



Accessible Bar Charts Through Textual Description Templates

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Abstract Data charts are very prevalent in everyday life in different contexts, from economics to politics. However, people with blindness and low vision do not have easy access to this information since they use screen reader software. This software does not extract the information available graphically, but only the chart legend and the text. Among the solutions proposed in the literature, there are crowdsourcing techniques when a person is responsible for interpreting the chart, which can cause bias in the chart's interpretation. To solve this problem, we proposed textual description templates for simple and grouped bar charts to inform the chart data in a standardized way to users, excluding the interpretation bias. The methodology of this work was divided into three stages: a definition of templates for textual description and testing with 30 participants; the application of textual description templates in an assistive technology tool and testing with 45 participants; the validation of the results found through interviews and tests with 3 specialists. We have iteratively refined templates generated at each stage with users tests, and we carried out quantitative and qualitative analyses. An assistive technology tool, ChartVision, was developed to consume the templates. Finally, we interviewed a specialist about how he would explain chart materials to blind students at university, and we carried out a validation of the final templates with two other professionals from the health and education areas who deal with people with blind people in their daily lives. The main contributions are three textual description bar charts templates: simple bar for applications with sequential reading or reading on-demand, grouped bar for applications with sequential reading, and grouped bar for applications on-demand. The secondary contribution is ChartVision. Other findings include considerations about the synthetic voice used in the tests, expected characteristics for a better understanding of the chart, and interaction ways to access the information.

Keywords: Human-Computer Interaction, Charts Textual Description Templates, Accessibility

1 Introduction

In 2012 the World Health Organization issued a report on blindness and visual impairment [WHO, 2012] based on data collected by a research published in The British Journal of Ophthalmology [Pascolini and Mariotti, 2012], which revealed that there were at least 285 million people in the world having some level of visual impairment, of which 39 million are blind. In Brazil, according to the 2010 census conducted by the Brazilian Institute of Geography and Statistics, there were 6.5 million people who had some level of visual impairment [IBGE, 2010].

People who are blind or with low vision use specific software to interact with computing devices. Stephanidis [2009] define screen readers as the primary assistive technology used by people with little or no functional vision; the primary goal of a screen reader is to capture the information on the screen and present it to the user through another medium accessible by them. It mediates between the user and the operating system, assisting blind users in accessing standard visual interfaces. Screen readers can use synthesized voice to provide access to the content presented on the screen, and some examples are: JAWS [Scientific, 2011] and DOSVOX [Borges, 1996] for computers, TalkBack and VoiceOver for smartphones. People with low vision can increase the font size and

use high contrast and color inversion, accessibility settings available in most modern operating systems.

Data charts are visual presentations of data and a common way to convey information [Wallgren *et al.*, 1996]; they allow for a quick grasp of tendencies and a quick comparison between values by representing them through graphical marks. Screen reader users cannot directly access the content of data charts present in the texts, whether in desktop applications (i.e., word or spreadsheet processors), mobile applications, or websites. This is far from ideal, as the charts' data are rarely available elsewhere in the text, decreasing and even completely preventing the reader's understanding. The creation of alternatives to provide blind and low vision people access to this type of content serves as an inclusion mechanism, allowing their reinsertion in the learning process, in the job market, and in any other context that may require the usage of charts.

Existing research reports the textual description of data charts both automatically and manually [Morash *et al.*, 2015; Demir *et al.*, 2010; Ferres *et al.*, 2010; Gunnarsson *et al.*, 2018]. Manual description occurs when a person provides descriptions to charts in textual form, allowing screen readers to read the charts' content. However, this type of procedure does not scale well, as it depends on the availability of people and can also include human error, as the descriptions derive

from the person's understanding of the chart. For the automated description, considering that the chart data would be obtained through specialized extraction tools, standardizing a textual form is a viable solution to convey the content to the user.

This paper is an extended version of the article "ChartVision: Accessible Vertical Bar Charts" published in the Proceedings of the 19th Brazilian Symposium on Human Factors in Computing Systems [de Oliveira *et al.*, 2020]. It is noteworthy that some preliminary tests are have also been published [de Oliveira *et al.*, 2019]. The original portion of this paper is that we present all the templates' conception and test processes. We also included the tests procedure and quantitative and qualitative tests analysis. In addition, final tests with specialists were included in the validation section. In summary, the initial article contained only the research part referring to the developed assistive technology tool.

Hence, the main research question that this paper seeks to answer is: "how to describe the content of bar charts to users?". The secondary questions of this research are: "what elements should be part of the exhibition of the contents of these charts? and what is the most appropriate way to expose this content? sequentially or according to user demand?". This work proposes templates for the textual description of simple and grouped bar charts. We selected this type of chart because it is one of the most used types in technical and scientific documents and also on the internet [Yang *et al.*, 2014; Battle *et al.*, 2018].

By proposing standardized ways to present textual descriptions in an intelligible form for bar charts, we allow users to have access to the data and to be able to interpret the information without the need or influence of other people in the process. The benefits of the templates proposed in this work the end-users, consumers of the textual descriptions generated from the templates, and the intermediate users, application developers with accessibility purposes who can use the templates to generate textual descriptions.

We defined the element templates based on electronic forms that collected information about the relevance of the elements of the charts. The electronic forms were created based on the elements of the bar charts and answered through the research team's dissemination on social networks. Volunteers who knew about bar charts were asked to answer the electronic form. We carried out user evaluations to verify the ease of understanding the textual descriptions. In these evaluation sessions, users listened to audio with a synthetic voice reading the textual descriptions of predefined charts and performed some tasks, such as drawing the chart and answering questions regarding what they listened to. We also developed and evaluated a smartphone tool that vocalizes bar charts based on the templates. Finally, the test results showed an average accuracy on the chart's content between 70% and 100%. Qualitative data also points out that most users understood the contents of simple and grouped vertical bar charts.

This work is organized as follows: the following section presents the fundamental concepts for understanding this work and related works; the "Methodology" section summarizes the approach used in this study; the section "Bar Chart Textual Description Templates" presents the templates

for the textual description of bar charts used in the tests, as well as the procedures for carrying out and analyzing the results. The "ChartVision" section presents the developed tool, the tests performed, and the results' analysis. Soon after, the "Validation" section portrays the verification of the results through interviews with specialists. In the end, we present the templates for textual description resulting from the research and the final considerations of the work.

2 Theoretical Background and Related Work

In this section, only the fundamental concepts related to this study's various development stages are presented, such as bar charts and textual description templates. Then, we present related works that address textual descriptions of charts. Finally, we present a brief qualitative user evaluation of the work that inspired this research.

2.1 Theoretical Concepts

Bar charts are one of the most used forms of visual representation of data. In bar charts, each bar corresponds to a numerical value, the bars are rectangular in shape, and their height is proportional to their value. It is considered a chart that is easy to read and represented by drawing [Wallgren *et al.*, 1996]. Figures 1 and 2 present the elements of a simple and grouped bar chart.

Representing data charts in alternative ways can help different groups of users. In this sense, text templates consist of text, with gaps and indications of what information should be inserted in the gaps to compose the final description. The interested party previously prepares these indications, preferably following well-structured guidelines, maintaining the fidelity of the data [Demir *et al.*, 2008]. The use of templates ensures that the textual representation of the data happens consistently, always maintaining the same information and same order of presentation and allowing it to be much more comprehensive to the target audience [Demir *et al.*, 2008]. The vocalization of the textual templates is a way to convey the accessible data, and users prefer to make them available only in textual form [Zou, 2015].

2.2 Charts Textual Description Works

Regarding the description of charts, we can highlight the work of Morash and others, which tested ways to generate templates of textual description [Morash *et al.*, 2015]. To accomplish this task, volunteer novice web developers used two ways to describe charts from the Web. In the first one, the researchers gave the volunteers guidelines for describing charts, and they could freely describe them. In the second, more efficient way, the volunteers had a window with gaps to fill with the charts' information. This work did not test the proposed templates with users.

The work of Demir *et al.* [2010] proposes a web browser extension, called SIGHT, that applies image processing techniques to extract the data present in charts on a web page. After the extraction, the module creates an XML (Extensible

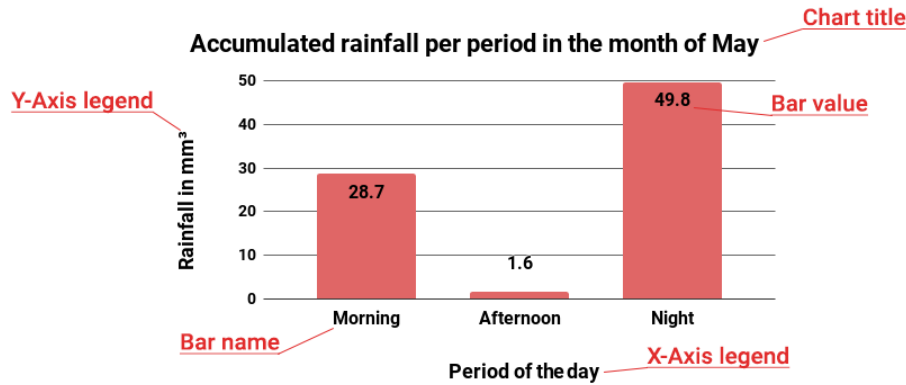


Figure 1. Elements of a simple bar chart.

