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A review of maps in PhDs: Is your map worth a 1000 words?

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Abstract

Maps are useful for providing location context and for graphically presenting spatial relationships. They are often used in PhD dissertations to show the location of a study area or to present scientific results. These maps have to tell their story without the PhD candidate being present. We searched for maps in 575 PhD dissertations, and reviewed 192 maps in 65 of these: 38% were created by PhD candidates, 48% were inserted and 14% were adapted from other sources. Maps prepared by PhD candidates had more design shortcomings than other maps. Nevertheless, the number of problems with maps from other sources suggests that guidelines for including them in a dissertation could be useful. Our results suggest that PhD candidates use GIS software to design maps, but that there is room for improvement to guide users towards appropriate design choices. The results will help to plan support services for PhD candidates at universities.

Keywords: map design; cartography; PhD dissertations; research communication

1. Introduction

Maps are graphical representations that show spatial relationships (Tyner, 2010). Because of their potential to provide spatial context and to graphically illustrate complex spatial phenomena, they are often used to contextualize research or to present scientific results.

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Ever-increasing volumes of geospatial data over the past few decades have resulted in the wide availability of data for making maps. Tools for analyzing and visualizing geospatial data are also readily available and used by anyone, including researchers. However, because anybody can now use online and desktop mapping products to make a map, concerns have been raised about the quality of maps (Wood, 2014; Medeiros, 2016; Kraak, Ricker and Engelhardt, 2018), and whether these maps accurately convey the information they present (Hay *et al.*, 2013; Robinson and Petchenik, 2014; Robinson, 2019). As postgraduate supervisors and academics, we asked ourselves if and how recent concerns about the quality of maps apply to maps in PhD dissertations. In an exploratory study (Coetzee et al. 2021), we reviewed maps in PhD dissertations published at three universities on three continents between 2015 and 2017 seeking answers to questions, such as: In which disciplines are maps used? Are maps used to indicate location of phenomena or research activities (e.g., sampling), to provide the spatial context of various phenomena (e.g., characteristics of the area surrounding a sample), or to present scientific results? Did the author prepare the maps or were they sourced from a third party?

Results showed that maps are used in a wide range of application fields, even in the Musical Arts (Ipsen, 2017) and Theology (Mushayavanhu, 2017), which confirms that people rely on maps for communicating information about geographic space and that cartography is not a skill that should be 'owned' solely by cartographers or geographic information scientists. Communicating geospatial information is a skill required by many more than that (Wikle and Sinton, 2021), and in the age of big (geospatial) data, the ability to effectively communicate geospatial information is gaining ever more relevance and importance

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(Robinson and Petchenik, 2014; UN GGIM, 2015). The current COVID-19 pandemic has put renewed focus on the need for trustworthy maps (Griffin, 2020; Juergens, 2020).

In this paper, we report the results of a follow-up study in which we examined a smaller set of PhD dissertations in more detail. The aim was to understand common pitfalls and shortcomings of maps in PhD theses. Based on the findings, we identified areas of concern with regards to the design and use of maps in PhDs, which can inform the development of material and support services at our respective universities. In the next section of the paper, we describe how the review of maps in PhD dissertations was done and in section 3 we present the results. In section 4, the results are discussed and we provide a concrete proposal for supporting PhD candidates with map making. Section 5 concludes.

2. Method

In this study, we reviewed PhD dissertations published in 2015, 2017 and 2019 by the University of Pretoria. 575 dissertations in PDF format were downloaded from the University of Pretoria's institutional repository (University of Pretoria, 2020). A few dissertations from these years were not available due to an embargo. The dissertations for 2016 and 2018 were not included, as we wanted to keep the sample size manageable but span a longer period. The University of Pretoria was selected through convenience sampling, since two of the researchers are affiliated with this university. The title, abstract, name of the department, and faculty were recorded for dissertations with maps. The latter two provide an impression of application fields in which maps are used.

We searched through each dissertation and evaluated any maps included in the dissertation. The evaluation method is described in more detail in 2.1. Remotely sensed

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images, such as satellite images and aerial photographs, were not evaluated, unless the author used an image as a background and displayed other features on top of the image. Sketches of areas and building plans were also not evaluated. Each map was evaluated by at least two researchers and one of the researchers evaluated all the maps. The questionnaire allowed five responses on the Likert scale: 'Strongly disagree', 'Somewhat disagree', 'Neither agree or disagree', 'Somewhat agree', 'Strongly agree'. To simplify the presentation of results we grouped responses close to each other on the Likert scale, e.g. if one researcher responded 'Strongly agree' and the other 'Somewhat agree', they are grouped into a 'Strongly agree' response. Similarly, 'Somewhat agree' and 'Neither agree or disagree' are grouped into 'Somewhat agree', etc. Significant differences in responses were discussed to understand why they were answered differently. Where the responses differed significantly, we discussed them and eventually reached consensus on the appropriate response.

