new; educators have been using three-dimensional models for centuries. He points out that physical objects offer a better understanding than virtual objects, which can be difficult to abstract.

3D printing creates resources adapted to different needs. Pinzetta and Frosch (2019) state that these resources enhance the senses of visually impaired students. 3D printing is a valuable tool in building the signification system for these students.

The technology of 3D printing has the potential to overcome barriers for visually impaired people and benefit the teaching of sighted and low-vision students with tactile didactic models. It allows for the production of resources in various scales and proportions. This technology is expected to expand educational possibilities, promoting a more inclusive society and contributing to knowledge (Pinho, 2021).

4. The "City Game"

The "City Game," conceived by Vasconcellos (1993), is a playful activity designed to teach basic cartography concepts to students at the beginning of their learning about the subject, promoting cartographic literacy. This pedagogical tool is inclusive, allowing students with and without visual impairments to work on geographic and cartographic concepts. It can be presented in two versions: a simple version with ten pieces and a complete version with twenty-four pieces, representing constructions of a small city. Both versions include a legend and a Styrofoam board covered with felt or Velcro for fixing the pieces, which can be worked on in groups or individually.

The rules of the game are as follows: first, place the square with the bandstand, for example, in the center of the covered Styrofoam board, indicating it as a reference. Then, using a compass or a drawn rose of the winds, determine the cardinal points, using the square as a reference. Then, the pieces should be added according to the game instructor's instructions, for example: "Fix the Church to the East of the square." The instructions can vary according to the desired difficulty level for the students. At the end of the city assembly, the student can draw the result, relating point of view, location, orientation, and legend.

This approach not only promotes inclusion in the educational environment but also encourages students' autonomy by allowing them to interact with the materials independently and meaningfully.

A version of the "City Game" has been widely applied in continuing education courses and workshops for teachers, promoted by researchers from LEMADI (Teaching and Didactic Material Laboratory) of the Department of Geography of FFLCH at the University of São Paulo. The proposal consisted of providing educators with an A4 sheet with a delimited area and a rose of the winds, requesting them to create tactile symbols for elements of an imaginary city, such as a church, hospital, city hall, market, houses, river, and police station. After creating the symbols, the teachers were challenged to arrange them according to specific instructions. In the workshops, due to the available resources, the symbols were glued, but always demonstrating the possibility of using loose pieces that could be fixed with Velcro or magnets on appropriate surfaces.

The feedback from teachers who implemented the activity in their classrooms in recent years has been highly positive. Many reported that students demonstrated a significantly improved understanding of topics such as

symbology, use of legends, and orientation by cardinal points.

In the Brazilian context, as established by the National Common Curricular Base, cartographic content is introduced in a structured manner to students aged 11 to 12. This approach often employs the 'city game' as a graphic resource through which students are encouraged to identify the location of different places using visual representations such as drawings and diagrams (Figure 1).

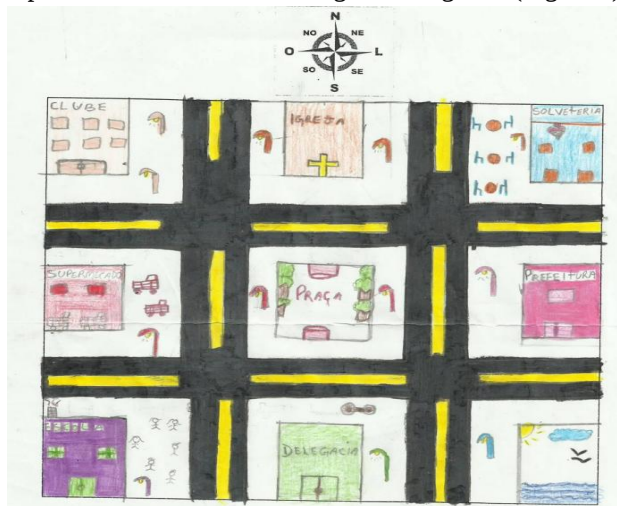


Figure 1. City game activity implemented with a student in the classroom.

5. Development and Creation of the Prototype

The prototype was developed using Tinkercad, a free website that allows the creation of digital three-dimensional models. The resource, containing a map and legend (Figure 2), was designed to have the same measurements as an A3 sheet (297x420mm), being divided into six different parts to facilitate its printing. The total size of the resource was chosen so that it would be possible, in the next stages of the research, to develop a two-dimensional version of the map and legend, contributing to the process of abstracting the three-dimensional reality into two-dimensional maps.



Figure 2. Didactic resource of the City Game made with a 3D printer.

All the graphical text also has Braille plates. The Braille plates were produced following the parameters found in NBR 9050:2020, which stipulates the measurements and

arrangement of the Braille cells to ensure standardization and quality.

For the printing of the plates, aiming for better resolution and print quality, the pieces were positioned vertically and printed separately from the rest of the resource, with a smaller layer height and printing speed, increasing the number of layers that form the dots and, consequently, increasing the resolution of the piece, as demonstrated by Ribeiro and Torres (2024).