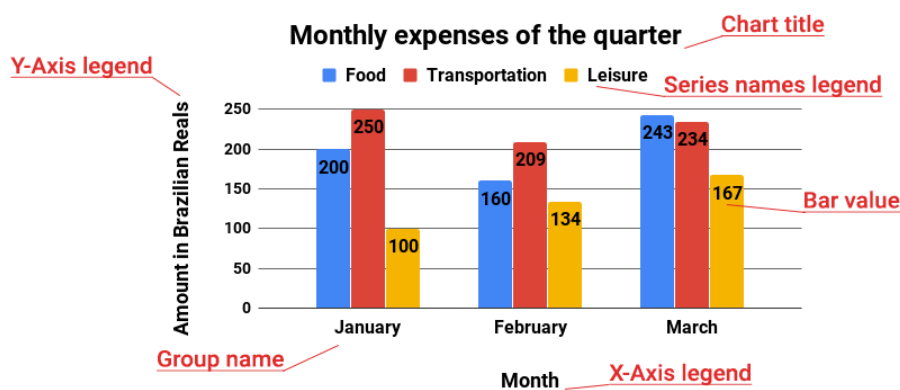


Figure 2. Elements of a grouped bar chart.

Markup Language) representation of the chart. Simple bar chart description options are then displayed. The user can access these descriptions in different ways after an initial summary of the chart is presented. Two tests were performed to validate SIGHT, one with sighted and one with visually impaired people. The goal of the first test was to investigate how well the system could identify important information about the charts that should be displayed, and the goal of the second test was to evaluate the usefulness and ease of use of SIGHT. The authors concluded from the first test that the users were reasonably satisfied with the summaries the system generated automatically. From the second test, the authors concluded that the most important information on the chart was selected, but many users suggested changes in the way data was presented. However, the study does not provide templates for describing the charts.

The research of Ferres *et al.* [2010] developed an application that allows the user to interact using the keyboard, and the application responds to it using a synthetic voice. The proposed tool consists of an extraction module, a generator of information in natural language, and an interface that allows the user to navigate the data. The application presents a textual description of line charts with interaction through natural language. The research volunteers were people with and without experience reading data charts. The tests contained line charts from only one newspaper, and all ten participants (six congenitally and four non-congenitally blind) were readers

of that newspaper. Two iterations of the proposed tool were tested. The way the tool presented the data was based on the volunteers' statements collected in previous tests. The test with users showed promising results in the interaction with the tool proposed. However, a textual description template was not made available.

In the work of Gunnarsson *et al.* [2018], the authors presented guidelines for the audio description of bar charts and applied them to their prototype. They performed tests using bar charts with many bars and users with and without visual impairment. During the test, the researchers asked one first volunteer to look at one chart and freely describe it to a second volunteer who did not get to see it. If the second volunteer were not visually impaired, they would have to draw the chart according to their understanding; otherwise, they should orally describe what was understood. The volunteers of the test claimed that the descriptions gave a good understanding of the chart, and the amount of information was satisfactory. The prototype used different descriptions for charts with different numbers of bars, and not all descriptions were made explicit in the research. The results presented the prototype and guidelines for describing accessible bar charts but not a description template.

The work of Lai *et al.* [2020] used neural networks to extract the textual elements from the charts, and along with annotations provided by the chart's author, an animation is created that indicates each element with its respective caption

Table 1. Overview of the related work [de Oliveira, 2020].

Features	Morash et al. [2015]	Demir et al. [2010]	Ferres et al. [2010]	Gunnarsson et al. [2018]	Lai et al. [2020]	This Work
Description origin	✓	✓		✓		✓
Description made available	✓					✓
Prototype		✓	✓	✓	✓	✓
User evaluation		✓	✓	✓	✓	✓

and annotation. In this way, the authors seek to assist the user’s understanding since short-term memory is volatile, so that, in a presentation, the user divides his attention between the presenter and the chart presented. Tests were carried out with users, and the application’s utility was verified, showing around 60% accuracy, but it is not yet ready for use since its authors highlighted some limitations, such as the difficulty of identifying secondary entities, for example, elements without text.

As mentioned in the previous paragraphs, there are works in the literature that explore and perform the textual description of charts and present tools for accessibility using synthesized voice [Morash et al., 2015; Demir et al., 2010; Ferres et al., 2010; Gunnarsson et al., 2018; Lai et al., 2020]. However, the works that present templates for a textual description of charts do not explain how they were conceived, do not evaluate them or do not make the templates available as a research result. This work presents templates for the textual description of bar charts, explains how the templates were built, and provides a tool that uses the templates, as well as their evaluation.

The comparison between these features and related works that address textual descriptions is available in Table 1. The Description origin feature refers to when the related work described how the template was conceived and what research was performed to produce the template. The Description made available feature refers to when the related work has made available the necessary details so that others can use the template. The Prototype feature refers to when the related work presented a computational tool that used the proposed templates. The User evaluation feature refers to when the related work presented some evaluation with users of the proposed template or tool.

2.3 Morash’s Template Evaluation

The research that inspired this work was a paper by Morash et al. [2015]. The authors carried out a study on the best way to describe charts for users on the Web. A group of people used a template proposed by the authors, where the participants should look at the chart and fill in gaps if the fields existed in the chart. Another group of people was introduced to accessibility guidelines for images on the Web and invited to describe the charts freely. The results showed that using the template was the best way to carry out the descriptions, but the study was about making the descriptions, and there was no assessment of how to present those descriptions to the final user.

In this context, there was a need to evaluate the template proposed by Morash and others. Thus, we carried out a test with five participants for a qualitative analysis of a version translated to Portuguese of the template proposed. The participants were from different areas of knowledge and had prior knowledge of bar charts.

We will reference the speeches of the participants by Mx, where x is the participant’s identifier. Participants received headphones, a pen, and a sheet of paper containing an outline for the construction of the chart with gaps for filling in information. This test had two charts, one simple bar chart, and one grouped bar chart. After listening to the information, the participant had to explain the content of the chart. The textual descriptions based on the templates of Morash et al. [2015] were:

- Simple bar chart: “This is a vertical bar chart, titled **GPA of computer engineering classes**, measuring **10 by 7 years**. The data ranges from **0 to 10** with increments of **2 points**.”
- Grouped bar chart: “This is a vertical bar chart, measuring **250 by 3 months**. The caption reads **Image 1. Average individual expenses of middle-class youth in the city of Belém in the first quarter of 2018**. The data ranges from **0 to 250** with increments of **50 reais**.”

The description is not clear enough for the volunteers to be able to draw the corresponding chart. None of the participants were able to reproduce the chart. Some were unable to understand the information regarding the axes, M1 said: “The general idea I managed to understand, only what became much more difficult is that I could not understand the axes, what each axis represents ...but I guess that the GPA is the horizontal and vertical axis is the years, 10 by 7. (...) For me, the essential thing was to know the axes.”. M3 confirmed the confusion caused by the axes: “(...) the chart goes from 0 to 10, I understood that it is their GPA, but this I did not understand this (referring to the X-axis) ...is it the course year? For me, it was confusing, I couldn’t identify what the Y-axis is and what the X-axis is.”.

Some participants were unaware of what an increment is, and, in a way, this may have influenced the interpretation of the chart’s content. Regarding the simple bar chart, M3 stated: “I found it confusing to understand ...I didn’t understand when it says from 0 to 10 with 2 increment points.”. About the grouped bar chart, he said: “I get confused when it says in increments of 50 reais, or increments of 2 ...I can’t understand what this is.”. M5 also commented on the lack of knowledge about increments: “One thing that caught my attention is that I have no idea what an increment is.”. M4 understood the increment but believed it was the value of the bars. About the simple bar chart, he said: “It is a vertical chart that measures every 2 points, measuring 10 for 7 years. As I understand it, the 7 years are horizontal and vertically go from 0 to 10 in intervals of 2 points.”.

There were situations in which the participants only understood the subjects covered by the chart, leading to the conclusion that the only information they could understand was the title of the chart. M2 stated about the simple bar chart: “I understood that it is about research that is being devel-

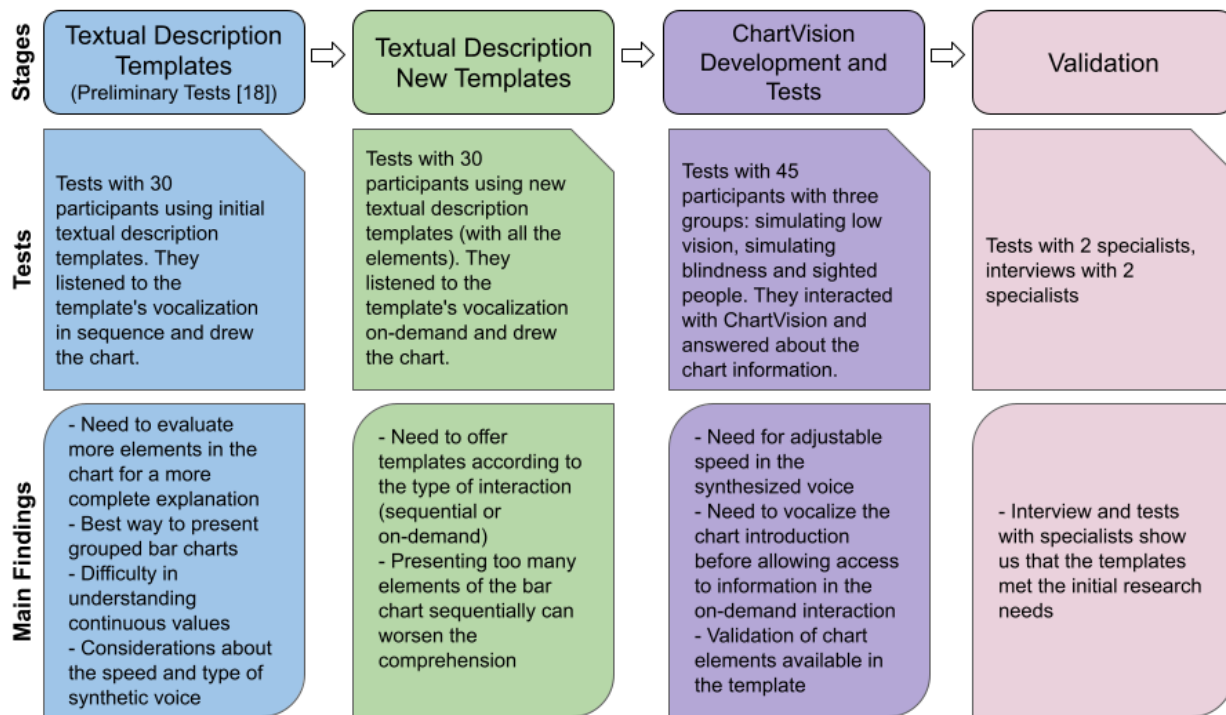


Figure 3. Methodology stages, test information and findings.

oped on engineering classes, but something very technical like that.”. M5 just said: “It’s about engineering students.”.