2.1 Map evaluation

We based our map evaluation on the design guidelines for thematic maps in Kessler & Slocum (2011) but adapted them to be applicable for all kinds of maps by consulting map design guidelines in Tyner (2010) and Slocum et al. (2009). To ensure that legibility was evaluated consistently, the zoom level of the PDF was set to 100% before we started the map evaluation. Data was collected via a Microsoft Form, which consisted of 45 qualitative and quantitative questions subdivided into 11 topics. Quantitative questions had responses on a Likert-type scale, while researchers provided justifications for their quantitative answers in the qualitative responses.

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Before we started the map evaluation, we specified the file name, figure number and page number as unique references for the map, and indicated whether the map was created by the PhD candidate, adapted from another source or inserted from another source. We assumed that maps without a source were created by PhD candidates, even though they may have received help from someone who was mentioned in the acknowledgements and not on the map itself. Next, the map was evaluated related to each of the topics listed in Table 1. The full questionnaire is available as supplementary material. When evaluating the map, we sometimes looked at the text referring to the map or text close to the map. However, we did not try to understand the full dissertation when assessing a map and its purpose.

Table 1. Topics and questions in the map evaluation questionnaire

Symbolization
Were logical design decisions made and appropriate symbols used? – Is there logic in representing the feature or phenomenon by a point, line or polygon symbol? – Were appropriate visual variables used to differentiate in a nominal, ordinal, interval or ratio classification? – For a thematic map, was an appropriate symbol used to represent the kind of data available? – Where applicable, was a logical progression of a colour ramp or grey scale used?
Legend
Is the legend design clear? – Are features or themes important for understanding the map included in a legend or explained in the caption? – Are symbols in the legend logically associated with their corresponding text? – If necessary, are symbols in the legend organized into groups?
Basic map design
Does the map achieve basic map design goals? – Is map balance achieved? – Are map elements ranked appropriately in the visual hierarchy (e.g., more important features or themes are graphically emphasized vs others)? – Is the figure-ground relationship clear? – Does the map have suitable contrast so that labels are readable and features can be differentiated from each other and against the background?
Lettering

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Is the text on the map readable and are conventions applied where applicable and appropriate? For example, italics for names of water-related features and names of line features follow the curve of the line.
Title and caption
Does the map have a title? If there is a title, where is it (e.g. on the map, in the legend, in the caption)? And does the title clearly and briefly describe the map topic?
Base information
Depending on the map's purpose, was appropriate base information included?
Inset maps
If required, was an inset map included e.g., to show the location of the map area or to show complex parts of the map in more detail?
Scale
If required for interpreting the map, was a scale included? If there is a scale, is it well designed, e.g. appropriate visual weight, min and max values, units of measure, style?
Projection
If the projection is critical to the map, was the choice of projection appropriate and is projection information included on the map?
Orientation
Is the orientation indicated, and if, is it essential for interpreting or understanding the map? If there is orientation, is it well designed, e.g., appropriate visual weight and in a style that matches the style of the map?
Source
Is information included about the source of the data on the map? If the map is adapted or inserted from another source, is a full reference to that source included?

3. Results

In this section, we first provide descriptive statistics about the maps that we reviewed, followed by the results of the map evaluation questionnaire, structured according to the different sections of the questionnaire.

3.1 Overview

We searched for maps in 575 PhD dissertations - 154 from 2019, 218 from 2017 and 203

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from 2015). Only 65 (11%) of them contained maps. In total, we reviewed 192 maps, of which 38% were created by PhD candidates, 48% inserted and 14% adapted from other sources. Figure 1 provides a breakdown of PhDs per faculty and department. Examples of two maps are included in Figures 2 and 3. Most PhDs with maps were awarded by the Faculty of Natural and Agricultural Sciences (30), followed by the Faculties of Humanities (10) and Education (6). At the University of Pretoria, each faculty is further subdivided into several departments. The highest number of PhDs with maps graduated from the Department of Agricultural Economics, Extension and Rural Development (8), followed by the Department of Educational Psychology (5) and the Department of Geography, Geoinformatics and Meteorology (4). Unsurprisingly, the largest number of maps were found in dissertations supervised in the Department of Geography, Geoinformatics and Meteorology (25), followed by the Department of Agricultural Economics, Extension and Rural Development (22) and Hydrogeology (17).