Twelve three-dimensional models (50x70mm) were created representing different locations (Bank, House, School, Factory, Fountain, Hospital, Church, Market, Park, Building, Sports Court, and Shopping Mall), with various shapes and sizes (Figure 3), facilitating tactile perception for visually impaired students.

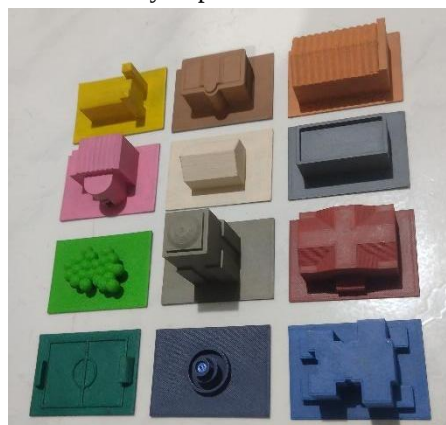


Figure 3. Models of the locations used in the resource.

The models can be moved and organized on the map, which has a grid composed of four rows and three columns (Figure 4). This allows students and the teacher to change the position and number of models during the use of the resource, creating the possibility for the introduction to be made with a small quantity, which will be increased as the student becomes familiar with the concepts being worked on. The rows and columns of the grid are identified by letters and numbers, allowing the basic concepts of geographic coordinates to be worked on.

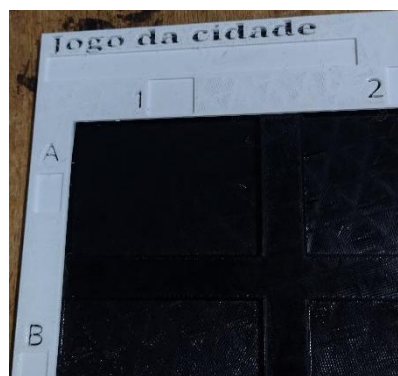


Figure 4. Rows and columns with numbers and letters of the resource (without paint) for the use of geographic coordinates.

The legend is composed of miniatures that are one-third the size of the pieces on the map (16.6x23.3mm), providing students with an understanding of different scales and the level of detail each presents (Figure 5).



Figure 5. Size comparison between a miniature of the map and of the legend.

Additionally, the legend contains two graphical scales that represent the miniatures of the map and the legend, illustrating that the area of the graphical representation can remain the same while representing different real areas. The scales were created using a unit based on the size of the legend miniatures (Figure 6).



Figure 6. 3D model of the compass rose and graphical scales of the resource.

The legend was designed to be separate from the map, allowing students to use the compass rose more freely, placing it in different positions on the map to aid in understanding reference points, location, and orientation. The settings used for printing the resource models can be seen in Table 1.

Printing Settings	
Printer	Creality Ender 3
Material	PLA
Layer Height	0.12 mm
Layer Height (braille)	0.08 mm
Printing Speed	50 mm/s
Printing Speed (braille)	40 mm/s
Total Weight	480g
Total Printing Time	62h08m

Table 1. Printing Settings

The models that make up the resource were designed to be printed in different parts, allowing smaller printers to produce them. This approach facilitates accessibility and the feasibility of printing, ensuring that more people can use the material without the need for large-scale equipment. To increase the contrast between the colors of

the models, the pieces were painted manually with a brush and PVA paint.

6. Conclusions

In teaching that uses maps, the difficulty increases for visually impaired students, as maps are essentially visual and cannot be simply transcribed to Braille (Gimenez, Sena, 2016). Additionally, maps use a language that requires an understanding of their elements for a satisfactory exploration of the potential for representing places, phenomena, and spatial processes.

The use of adapted didactic resources broadens the possibilities of understanding for these students. Initially, they are trained to read and interpret maps, and later, to explore these representations in the development of geographic reasoning. The demand generated by the use of technology highlights the need to take full advantage of its potential in the educational system, especially in the pedagogical components and in teaching and learning processes.

Rapid prototyping is a powerful tool for creating tactile maps, allowing the fast and accessible production of 3D models. Technologies like 3D printing enable the creation of maps with relief and essential details, helping visually impaired people to better understand the space around them. Moreover, these maps can be customized to meet individual needs.

However, this technology has limitations, such as difficulty in representing very small details or areas with a lot of information. The resolution of the material can affect the clarity of tactile reading, making it difficult to perceive small differences, such as minimal elevations or fine textures. Therefore, despite being extremely useful, rapid prototyping still faces challenges to ensure a fully effective tactile experience and should be continuously studied and debated by researchers and educators to optimize its use.

3D printers have significantly expanded their applications. However, it is essential to understand that 3D printing should be seen as an additional tool for teachers and students, not as an end in itself. For it to be effective, its use must be aligned with the content and based on appropriate pedagogical practices, being systematically integrated into the teaching process.

It is hoped that this work will contribute to the dissemination and debate on adapted didactic resources for teaching cartography. All models created during the project, after undergoing the necessary tests, will be made freely available in an online repository of three-dimensional models.

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