The participants’ statements showed that the template is not sufficient for users to understand the chart. In most cases, the participants only understood the title of the chart without understanding the other elements. However, as previously mentioned, the work of Morash *et al.* [2015] did not test the template with users, nor does it propose to do so. In this context, this work proposed and extensively evaluate templates that would allow the understanding of the main elements of the chart.

3 Methodology

The researchers carried out the process of creating and evaluating the templates in an iterative manner, carrying out a new test after each cycle of creation and refinement of templates.

Initially, we elaborated an electronic form with elements contained in a bar chart. Volunteers classified each element on a scale from 0 to 10, according to their relevance in understanding the chart. The form was distributed on social media, and the only requirement to answer it was to know vertical bar charts. We consider it as an experience in bar charts, to know the elements of these charts and understand their meanings, being able to interpret them. Ninety-four participants, from all areas of knowledge, answered this survey, and the results provided a basis for creating the initial description templates. Afterward, we carried out another round of tests with 15 more volunteers, in which they heard the description of 4 simple bar charts with 3, 5, 7, and 9 bars, respectively. The volunteers were undergraduate and graduate students of exact science courses at the Federal University of Pará and were selected using a non-probabilistic sampling technique known as con-

venience sampling. In this type of sampling, participants are selected according to availability, location, and interest in participating in the research [Etikan *et al.*, 2016]. During the test, the participants drew the chart described according to their understanding and answered six questions about the chart.

We also carried out a round of tests to evaluate three templates proposed to describe grouped bar charts with 15 participants who did not participate in the first test but had the same profile as in the first test. The test procedure was similar to the previous, where the participant listened to the description, drew the chart, and answered six questions regarding the chart. Each participant heard the description using three different templates and could choose their favorite at the end of the test. Initially, the vocalization templates were proposed and evaluated for uninterrupted vocalization. More details on the process of creating and evaluating these templates were published in a previous research [de Oliveira *et al.*, 2019].

At this stage, not all elements of the bar charts had been evaluated, and some test participants pointed out the need to include elements such as the amplitudes of the axes. Then, a new question emerged to be investigated: Was the number of elements present in the template enough to understand the bar chart? Furthermore, we verified that the template provided by Morash *et al.* [2015] also contained elements that we were not evaluated at the time. Then, we found that it was necessary to assess the need for a more detailed explanation of the bar chart with more elements. Therefore, new templates were defined and tested. We divided the methodology of this work into three stages: i) The definition of new templates for the textual description and the realization of tests; ii) The application of textual description templates in an assistive technology tool and the performance of tests; iii) The validation of the results found through comparisons and

interviews with specialists. Figure 3 shows the research steps, information about the test, and the main results found.

4 Bar Chart Textual Description Templates

The initial tests showed that the templates still needed improvement. There was a need to assess the relevance of other elements of the chart in the textual description. For this, we applied a new electronic form that was released on social networks, this time, 163 people responded, all of whom had the requirement to have experience in using bar charts.

This second form was different, we included a section about the experience with blind and visually impaired people, and 23 participants claimed to have this experience. For this, it was considered as an experience to have already lived or worked with people with visual impairment. The responses of the participants showed us that the participants who claimed to have experience with blind people or people with visual impairment had a family member, or worked with someone with visual impairment, either as a co-worker or being a teacher of blind students. We added some questions referring to charts that were not present in the first form: bar groups, Y-axis unit of measure, legend of the chart, increment value on the y axis, and color. The inclusion of these elements aims to assist in evaluating the template proposed by Morash *et al.* [2015] later in the Validation section.

Figure 4 shows the results of the second form. We selected, again, the elements that obtained a relevance greater than 60% to compose the templates, named template for simple bar charts and template for grouped bar charts. Considering the increase in the number of chart elements in relation to the first templates, a new question arose: how does the number of elements present in the description of the chart influence the understanding of its content? Thus, we proposed a new template for each type of bar chart (simple and grouped), this time containing all the chart elements, regardless of the relevance given to them by the participants.

The italic phrases indicate the elements that do not belong to the other two tested templates:

- **Textual description template for Simple Bar Charts with All Elements:**

This is a vertical bar chart.

It's title is {title}

The y-axis legend is {y-axis label}.

The x-axis legend is {x-axis label}.

The bar values vary between {minimum value} e {maximum value},

and its color is {color}. The first bar is {name of the first bar} and has value {value of the first bar}.

(. . .) The {nth} bar is {name of the nth bar} and has value {value of the nth bar}. Its average value is {mean}. Its standard deviation is {standard deviation}.

- **Textual description template for Grouped Bar Charts with All Elements:**

This is a vertical grouped bar chart.

It's title is {title}.

The y-axis legend is {y-axis label}.

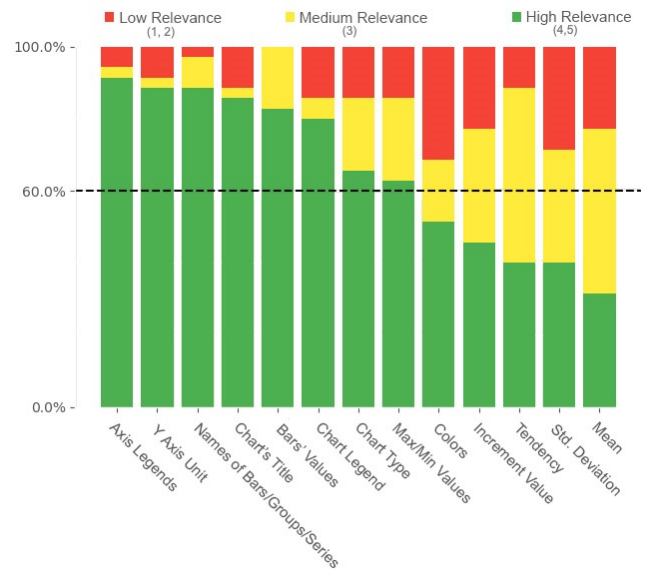


Figure 4. Relevance proportion for each chart element in the second electronic form.

The x-axis legend is {x-axis label}.

The chart is made up by the bar groups {name of the bar groups}.

Each group contains {number of bar per groups} bars: {name of the bars}, that are the color {color of the first serie}, (. . .) and {color of the nth serie}, in this order.

The bar values vary between {minimum value} e {maximum value}. The first group of bars is {name of the first bar group} and has values {value of the first bar, (. . .), value of the nth bar}.

The {nth} group of bars is {name of the nth bar group} and has values {value of the first bar, (. . .), value of the nth bar}

Its average value is {mean}. Its standard deviation is {standard deviation}.

4.1 Templates Test Procedure

Thirty volunteers participated in the next test, selected using the convenience sampling method, all undergraduate and post-graduate students from all areas of knowledge at the Federal University of Pará, 15 of whom used the textual description based on the adapted templates for simple and grouped bar charts, while the other 15 used the textual description based on the templates for simple and grouped bar charts with all elements. There was a repetition of approximately a third of the participants in relation to the previous tests. Still, the effect on the results is minimal, considering a six-month interval between the first tests and the test with the adapted templates. The participants received a headset, pen, and paper sheet with the outline of a chart and gaps to fill in with the information heard in the audio with the textual description of the charts. They listened to the description of a simple and grouped bar chart.

In this test, the volunteers could obtain the information on demand; they could listen to the information in the order they wanted, access each piece of information up to two times, and interact via a computer's keyboard. We decided to limit the

number of interactions so that the test procedure was not tiring and the number of actions was similar among participants. The volunteer could consult a list of commands presented on the computer screen and type the key corresponding to the information they wanted to hear. The participants started by listening to the description of a simple bar chart, and, they should draw the equivalent chart with as much detail as possible. They then listened to the description for a grouped bar chart and had to draw the equivalent chart. In addition, participants also had to explain the chart's content and comment on the descriptions they heard.

The purpose of this test was to evaluate the adapted templates and the templates with all elements, making it possible to verify if and how the number of elements described can influence the understanding of the content of the chart.

4.2 Templates Test Results

We present the results according to the type of evaluation: quantitative, statistical, and qualitative. Analyzing all the drawings made by the volunteers, each chart element received a score of 0 if it was wrong, 1 if it was correct, and 0.5 if they were partially right. The quantitative and statistical analyses show the number of correct answers and errors in the participants' activities and the statistical significance analysis of the tests' accuracy. We will reference the speeches of the participants by Px, where x is the participant's identifier.