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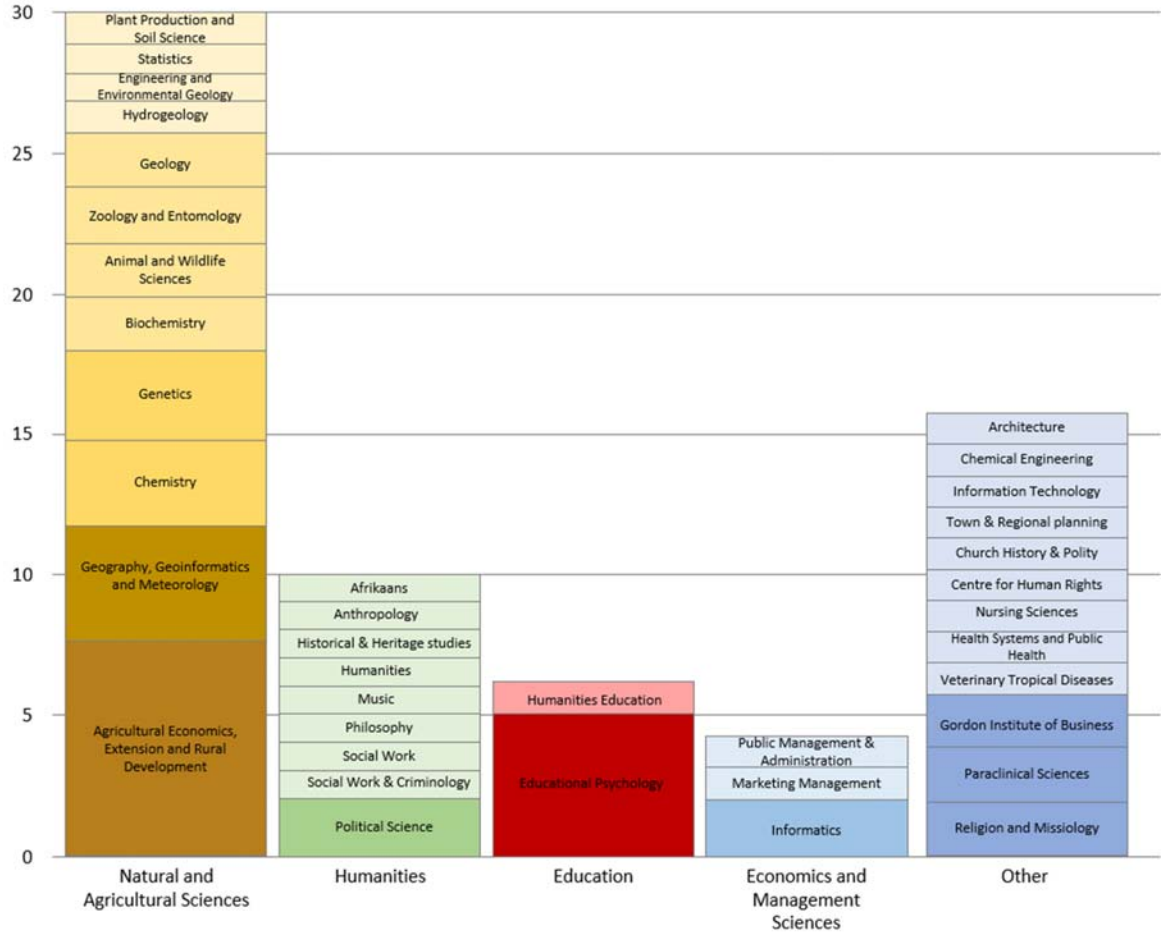

Figure 1. Number of PhDs with maps per faculty and department

The general admission requirement to doctoral study is a master's degree. Each department may specify additional requirements, e.g., the discipline and minimum mark obtained for the master's degree. Information about gender, biological age and educational background are not published in the dissertation. However, one could argue that a PhD candidate's biological age is not as important as their academic age, reflected by their admission to and graduation of a PhD. Figure 4 shows the gender and international status split of PhD graduates for the years for which we reviewed dissertations.

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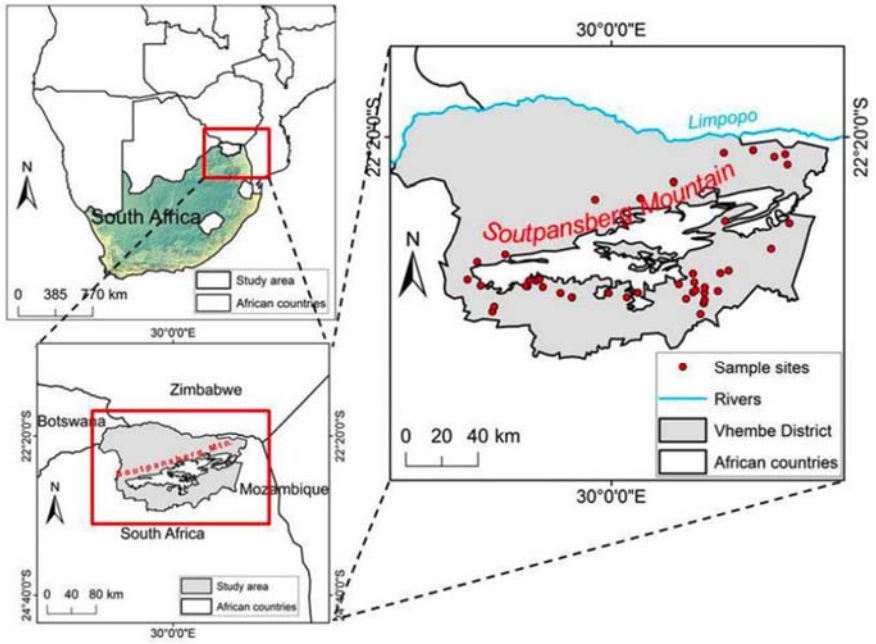

Figure 6.1. Limits of the study area (Vhembe District Municipality) and the sample locations used for modelling (shown by red dots).

Figure 2. Example of a study area map (Source: Malahlela, 2019)

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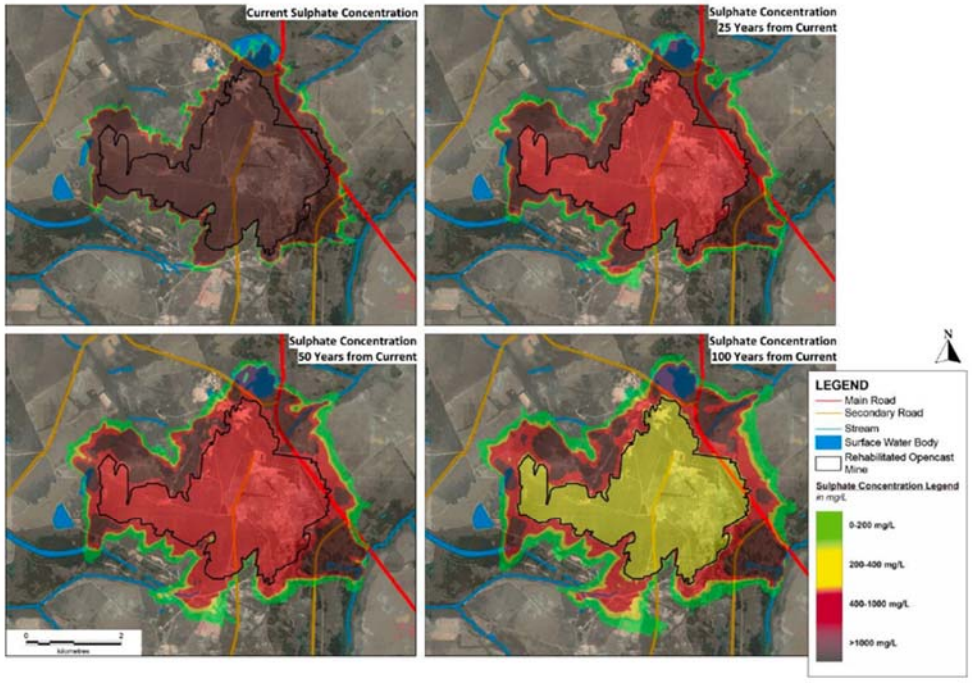
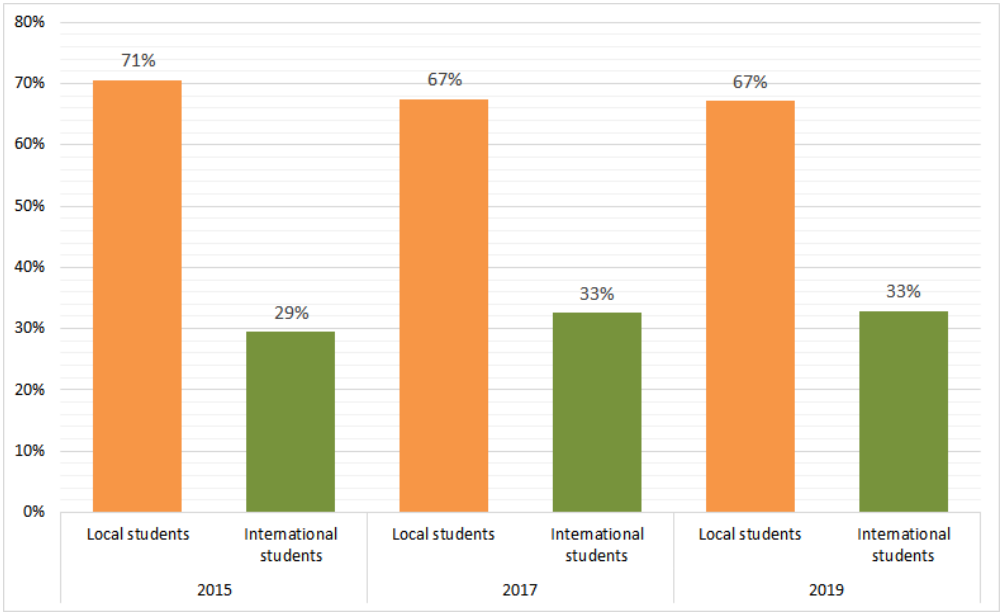


Figure 116: Sulfate concentration contours for the long term contaminant transport simulation for E-Mine

Figure 3. Example of a map that presents scientific results (Source: Huisamen, 2017)



(a)