4.3 Quantitative Analysis

In the test, we used two charts and four templates. The template with all elements had three more elements than the adapted templates (color, mean and standard deviation). Therefore, we will make a comparison with the elements common to each pair of charts. We compared the simple bar chart with the two templates and did the same for the grouped bar chart.

Analyzing the average percentages of the accuracy, we noticed that, quantitatively, the adapted templates with fewer elements had better performance in both charts. In other words, the more elements, the worse the number of correct answers on the chart elements (Figure 5).

Figure 6 and Figure 7 show a more significant number of errors in the template that used all the elements of the chart. In the simple bar chart, the greatest amount of errors was in the color element; many participants did not consider it relevant to be noted in the drawing, especially in the simple bar chart where all the bars are the same color. In the template for grouped bar charts, there were also significant errors for the color, the values of the groups' bars, and the maximum and minimum values.

4.4 Statistical Analysis

We performed the analysis in stages, having the description template used as a comparison parameter. Therefore, the test's correctness analysis was performed with the simple bar chart, comparing the adapted templates and the template with all elements. Subsequently, we performed the same analysis for the grouped bar chart.

The test with a simple bar chart was analyzed in parts, using the description template used as a comparison parameter. Therefore, we analyzed the participants' successes with the simple bar chart, comparing the simple bar chart template and the simple bar chart template with all elements. First, we applied Kolmogorov-Smirnov and Shapiro-Wilk statistical tests to verify the data distribution. Table 2 shows the results of these tests, as the value $p < 0.05$, so it is assumed that the distribution is not normal.

We applied the same tests to the grouped bar charts, and in all, $p > 0.05$. That is, the null hypothesis, which assumes that the distribution is normal, has been accepted. The results are available in Table 3.

In the next stage, the objective was to determine if the template used influenced the number of correct answers in the tests. As the simple bar chart did not present a normal distribution, it was necessary to choose a non-parametric test for this analysis. The appropriate statistical test for this case is the Mann-Whitney test, and the $p = 0.846$, so the null hypothesis that there is no significant difference between the groups was accepted.

The grouped bar chart results have a normal distribution, and it was possible to apply a parametric test. As there were two distinct groups at two distinct moments, the test indicated was the T-test for independent samples. The T-test has a null hypothesis that the difference between the groups is not statistically significant. The $p = 0.321$, and the null hypothesis was accepted.

4.5 Qualitative Analysis

We performed the qualitative analysis from the analysis of the participants' discourse [Potter and Edwards, 1996] on the tests performed, from which recurrent patterns emerged that highlight essential points about the proposed templates. We considered the verbalizations of the participants when commenting on each chart explored in the tests.

On-Demand Information with Command Prompt Interaction

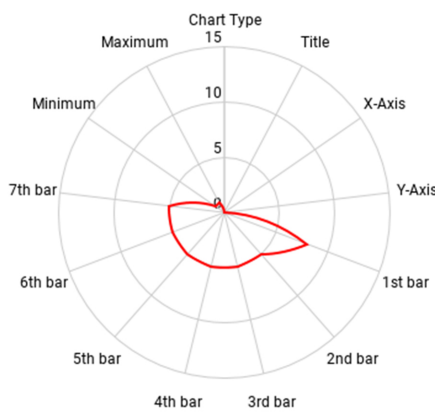
Participants liked interacting with the command prompt: *"I thought it was really cool to press and listen, I had never seen it before, and it helped me a lot."* said P25. Based on the participants' speeches, we noticed that they liked the information being provided on demand, not in uninterrupted audio. When asked if the way of obtaining information influenced the understanding of the chart, P1 said: *"I think so, but in a good way, there is this option 'D' that reads everything together, and if there were only that option, we wouldn't be able to get almost anything from the what was said. So, choosing what information you want to hear each time influenced in a good way."* This way of acquiring information also helped those who heard the full description first and missed parts of the information; when asked, P5 replied: *"It made it easier because I could focus on something I missed in the full description."*

Participant P6 explained their strategy for understanding the simple bar chart instantiated from the adapted simple bar chart template: *"(...) I went in stages. First, I wanted to know*

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	
Simple Bar Chart	100,0	46,2	92,3	100,0	61,5	100,0	92,3	38,5	84,6	100,0	92,3	100,0	46,2	46,2	92,3	79,5
Grouped Bar Chart	100,0	60,5	90,9	100,0	96,9	69,6	78,7	63,6	54,5	100,0	78,7	51,5	87,8	66,5	87,8	79,2
	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	
Simple Bar Chart With All Elements	81,3	93,8	37,5	93,8	93,8	68,8	81,3	37,5	93,8	93,8	31,3	50,0	50,0	50,0	100,0	70,4
Grouped Bar Chart With All Elements	85,7	90,4	35,7	92,9	100,0	50,0	92,9	71,4	85,7	85,7	49,9	71,4	50,0	66,6	80,9	74,0

Figure 5. Percentage of accuracy per participant and average accuracy per chart.

Template For Simple Bar Chart



Template For Simple Bar Chart With All Elements

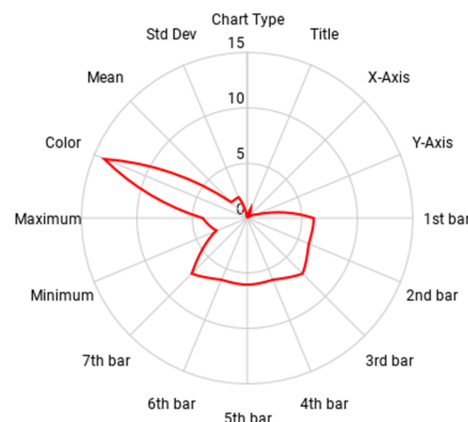


Figure 6. Number of errors in tests performed with the simple bar chart.

what it was about, so I went for the title. Then I wanted to know what measures he used, so I went on the Y-axis, then on the X-axis, then I went from bar to bar ...then I was able to get an overview of the chart just to confirm what I had seen. It was very clear to me. I thought it was very good, I liked it a lot. ” Still, regarding the information division of the information into parts, P22 emphasized: “Having the possibility to listen in parts is very good, so as not to have to hear the whole thing again.”. P27’s speech reinforced: “I had forgotten the value of this bar, and I could hear only that value instead of having to listen to the entire description.”.

Regarding the order of information, P10 suggested: “I think it has to be oriented to people who start by listening to the full description so that they have an overview, then if they want, they can go one by one to listen.”.

Bar Colors in Charts

Another recurring pattern that emerged was the confusion that information about colors caused. P18 found the information unnecessary: “I don’t think I needed to know the color of the chart unless I could paint the chart.”. P25 commented on the two charts, about the simple bar chart, he said: “Out of nowhere it said that the bar is blue, I was a little lost. ”, and about the grouped bar chart: “And again the colors ... I don’t know if it’s relevant information.”. Specialists who answered the second online survey stressed the importance of color for

people to create a mental model of the chart, but this element only makes sense when people became blind later in life, and knew the colors previously.

Grouped Bars Chart Template

Some participants complained or suggested changes in the chart description template, P28 stated: “(...) When it says each group, for example, January, he speaks the values but does not speak of what the values are about. I know that it gives this information previously, but the person can forget.”. This is because there is a command that returns the groups, another command that returns the series, but when the group is requested, the returned phrase is composed of the group’s name and the value of the series.

Some participants also commented on the reading of groups and series in the description templates for grouped bar charts. P4 commented: “(...) maybe if it repeated what the value is about, like, food, transportation or leisure before saying the value, it would be better to understand.”. P16 confirmed: “I think I should repeat the series, like ‘food 200, transportation 250 and leisure 100’, because if there are too many series the person will forget.”. Because of this way of describing without repeating the series, some participants forgot, P7 and P8 commented, respectively: “(...) I forgot what each of these ...is, food, transportation and something I didn’t wrote don.”, and ‘Each month consists of 3 bars, you have the values of

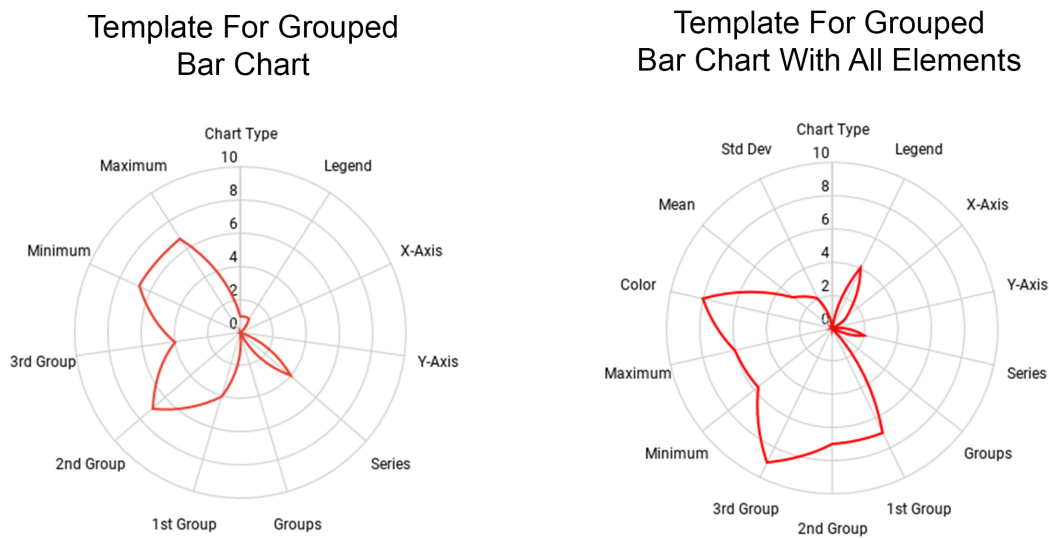


Figure 7. Number of errors in tests performed with the grouped bar chart.