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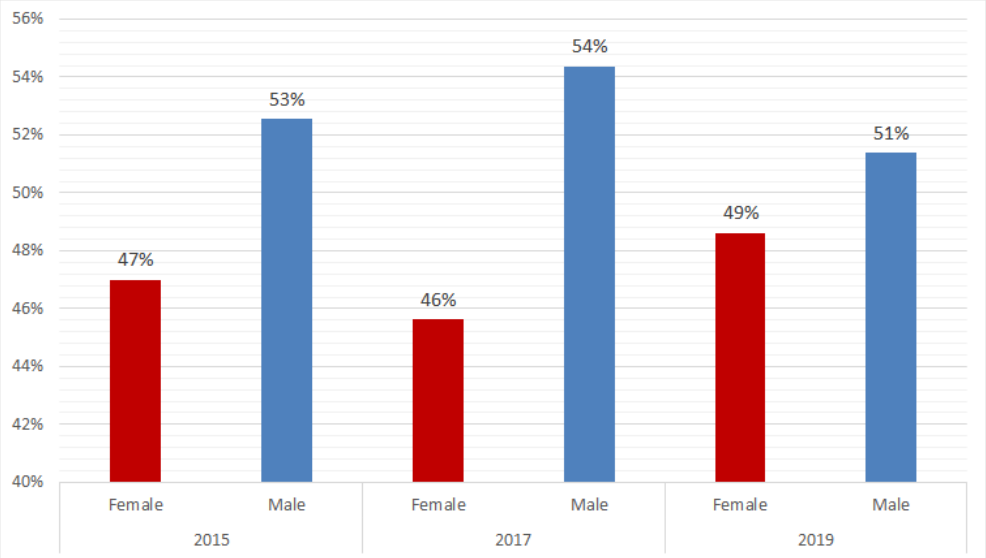

(b)

Figure 4. Split between local and international PhD graduates (a) and gender split (b) for the years 2015, 2017 and 2019.

3.2 Results per topic in the questionnaire

In this section we provide results for each topic in the questionnaire. We identified whether there was a common shortcoming and analyzed the qualitative responses for these maps in order to better understand where the problem lies. We also compared shortcomings between maps created by PhD candidates or those from other sources. Common shortcomings are summarized in the last subsection.

3.2.1 Symbolization

We strongly agreed that most maps (85%) were based on logical design decisions, i.e., appropriate symbols and visual variables were used to represent the geographic phenomena.

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3.2.2 Legend

In most maps, either the legend was present and necessary (61%) or there was no legend and it was also not necessary (26%). A legend was present in 86% of the maps created by PhD candidates, while only 50% of the maps from other sources had legends. In a small number of maps, legend information was provided in the caption only (5%) or the caption provided information that complemented the legend (2%).

For 29% of the maps, we considered a legend to be irrelevant, e.g., if the features are described in the caption. For only 2% of the maps, we thought that a legend title was missing. A considerable number of legends did not have a title (31%), which we considered to be appropriate. In 43% of the legends, the title was something like 'Key' or 'Legend', typically the default value when a legend is created with software. Slocum et al. (2009) advise against the use of such a legend title, and it was more prevalent when PhD candidates had created the maps (57%) compared to maps from other sources (31%).

In 84% of the legends, we strongly agreed that the legend appropriately represented features on the map. In 4% of the maps, units were not specified in the legend, but would have contributed to understanding the map. Overall, we considered most legends (83%) to be well designed, i.e., as and when necessary, the legend had a subtle bounding box, representative symbols were logically associated with feature descriptions and/or symbols were appropriately arranged into groups. Maps from other sources had significantly more problems (25%) than maps created by PhD candidates (9%). Problems with legend design were mostly related to text that was not legible and colours that could not be distinguished from each other.

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3.2.3 Basic map design

Next, we assessed basic map design goals, such as map balance, whether the figure-ground relationship was clear and whether the map had appropriate contrast and visual hierarchy.

In approximately 34% of the maps, map elements were not well distributed, e.g. resulting in unused white space which could have been better used. Frequency of balance problems was similar for maps from other sources (67%) and those created by PhD candidates (65%).

For more than 50% of the maps, there was room for improvement in clarifying the figure-ground relationship but only a few (3%) raised strong concerns. There was no significant difference in the distribution of responses for maps by PhD candidates and maps from other sources.

Visual hierarchy was problematic in 43% of the maps, and fewer sourced maps had problems (40%) than maps created by PhD candidates (49%). Problems varied, including the primary element not having highest visual weight or an insignificant map element having too much visual weight.

Contrast was a problem in 43% of the maps. Maps from other sources fared slightly better (40% with problems) than maps created by PhD candidates (49% with problems). The most common problem was labels that did not contrast well against their backgrounds and in some cases, lines (e.g. country borders or administrative boundaries) were not discernible.

3.2.4 Lettering

There were text readability problems with approximately 64% of the maps, without much difference on maps from other sources (64%) and maps created by the candidates (62%).

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In 40% of the maps there was room for improvement in the lettering, but generally these did not raise major concerns and we did not expect the maps to strictly follow conventions, such as using Italics for labels of water features, which are sometimes applied on topographic maps.

3.2.5 Title and caption

Titles of maps in dissertations are typically included in the caption (71%) or they are on the map with some parts of the title in the caption (22%). In most cases, we found the title to be clear and descriptive of the map's theme or purpose (85%). The difference between PhD candidate maps and other maps is interesting: the title was not clear in 18% of other maps, while this was a problem only in 10% of the PhD candidate maps.

3.2.6 Base information

Here we assessed whether enough base information was included for orientation and to understand the map. For only 40% of the maps we strongly agreed that the base information was appropriate and for as many as 15% of the maps we strongly disagreed with the base information on the maps. However, there was often disagreement between the two researchers' evaluations of the appropriateness of base information on a specific map, indicative of the subjective nature of this design goal. Recommendations for improving the base information include adding features (e.g. roads and town names for orientation) and labels (e.g. names of countries and administrative boundaries). Appropriate base information was more often included in maps from other sources (47%) than maps created by the candidates (28%).

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3.2.7 Inset maps

We considered location inset maps to be important in PhDs with an international target audience, at least on the first map about the research study area. External examiners are often from another country or different part of the world and do not necessarily know where a particular study area is. On 18% of the maps, an inset map to show the location of the main map could have improved a reader's understanding of the map, e.g. to show where the map is located in the world or in a country. Where a location inset map was included, most of them (at least 75%) were poorly designed in our opinion, regardless whether they were created by PhD candidates or inserted/adapted from other sources. Problems included inappropriate colour choices, text sizes and general map design issues.

Most maps (93%) did not need an inset map to provide more detail about a complex area of the map, but those few (n=6) that were included, were not well designed, exhibiting similar problems as the location inset maps.

3.2.8 Scale

We considered an indication of scale to be important because the target audience for a PhD dissertation is global, and they would in many cases need a scale to understand and interpret the size of the area and features portrayed on a map. On 55% of the maps, a scale was essential but not included. This problem was much more common on maps from other sources (39%) than maps created by PhD candidates (18%).The design of at least 21% of the scales did not meet the guidelines specified by Slocum et al. (2009), and this problem was significantly more frequent in PhD candidate maps (27%) than in other maps (13%). Design problems included inappropriate colours, visual weight and text sizes, and on some maps

more subdivisions on the scale bar would have been useful.

3.2.9 Projection

Only a small number of maps included information about the projection on the map. 12% of the maps, most of them from other sources, were clearly distorted or skewed (width and height changed disproportionately) when inserted into the PhD dissertation.

3.2.10 Orientation

On 40% of the maps, an orientation symbol was not essential, yet included. This was significantly more often the case in PhD candidate maps (61%) than in other maps (27%). Very few maps (2%) lacked an orientation indication when it was needed, e.g. those at a very large scale (small area). Most of the time, a north arrow (71%) was used for orientation, followed by marginal tic marks (9%) and a graticule of latitudes and longitudes (5%). Some PhD candidate maps included more than one indication of orientation, e.g. a north arrow as well as a graticule.

The way in which orientation was indicated was frequently problematic: on 23% of the maps there was some room for improvement regarding the orientation, and this problem was also significantly more frequent on PhD candidate maps (27%) than others (17%). Most problems refer to a North arrow that has too much visual weight.

3.2.11 Source

We followed the guideline in Slocum et al. (2009), suggesting that sources of base information such as roads and administrative boundaries are normally omitted from a map.

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Nevertheless, on 45% of the maps, the data source for the map was not appropriately acknowledged, neither on the map nor in its caption. For maps from other sources, it is possible that data sources were acknowledged in the other source. For maps by PhD candidates, information about data sources for their PhD research (and used on maps) could have been provided in another part of the dissertation, e.g. in the method chapter. Since we did not study the entire dissertation, we would have missed that.

More than half of the maps (57%) inserted or adapted from other sources had a reference to the source of the map. However, these references were often incomplete (e.g. URL only), not included in the vicinity of the map or inadequate for tracing the map. For example, if a URL was included in the reference, some URLs did not exist anymore while others referenced the Home page of a website, making it difficult, if not impossible, to find the map.

3.2.12 Summary of shortcomings

Figure 5 provides an overview of shortcomings (i.e., 25% or more of the maps had the respective shortcoming) found in PhD candidate maps and maps from other sources respectively.

Overall, the three most frequent shortcomings in maps were text that was difficult to read (64%), base information that could be improved (60%) and more than 50% of all maps had a poor figure-ground differentiation. We considered most of the location inset maps (76%) and all the inset maps for complex areas to be poorly designed, however, there were only a small number of these maps (n=34 and n=6 respectively). There was no significant difference between inset maps designed by PhD candidates and those from other sources.

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For PhD candidate maps, the top three shortcomings were base information that could be improved (72%), text that was difficult to read (62%) and including orientation even if it was not needed (61%). An inappropriate legend title (57%) and poor figure-ground (56%) also appeared in more than half of PhD candidate maps.

In maps from other sources, the most frequent shortcomings were text that was difficult to read (64%), poor figure-ground differentiation (55%) and base information that could be improved (54%). In 50% of the maps, the source for data used on the maps was not included.