Table 2. Normality test for simple bar chart.

Template	Kolmogorov-Smirnov			Shapiro Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Simple bar chart	.303	15	.001	.766	15	.001
Simple bar chart with all elements	.286	15	.002	.797	15	.003

...I forgot ...”.

4.6 Overview of Templates Test Results

Quantitative, statistical, and qualitative tests were performed to assess whether the number of elements available in the simple and grouped bar chart templates interfered with their understanding.

Quantitative results show that the more vocalized elements, the greater the errors participants make when drawing the charts. This problem is even more severe for clustered bar charts. Despite this, the statistical analysis results show that the difference between the groups tested is not statistically significant. Then, the discourse analysis in the qualitative results showed us the need to adapt the template to grouped bar charts and confirmed that the excess of elements could impair the understanding of the chart. This problem is minimized by on-demand interaction but not eliminated.

With this second version of the templates tested, the next step in the research was to apply the templates in a computational tool. ChartVision’s mission is to consume the proposed and evaluated templates so that it is possible to verify the first target audience expected to use the proposed templates, the assistive tool developers.

5 ChartVision

ChartVision¹ is an assistive tool for smartphones with interaction via a touchscreen that applies textual description

templates of simple and grouped bar charts [ChartVision-App, 2020]. The user can choose configuration options to customize the chart visualization to best suit their visual impairment. The user-configurable options available are listed and described below:

- **Vocalization:** allows listening to the description of the chart elements the user touches;
- **Vibration:** enables the haptic vibratory response when navigating the chart elements;
- **High Contrast:** follows high contrast guidelines that always guarantee maximum contrast between the visual elements and the background;
- **Font Size:** allows you to select from three font sizes for viewing the chart, small, medium, and large.

The application allows two different ways to load the charts. The first is by reading a QR code, and the second is by reading NFC tags. The tool loads the data from a JSON file containing the necessary information to visualize the charts and vocalize its textual description. The JSON encoding the chart data must conform to the Vega-Lite language specification for simple bar charts and grouped bar charts. Platforms, sites, books, posters, magazines, and other media can offer QR codes or NFC tags to be scanned by the user, but for now, as the purpose was to evaluate and validate further the use of the chart vocalization templates in a tool and the interaction with the tool, we do not offer direct integration through external URLs.

As shown in Figure 8, ChartVision uses the MPAndroid-Chart library and Vega-Lite API. The MPAndroidChart API has limitations to support touching the captions of the grouped bar chart series, i. e., and it vocalizes these elements; how-

¹alantas.dev/downloads/ChartVision.apk

Table 3. Normality test for grouped bar chart.

Template	Kolmogorov-Smirnov			Shapiro Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Grouped bar chart	.160	15	.200	.916	15	.168
Grouped bar chart with all elements	.161	15	.200	.896	15	.081

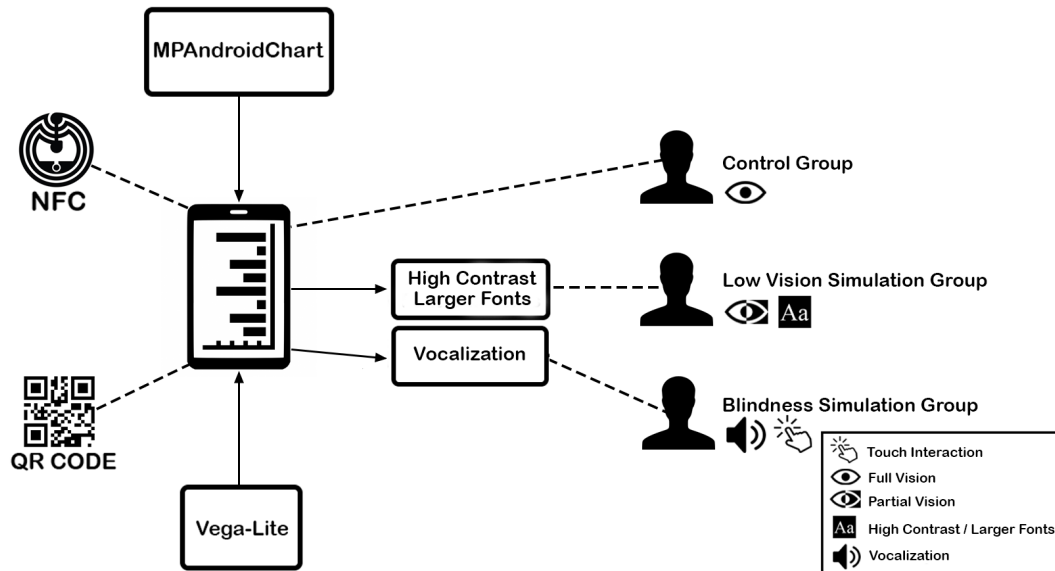


Figure 8. Overview of the implementation and evaluation of the system [Silva, 2019].

ever, it does not allow them to be interactive. The file with the chart’s information is loaded through a QR code or NFC tag, followed by an evaluation step performed by three groups of users. The platform chosen for the development of the application was Android because of its larger market share [Statcounter, 2020]. ChartVision uses MPAndroidChart API to generate the charts, the Mobile Vision API for reading QR codes, the Vega-Lite language to encode the charts, and finally, Google’s Text-to-Speech as the speech synthesis API. While Google’s Text-to-Speech API allows us to set the voice and playback speed, for ChartVision vocalization, we set it to the default voice and speed.

The chart display screen allows touch interaction, auditory response for blind people, and high contrast visualization with different font sizes for people with low vision. The bars of the chart are in the center, the title of the chart is at the top end of the view, and the legends of the X and Y axis are at the bottom end and the left side end, respectively.

With the touch interaction, the tool vocalizes any element of the chart touched by the user. The user can touch a single element or slide over the device’s screen, allowing them to search for the desired element while the audio description and the haptic response guides them in exploring the elements.

To make it easier for the blind user to find the axes’ title and subtitles, the areas that can be touched to interact with them are not limited to the size of their textual element. Figure 9 shows the interaction areas highlighted in different colors. The entire green area at the top end corresponds to the title element, any touch on the green region will trigger the title’s description. Just as the entire region in red corresponds to the Y axis legend, the entire region in yellow corresponds to the X axis legend, and the entire region in purple is where the interaction with the bars of the chart occurs.

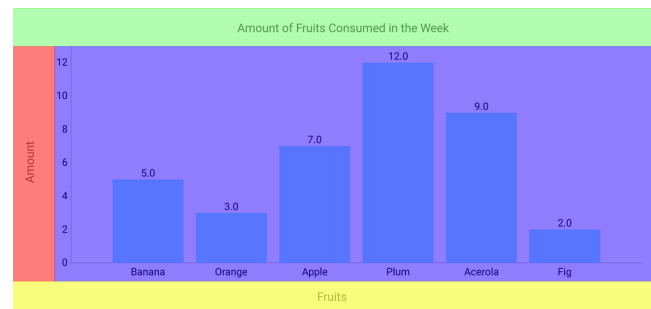


Figure 9. Interaction regions of the chart [Silva, 2019]

The tool developed in this work used the accessibility guidelines defined by the W3C (World Wide Web Consortium) for its high contrast option. The W3C has a series of accessibility guidelines for websites, called WCAG [Caldwell et al., 2008]. The WCAG, in its 2.0 version, states that to guarantee the appropriate contrast between the visual elements and the background, the colors must have a contrast ratio of at least 7:1. It also tells that light elements on dark backgrounds guarantee a better visualization of textual elements, even for the same contrast ratio value.

Based on this, the charts’ high contrast visualization has a black background color, and the textual elements in a yellow hue with a contrast ratio of 19:1, much higher than the minimum indicated, to guarantee its reading. The charts’ bars are also generated based on a list of predefined colors where they all have the minimum contrast against the black background. Figure 10 shows the application view for a simple high-contrast bar chart.

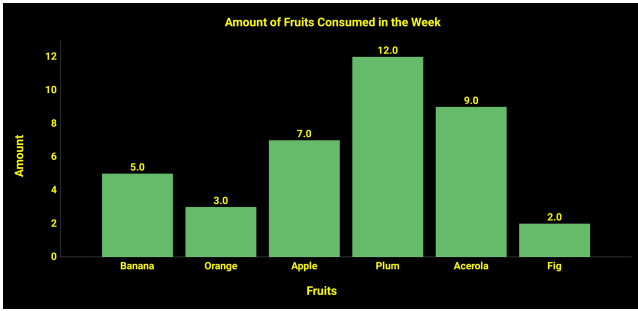


Figure 10. Visualization of a high contrast bar chart [Silva, 2019].

5.1 ChartVision Test Procedure

We tested ChartVision with volunteers in order to further evaluate and validate the chart description templates proposed. This test provided a real-world scenario of the templates being consumed by a tool made for the final user. We chose to conduct the test with sighted people but using ways to simulate low vision and blindness. Capability-loss simulators are a class of tools used to temporarily represent users who are otherwise difficult to access, especially in an initial evaluation with time and budget constraints.