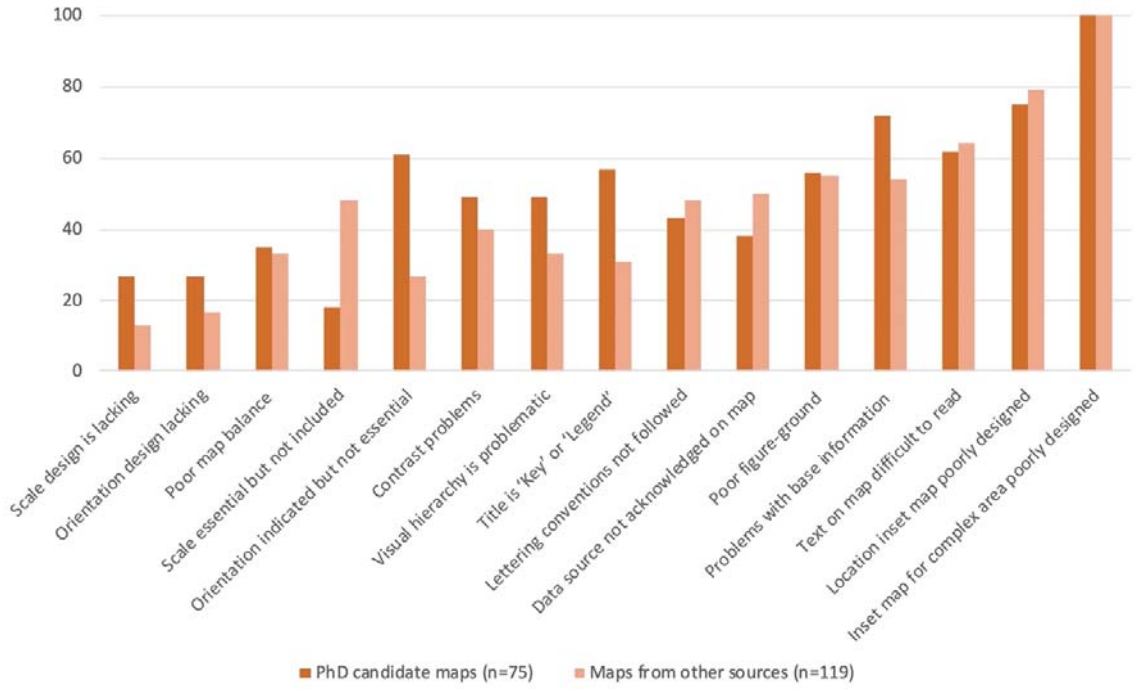

Figure 5. Shortcomings in the reviewed maps

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4. Discussion

4.1 Maps by PhD candidates

For PhD candidate maps, an inappropriate legend title was a common shortcoming that was less frequent in maps from other sources. This, and the very few shortcomings related to the symbolization and feature styling in the legend suggest (unsurprisingly) that PhD candidates use software to prepare maps and legends, often readily accepting the legend design prepared by the software without much critical review. This results in maps with legend titles such as 'Key' or 'Legend' and file names (e.g., 'highway_2021_v1'), instead of proper names of the features (e.g., 'Highway'), in the legend. However, apart from these, there were otherwise very few shortcomings in the legends so that one can conclude that today's software does a good job at designing legends for maps. Also, GIS software makes it difficult, if not impossible, to create a legend that deviates from the feature styling on the map.

According to Slocum *et al.* (2009), it is a common misconception that every map needs a north arrow, and selecting visual variables that effectively communicate a particular message remains a challenge (Muehlenhaus, 2013; Klettner, 2019). Contrast, appropriate visual hierarchy, map balance, text legibility, design problems with the scale and orientation (mostly related to too much visual weight) and extraneous inclusion of the north arrow are the most prevalent challenges for PhD candidates. Based on our experience as educators, these challenges are typical for first-time map makers, and they could benefit from software that guides them towards appropriate map design choices. Today's software for preparing presentation slides, e.g., Microsoft PowerPoint or Apple's Keynote, suggests slide layouts

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and colours based on good design principles for visual hierarchy, text legibility, etc. Such functionality is not yet readily available in map making software.

Base information, such as roads or names of places and countries, provides a frame of geographic reference for interpreting a map (Slocum *et al.*, 2009). The results clearly show that the question of appropriate base information is a subjective one. We often differed significantly in our opinions on whether appropriate base information was included, but there were also glaring omissions on which we agreed. For example, several maps showed a single country with areas (e.g., administrative areas or other boundaries) shaded in different colours without labels for them and without any base information such as rivers, roads or place names to provide a frame of reference. Such information is important for anyone, especially if they are not familiar with the country.

PhD candidates also seem to disregard other map elements required for an international audience (most importantly, examiners), such as a scale. The scale provides useful information about the size of the area covered by the map and distances between features on the map. However, this was one of the responses with much initial disagreement between the co-authors on whether a scale was required on a map or not.