Blindfolding test participants to simulate blindness is a procedure used to validate accessible computational applications [Awada et al., 2013; Kamel and Landay, 2002; Pires et al., 2013; Goodman-Deane et al., 2007; Cardoso and Clarkson, 2012], and a common way to simulate low vision is to use special glasses with lenses that distort vision. Several low visual acuity simulators of this type exist and are commercially available [Zimmerman, 2019; Cardoso and Clarkson, 2012]. Cambridge Engineering Design Centre sells their implementation, called Cambridge Simulation Glasses [Cardoso and Clarkson, 2012], in the form of lightweight glasses made of paper to allow the user to wear several glasses simultaneously to simulate different severities of vision loss. Despite not genuinely representing a visually impaired person, these options can provide valuable insights to make the system more suitable for testing visually impaired people.

In addition to the literature supporting the use of simulators, we wanted to minimally guarantee some quality criteria for the templates and tools so that we could carry out tests with blind people in the next step of the research. We understand that there are differences in the mental models of people who see and blind people, including various levels of visual impairment. However, it is not a challenge of the current work, which focuses only on proposing, evaluating, and consuming the templates. We wanted to get to the tests with blind users with the templates and the tool already tested previously within the possibilities.

For the group of participants simulating low vision, special goggles were developed following the suggestions in the research of Zagar and Baggary [2010], using a pair of welding goggles and decreasing the transparency of the lenses by painting them with clear nail polish. We applied layers of clear nail polish until using the glasses decreased the visual acuity to the same level that using two Cambridge Simulation Glasses would achieve, which is, on average, 0.26 logMAR [Goodman-Deane et al., 2013]. For the group of participants simulating a blind person, we used welding goggles with completely obstructed lenses to entirely block the participant’s

vision. Figure 11 shows the simulation goggles for low visual acuity and blindness used in the tests.



Figure 11. Goggles used in the tests [Silva, 2019].

We conducted the study with 45 people, all undergraduate and graduate students at the Federal University of Pará, and from all three major areas of knowledge. The only criteria required to participate in the tests was for the participant to know what bar charts were. The selection of volunteers was made through a brief conversation, inviting the participant to take the test applied in this research. After, the research was then presented verbally, showing the study’s motivation, the objectives, the estimated duration of the test, and the steps of each task they would have to perform.

Participants were divided into three groups: a control group, who took the test and could look at the chart; a group that wore goggles to decrease visual acuity; and a group that performed the test while being blindfolded. Each group contained 15 participants randomly chosen. To participate in the tests, the volunteer went through a quick summary of bar charts, where they received an explanation about the names and functions of each visual element that make up simple and a grouped bar charts (series, groups, axes, legends, and titles) using two charts created just for this stage. Afterward, the volunteer could try out the application, getting to know all the menus, all the ways to load charts, the main form of interaction, and how to choose the options that fit each visual impairment group better. Table 4 presents the settings for each group.

Table 4. Settings used for each test group [Silva, 2019].

GROUP	Vocalization	Vibration	High Contrast	Font Size
Control	Off	Off	Off	Small
Low Vision	Off	Off	On	Large
Blind	On	On	Off	Small

The test procedure used two charts, a simple bar chart (Chart A) and a grouped bar chart (Chart B). Both can be seen in Figure 12 and Figure 13, respectively. Each group was presented first with Chart A and then with Chart B.

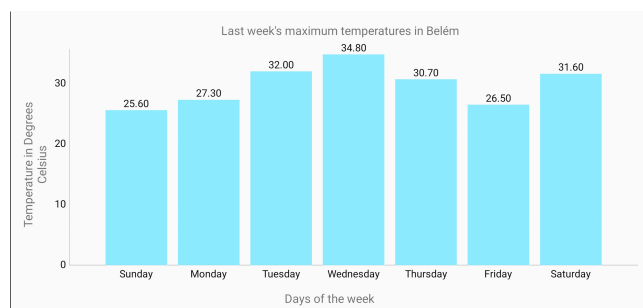


Figure 12. Chart A [Silva, 2019].

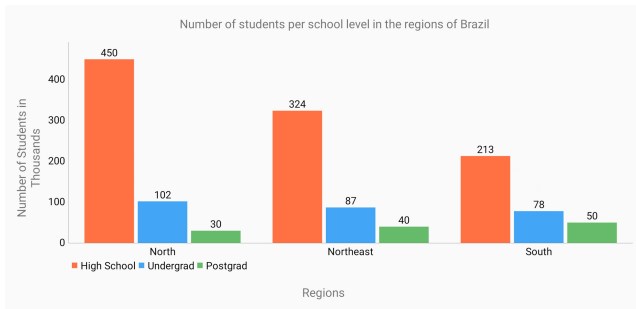


Figure 13. Chart B [Silva, 2019].

The control group participants could look at the charts, the participants in the low vision simulation group viewed the charts through the simulation goggles and with the application configured with high contrast and large fonts, and the participants in the blindness simulation group were blindfolded and interacted with charts through touch and auditory and haptic response.

The participant could analyze each chart for 2 minutes and then give a verbal summary of the chart’s content. In the end, the participant answered six questions about each chart. Questions 1, 2, and 3 were the same for both types of charts: Q1 - What is the chart’s title?; Q2 - What is the X axis legend?; and Q3 - What is the Y axis legend?. The participants answered the following questions for the simple bar chart: Q4A - How many bars does the chart have?; Q5A - Which are the two days with the highest temperature?; and Q6A - What is the lowest temperature?. For the grouped bar chart, they answered the following questions: Q4B - What are the names of the groups?; Q5B - How many post-graduate students are there in the northeast?; and Q6B - Which region has the most high school students?

During the test, in addition to the objective and subjective questions asked at each stage, the participants had to describe the charts with their own words, as they would if they had to explain them to another person.

We did not perform statistical tests with the results of these tests because the test application settings were different. The tool’s tests were configured differently for each user group, which makes it challenging to perform a statistical comparison.

5.2 ChartVision Quantitative Analysis Results

Figure 14 and Figure 15 show the number of errors for each question in each group of tests for Chart A and Chart B, respectively. For the control group, Q5A and Q6A had the most errors for Chart A. Both questions involve comparing all bars. Participants who got these questions wrong tried to answer them by only comparing the bars’ height visually and ignoring their quantitative values, but the chart purposely has bars with very close values, which possibly confused them.

Question Q4B was the one that got the most wrong answers among all groups, which can be associated with a poor understanding of the elements of the grouped bar charts. All participants who missed this question confused Groups with Series and, instead of answering Q4B with Groups “North, Northeast and South”, answered “High School, Graduation and Post-Graduation” which are, in fact, the Series. From the twenty-one participants who missed Q4B, only five (23.8%)

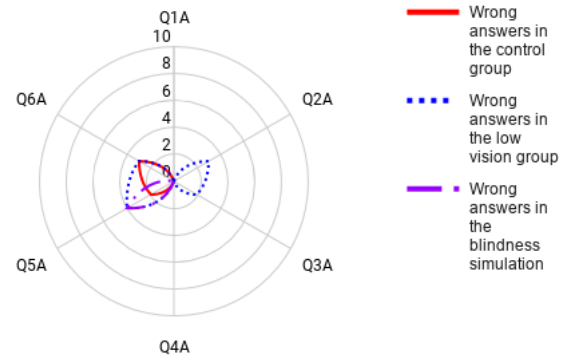


Figure 14. Number of errors for chart A [de Oliveira, 2020].

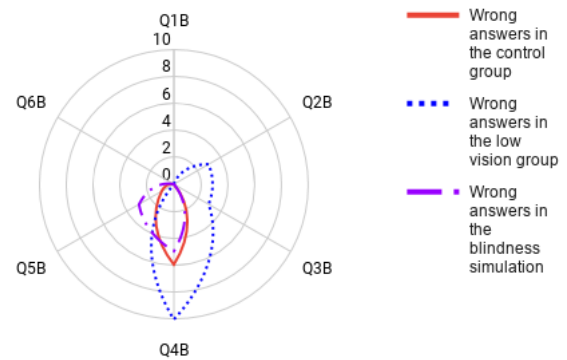


Figure 15. Number of errors for chart B [de Oliveira, 2020].

were from the area of the exact sciences, probably due to its students’ familiarity with charts. It is important to state that before the test started, all participants received a small training, getting to know or remembering the names of all the elements of a bar chart.

It is noticeable that the low vision simulation group was the one that accumulated the most errors. Some participants got questions Q2A, Q2B, Q3A, and Q3B wrong, which refer to the X and Y axes’ legends. All participants who missed these questions confused the X axis with the Y axis, possibly due to the lack of familiarity with charts. Question Q5A had a large number of errors, possibly due to the greater difficulty in comparing the bars’ height by the participants wearing the low vision simulation goggles.

The group simulating blindness had the least amount of errors, even less than the control group; this is because the charts’ vocalization template states the name of the element it is reading and avoids confusion. For example, when tapping the X axis legend, the application answers “The legend of the axis X is (...)”, eliminating the need for prior knowledge of which of the two axes is X.

5.3 ChartVision Qualitative Analysis Results

For the qualitative analysis, we considered the description of the charts given by the participants, as well as what they commented about their experience at the end of each stage of the test. By analyzing the participants’ discourse [Potter and Edwards, 1996] on the tests performed, recurrent patterns emerged that highlight essential points about the prototype. Discussed below are the recurring patterns that emerged from this analysis.

Chart Introduction

When a chart is loaded, if the vocalization is on, the chart’s type is vocalized for the user, explaining if it is a simple bar chart or a grouped bar chart. Three participants in the blindness simulation group commented on the possible inclusion of an introduction that would reveal more aspects about the chart. P75 argues “*It (the voice) doesn’t say the number of bars, groups, and series. It would help a lot. Make it clearer.*”, while P44 did not find the last group of bars of the grouped bar chart and only discovered that there was one more group taking off the goggles, he argues “*Only now I can see that there is a South group, the voice should say the number of groups and series. Or at least the number of bars*”. We can easily modify the introduction with an option in the settings where the user can choose whether he wants the introduction more detailed or not.

Low Vision Simulation Goggles

Two participants in the low vision simulation group gave evidence that the low visual acuity simulation goggles fulfilled their purpose of simulating a person with low vision. P43 said: “*I think the goggles make seeing harder, but not that much. I can still see.*” And P71 said: “*Everything is blurry and difficult to see (...)*”, this confirms what is presented by Cardoso and Clarkson [2012], that despite not replacing tests with visually impaired people, low visual simulation goggles are a useful tool for preliminary testing on assistive tool design.

Synthetic Voice

P35 found the synthesized voice unpleasant: “*I just found the woman’s voice annoying*” and P44 commented on the speed of the vocalization: “*(...) when she’s describing the chart, it is very fast. It could be more paced*”. The application uses Google’s speech synthesis API with the standard voice and speed, the adjustment of these two options is available through the API, and it may be interesting to add an option in the settings so that the user can also adjust the speed and select the voice they prefer for vocalization.

Series Legend

The application presents the grouped bar charts as shown in Figure 13, with a visual element representing the legend of the series that make up the chart groups; however, this element is not interactive. When it is touched, the tool does not vocalize the series as it does for other chart elements. The application does not implement this option due to the lack of support from the MPAndroidChart API for touch events over the series legends. Although the application states the series’s names when it is vocalizing each group of bars, participants from the blindness simulation group felt the lack of an interactive element. P31 and P40 said, respectively: “*In this one, I felt a difficulty for not having an element of the series so that I could interact with, I had to discover the series touching in each group. If it had an element for the series, it would be faster.*” and “*(...) there is no legend element to touch for*

it (the tool) to read the series for me. I looked for it at the beginning, but I didn’t find it.”.

Relevance of the Elements of the Chart

After a first moment of observing the chart, the participant’s first task in the test was to describe the chart he saw. This step’s purpose was to discover the relevance of each element of the chart to the user. Some participants, like P53, were very minimalist, stating about Chart A (Figure 12): “*It illustrates the temperatures of the last week in Belém*”. Some, like the P65, were extremely detailed, describing Chart B’s (Figure 13) title, legend of the X and Y axes, unit of the Y axis, names of groups and series, and the minimum and maximum values of each series.

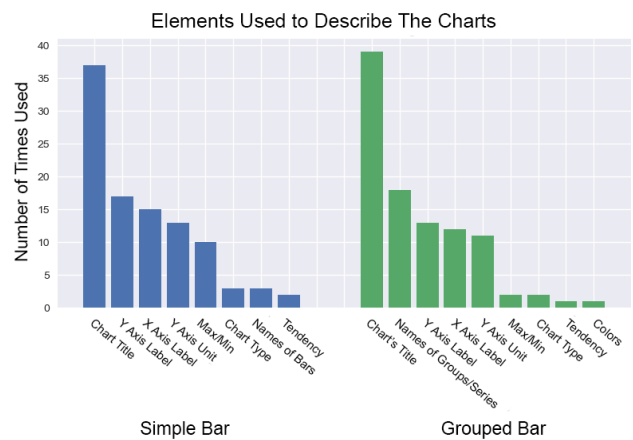


Figure 16. Frequency of use of chart elements in the descriptions given by the participants [Silva, 2019].

Figure 16 shows the elements most used by participants to describe charts A and B. The title of the chart is the most used element in both. In the grouped bar chart, the second most used element was the name of the groups and series, followed by the axes’ legends. For the simple bar charts, the X and Y axes’ legends occupy positions 3 and 2, respectively. The participants barely mentioned bar names in the simple bar chart, probably because there are many bars; describe them individually would be a tiring task. In contrast, there were many mentions of minimum and maximum values. In grouped bar charts, the participants barely mentioned the minimum and maximum, perhaps because there is more than one way to give the maximum and minimum of a grouped bar chart.

6 Validation

This section presents the description templates and the prototype to a specialist from Accessibility Coordination, responsible for translating study materials for students at the Federal University of Pará. Finally, we present tests for the final templates with accessibility specialists.

6.1 Interview with a Specialist

After the tests, the authors had the opportunity to interview a specialist, an employee of the Accessibility Coordination of

the Federal University of Pará responsible for the specialized coordination in visual impairment since 2017, specializing in special education - visual impairment. He shared his needs in producing and translating teaching materials for students and also tried using ChartVision.

Current Scenario

The specialist interviewed works adapting graphic materials for students with visual impairments, both images and data charts. We asked him, first, about how he currently adapts content, and he replied: “(...) *We print the materials in braille for them, maps, charts, everything. We print it using that machine over there. A braille printer. (...) We either do it this way, or we describe the images as if it were an audio description.*”. The university has two braille printers that punch the content on a special paper. Still, according to the specialist, each printer costs around twenty thousand Brazilian reais. The Accessibility Coordination team adapts and analyzes all graphic content using special software called Monet [Monet, 2019] so that the braille printer can then print it. When a student asks for a synthesized voice description, the same employee creates a textual description of the chart that is made available to the student.

Braille Literacy

The specialist also said that most students depend more on the audio description than braille materials, as not all of them know braille. Especially students with low vision or with vision loss. He said: “(...) *Not all students can read braille. In fact, most arrive knowing very little braille. (...) Generally for congenitally blind people, learning braille is a little faster. However, most of them use screen reader programs like DOSVOX. For those who are losing sight now, it's more complicated (...)*”.

Audio Description

When asked about how he makes the audio description of the charts for students who use reader software, the specialist replied: “*We analyze the chart, understand what it wants to say and give an overview (...)*”. The authors showed the specialist two charts, one with simple bars and one with grouped bars, and asked him to describe them as he would to a student. The specialist's descriptions are very similar to the ones proposed in this work, which further validates the vocalization templates used.

Presenting the Application

We presented ChartVision to the specialist, who had a chance to try all forms of interaction. The specialist showed interest in the tool, congratulated the team, and said: “*I think your work is amazing, it will kind of endanger my job (laughs) (...). Very nice!*”. He also suggested the implementation of support for the description of tables and spreadsheets, widely used by students, and that screen readers are also unable to read: “*An interesting thing would also be to extract and generate charts from tables, the visually impaired Statistics students are having a hard time with spreadsheets. They cannot access*

this information, and readers cannot read them. When we receive materials with tables, it is very difficult. We have to adapt everything.”.

6.2 Tests with Specialists

We carried out a final test with the participation of four specialist volunteers. In this case, people with professional experience with people with blindness and low vision were considered specialists. The group of participants was composed of a professor of the area of the exact sciences (S1), an occupational therapist (S2), and two professionals from the UFPA Accessibility Coordination (COACCESS) responsible for the description of images and charts for visually impaired students (S3 and S4). The participants received headphones, a paper containing a sketch for the construction of the chart, and a pen. Two of the participants, S1 and S2, listened to the audios containing sequential reading templates. Two others, S3 and S4, listened to audios with the templates for on-demand reading. The participant should draw the chart according to the description given to them through the descriptions heard. Each audio could be heard up to two times by each participant. We performed only qualitative analysis, as the number of participants was reduced considering specialists' profile, making the samples too small for a significant quantitative or statistical analysis.

Chart Information

One of the recurring patterns that emerged was regarding the information contained in the chart. According to S1's comment, the information provided by the audio is sufficient for its full understanding. The participant said: “*I think everything I heard was necessary.*” Still on this topic, S2 commented: “*From the basic information of the chart there is everything, I think I would not add any more information*” and added: “*You managed to dry up well what it was, I think it was good*”. Participant S3 was satisfied with the information present in the templates but made an observation in his speech: “*Look, maybe I'm mistaken, but I think the colors are missing, not for a blind student, but for a low vision student. The student with low vision has some trace of vision, even if they are already close to blindness, and in this case, some legend with color information can help them. Now concerning the blind, this information would not be so useful, especially if they are congenitally blind.*”. Containing information about the colors seemed interesting initially. Still, the tests with the users showed that it is not really important information, and they can even cause the participants to miss other pieces of information.

Synthetic Voice

The participants made some relevant comments regarding the voice and reading speed. S1 commented positively about the voice used; during the test, the participant said: “*(...) I liked the voice, it's soft, good*”. About the speed, S3 made some considerations: “*I think the voice should be faster, because blind users prefer much faster reading. For inexperienced users (who lost their sight late), and are not used to this type*

of reading, the standard speed meets their satisfaction”. Still concerning speed, the pauses made during the reading by the synthetic voice did not please the participant S2, who said: “This broken information disturbed me, it may not disturb the visually impaired (...) And I don’t know if that voice the way it is, I don’t know if it helps a lot, not the voice itself, but the cadence with which it speaks”. It is worth remembering that the speed of the voices used in the tests was the standard speed provided by the API. As for the pauses made during the reading, it should be checked with more attention in the future.

Automatic Interpretation of the Chart by the Prototype

Some participants suggested that the prototype would assist in the interpretation of chart data. According to S1: “The month with the most transportation was this, the month of food was that (...) giving this “overview” of the chart to the blind person so that they can generate this information at the end.” Participant S2 argued: “(...) informing the disabled even more than the information on the chart, in terms of interpretation, can make it very easy in some aspects. But it will depend on what you want to go through, if it’s something more objective, it’s great”. In contrast, participant S4 stated: “I really liked it, it is a neutral reading, it does not interpret the chart, it only gives the data.”. It is important to remember that one of the justifications of this work is to make the visually impaired independent to interpret the data of a chart.

7 Final Templates

The description template for simple bar charts did not change, but we can conclude that the template is unique, regardless of the form of interaction used in the application. We adapted the template for grouped bar charts after the tests performed with ChatVision. This change consists of adding the numbers of bars, groups, and series in the textual description. The final version of the template is presented below and separated into two versions, when data is requested sequentially, without interruptions, and when data is requested on-demand, as is the case with ChartVision. We keep different scenarios for templates because we understand that a blind person using a screen reader would not read the chart information on demand. However, a person with low vision using ChartVision, for example, could use the template information using on-demand interaction. So, in this way, we attend to different people on different occasions.

- **Simple bar for applications with sequential reading or reading on-demand:**

This is a vertical bar chart.

It’s title is {title}.

The y-axis legend is {y-axis label}.

The x-axis legend is {x-axis label}.

The number of bars is {number of bars}.

The first bar is {name of the first bar} and has value {value of the first bar}.

The {nth} bar is {name of the nth bar} and has value {value of the nth bar}.

- **Grouped bar for applications with sequential reading:**

This is a grouped vertical bar chart.

It’s title is {title}.

The y-axis legend is {y-axis label}.

The x-axis legend is {x-axis label}.

The chart is made up by {number of groups} groups of bars: {name of the first group, (...) name of the nth group}.

Each group contains {number of bars} bars: {name of the first bar, (...), name of the nth bar}, which will be presented in that order.

The first group of bars is {name of the first bar group} and has values {value of the first bar, (...), value of the nth bar}.

The {nth} group of bars is {name of the nth bar group} and has values {value of the first bar, (...), value of the nth bar}.

- **Grouped bar for applications reading on-demand:**

This is a grouped vertical bar chart.

It’s title is {title}.

The y-axis legend is {y-axis label}.

The x-axis legend is {x-axis label}.

The chart is made up by {number of groups} groups of bars: {name of the first group, (...) name of the nth group}.

Each group contains {number of bars} bars: {name of the first bar, (...), name of the nth bar}.

The first group of bars is {name of the first bar group}.

The series {name of the first series} has value {value of the first series}. (...), the series {name of the kth series} has value {value of the kth series}.

The nth group of bars is {name of the nth bar group}.

The series {name of the first series} has value {value of the first series}. (...), the series {name of the kth series} has value {value of the kth series}.

The grouped bar chart templates differ in how they present groups and series names, which have to be repeated in the case of access on-demand. For each group, the series name and its value in the chart are mentioned again.

8 Discussion

With all the knowledge acquired during the research, we can make some considerations about the use of the templates, the charts it can describe, and the tools that will use them. These are:

- Round off continuous values to bar values, when possible. The research showed that charts with non-integer values are more challenging to understand.
- Make it possible to change the reading order of the bar data. In some cases, an order different from that expected by the user makes understanding difficult. For example, if the X-axis legend is the days of the week in order, but the bar values are out of order, and the user expected the values in ascending order, this makes it difficult to understand. A tool can give the user the possibility to order the bars as they prefer.

- Summarize titles and labels. Very extensive textual components seem to be harder to understand. A tool can allow for the automatic or manual reconstruction of charts, renaming titles and labels.
- Describe the chart with a brief introduction before providing the full textual description. Tests with people simulating blindness allowed for this to be verified. The participants interacted without knowing the chart's dimension, and in an exploratory way, describing important features of the chart beforehand helps the participant have an overview of the chart.
- Allow access to the full description or in parts. Even when the interaction option is on-demand, it is suggested that there is a command to read the full textual description.
- Control the speed of vocalization. Tools should have the option of controlling speech speed. For example, blind users have a habit of listening to screen readers at high speeds, but for other contexts, such as teaching about charts to beginners, vocalization must be slower.
- Allow the choosing of synthetic voice. Some participants complained about the voice used in the tests (Google Speech standard), so it is suggested that the tools that use the templates have configuration option to change the synthetic voice.
- Allow for multiple forms of interaction. It is interesting to allow different speaking commands with codes (such as shortcuts) or complete sentences for voice interaction. In the case of keyboard interaction, research can explore different ways to configure the shortcuts for accessing information.
- From the analysis of the answers to the questions, we can conclude that the proposed interaction for blind people works well to allow the exploration of the charts' content and even adds information that facilitates further understanding of the chart, suggesting that it can also be used in the learning process, to teach blind people on the using and understanding of charts. The alternative for people with low vision also allows chart content to be accessible to this group of individuals, although corrections may still be needed to facilitate direct comparison between visual components with very approximate values.

9 Final Considerations

This work aimed to define textual description templates for the vocalization of data of vertical bar charts, simple or grouped, in a comprehensible way. The templates were created and evaluated in several stages. The data collected were analyzed in a quantitative, statistical (when possible), and qualitative way.

This work also presented a tool that allows visually impaired and blind people to interact and obtain the content of simple and grouped bar charts. The access to the information of the chart happens through descriptions produced from the proposed templates. Based on the tests performed, we can attest that a tool has the potential to meet the purposes for which it is intended, allowing interaction with charts and presentation of information by different types of people with different

types of vision-related characteristics. The tests were with visual impairment simulation, so there are limitations to be considered. Based on the high amount of errors, we verified that there is room for improvement, especially for people with low vision, perhaps allowing for even larger font sizes. The current maximum font size is a limitation of the MPAndroidChart API, used to generate the charts' visualization, which is open source and can be modified to increase the font size further. The tests also indicated modifications for the templates, such as including the number of bars, groups, and series in the introduction. In addition, the speech speed and the could become configurable.

Charts are essential tools for presenting data in both academic and professional environments but are intrinsically visual. The adaptation of charts for a spoken representation represents the possibility of inclusion in the learning process for 6.5 million visually disabled people only in Brazil [IBGE, 2010]. To the best of our knowledge, no other software with the same purpose exists in the literature, and ChartVision proved to be a viable option potential for these people.

This work proposed to answer "How to describe the content of bar charts for users?". The answer was the creation of textual description templates for simple and grouped bar charts. One of the secondary questions is "What elements of these charts should be exposed?". The answer is the following elements: chart type, title, X-Axis legend, Y-Axis legend, number of bars, name of the bars, and values of the bars; for grouped bar charts, the number and name of groups and series are added. As for another subsequent question, "What is the most appropriate way to expose this content? Sequentially or on-demand?". The way to expose the content to simple bar charts is unique, as the data is very concise and straightforward. For grouped bar charts, two ways are considered to expose the information depending on the interaction mode, whether it is sequential or on-demand.

Finally, we can say that this research has two main contributions: the textual description templates for simple and grouped bar charts; and ChartVision as an assistive technology tool. This paper demonstrates the stages of building and evaluating the templates and the ChartVision assistive tool.

9.1 Limitations

One of the work's main limitations is the profiles of the volunteers who participated in the tests. It is necessary to use more homogeneous samples to have comparison parameters. We carried out the tests at a University, and the only criterion for selecting participants was to confirm prior knowledge about bar charts. The participants' academic degree was not an elimination criterion. It wasn't easy to find people with availability to perform the tests, which lasted around 15 minutes, especially because we did not repeat the volunteers.

On the one hand, the absence of blind people in the tests limits the research. On the other hand, we wanted to ensure that the templates were consistently evaluated to avoid losing blind volunteers who might have been frustrated with templates still under construction. As this audience is rare, we avoid using it in the template construction and tool creation phases. Thus, tests with the blind are part of future work. However, it is worth considering the hypothesis that

the results will be different, given that blind people used to computational tools have a very high ability to understand the vocalization of interface elements. Also, depending on the level of blindness, users' mental models are different; whether they lost sight after being literate or were born blind, the way they plot charts can be completely different. Tests with blind people are a future challenge for this research.

9.2 Future Works

The accessibility specialist interviewed suggested developing a way to describe Microsoft Excel tables since screen readers cannot access their content correctly. A tool that describes tables not only for productive suites but also for websites can be developed.

ChartVision, being a tool that allowed interaction with the chart elements, did not allow access to elements that are not easily selectable. It is future work to make this improvement in the prototype, to study a way to make an element accessible via touchscreen even when they do not have a delimited area on the device screen, such as groups, series, and number of bars.

An important future work is to extend the templates to other types of data charts, such as pie, radar, donuts, lines, areas, and others. Some elements between the chart types are similar, but research is necessary to investigate how to best explain each of them. In this phase of the research, we built templates to evaluate the best way to present the charts' content and their applicability in an assistive tool, but it is also necessary to carry out tests with blind people to further validate the templates and the tool.

Another future work would be to implement a way to interact with the charts by asking questions. It is possible to create a question-answer system, allowing the user to ask, for example, for the values of the bars, the highest or lowest value in the chart, or the title of the chart. This would be a more natural form of interaction but requires a great deal of effort to implement.

Another future work is testing with blind people. This was not the audience for this first phase of the work, as we aimed to build the templates and evaluate how to expose the content of the chart. However, the change of public can produce several questions. For example, in the electronic form, accessibility specialists responded that the color element was important, but the tests we carried out did not confirm this. More studies are needed to verify the need for this element, especially if the vocalization is aimed at people with visual impairments.

Lastly, related to the previous stage of this research, it is the automated extraction of data from the charts. This step was not the objective of this research, but efficiently implementing this would automate the entire process, making it much easier to make accessible content available for the blind and the visually impaired.

Declarations

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Authors' Contributions

CLTO contributed to the proposed templates and theoretical foundation of the research. ATAS contributed to the chartvision tool and related tests. JMM and MPM contributed by guiding the research. All authors write, read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The data analysis is available from the corresponding author on a reasonable request.

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