4.2 Maps from other sources

There was frequent use of maps from other sources in the PhD dissertations, but their presentation was often problematic, e.g., the map was included, even if it was difficult to read the text on an A4 page. This could be the result of re-using a map in the PhD dissertation that was designed for a different page size and/or medium, e.g., squeezing a wall map of a country (downloaded from the internet) into an A4 page of the dissertation. Similarly, we suspect that

the absence of a scale bar arises from inserting or adapting maps that were designed for other purposes, e.g., the scale could have been provided in the caption or text describing the map in the source. Due to many references for maps not being traceable, e.g., the URL did not exist anymore, we could however not confirm whether this was the reason for these problems.

The title and caption of maps from other sources were often lacking, probably because the candidates included maps (with their titles) that were designed for a different purpose than that required in the dissertation. For example, several species distribution maps had very brief captions, typical for such maps prepared for an atlas or series of maps for a region or continent. When a single map from the series is included in the PhD dissertation, the map title or figure caption should provide context, e.g., by including the region name. Similarly, care should be taken to include the legend (or a description thereof) when a map is inserted from another source. Interestingly, problems with including maps from other sources is not only a problem for PhD candidates. Fish (2020) found that maps in climate change communication were often republished without updating the design and therefore information required to understand the map was often missing.

A few maps from other sources were skewed or distorted, showing that PhD candidates did not consider appropriate communication of size and distance via the map. Such maps do not add much (if any) value.

4.3 All maps

Inset maps are difficult to design (Thompson, 2008) and the results of our study confirm this. All inset maps for complex areas were considered to be poorly designed, and two thirds of those for locations. Location inset maps were often absent when a PhD candidate inserted a

map from another source, possibly because a location inset map was not required in the other source. On the other hand, some students included a location inset map for the study area on each map, while they could have introduced the study area on the first map and subsequently assumed that the reader knows where the study area is located.

According to Slocum *et al.* (2009), the data source for roads or administrative boundaries is usually not included on the map. This rule may originate from an age where there was a single source for such data, namely a national mapping agency. Today, there are many sources for such data, including government organizations, private companies or crowdsourced data from OpenStreetMap. While one could save space by not including the data sources on the map itself, the source should be acknowledged somewhere in the PhD dissertation.

Furthermore, to interpret the themes on a map, especially those relevant to the candidate's research, information about the data is required. Many PhD candidate maps did not provide any information about the data source for themes presented on the map, not even a date (e.g., for migration data or terrorism locations) or who collected the data (e.g., another organization or the PhD candidate). Projection information was provided on very few maps, and we tend to agree that this is generally acceptable.

4.4 Other observations

As a rule, tables and pictures should be cited in the text of a PhD dissertation or research publication, however, some maps were just 'dumped' in the dissertation, assuming that readers would automatically understand their purpose.

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Among all the PhD dissertations, we only found one (badly executed) 3D representation of population density. The same was true for our earlier exploratory study (Coetzee et al., 2021). It seems that dissertations are still prepared as if they were to be read only on an A4 hardcopy page, without making use of animated maps or interactive online maps.

4.5 Implications for supporting PhD candidates

In our earlier exploratory study (Coetzee et al., 2021), 12% of all PhD dissertations included maps; for this study, the percentage was 11%. For the exploratory study, maps in dissertations from three universities on three continents were reviewed, and most dissertations included one or two maps to indicate location of phenomena or research activities or to provide spatial context for phenomena. Dissertations that used maps to explain scientific results generally had many maps. This study revealed the same characteristics, i.e., only a small number of dissertations used maps to communicate scientific results; the others had one or two locational maps. It would be interesting to know whether these percentages hold true generally, but for that, a much larger sample of dissertations would have to be reviewed.

These statistics are useful for planning support services at our universities. For example, for the University of Pretoria, every year approximately 270 PhD candidates include maps in their PhD dissertations and most of these are from disciplines in the natural sciences and humanities or social sciences. They would be the target audience for cartographic support services. In the earlier exploratory study, only a small number of PhD candidates presented their research results in maps, namely 4% of all reviewed dissertations

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and 31% of the dissertations with maps. In the latter case, the dissertation generally included more maps. In other words, the largest number of PhD candidates need support for locational maps, while a small group of PhD candidates require more support and training to represent scientific results, which may include complex relationships. These are two very different requirements – the former could be addressed by providing a well-advertised mapping service, while the latter requires purposeful training, possibly working hands-on in specific software.

There are many shortcomings in the maps that we reviewed, some less severe than others. Shortcomings regarding visual hierarchy, contrast and the readability of lettering can significantly impact conveying the map's message. On the other hand, an inappropriate legend title (e.g., 'Key' or 'Legend') is not desirable but certainly not a severe shortcoming, as illustrated in Figure 6. A map is not necessarily bad just because it does not follow all the scientific principles (Muehlenhaus, 2013). However, in many cases a few small improvements would have resulted in a map that communicates the intended message significantly better, thereby supporting research communication of the dissertation generally.

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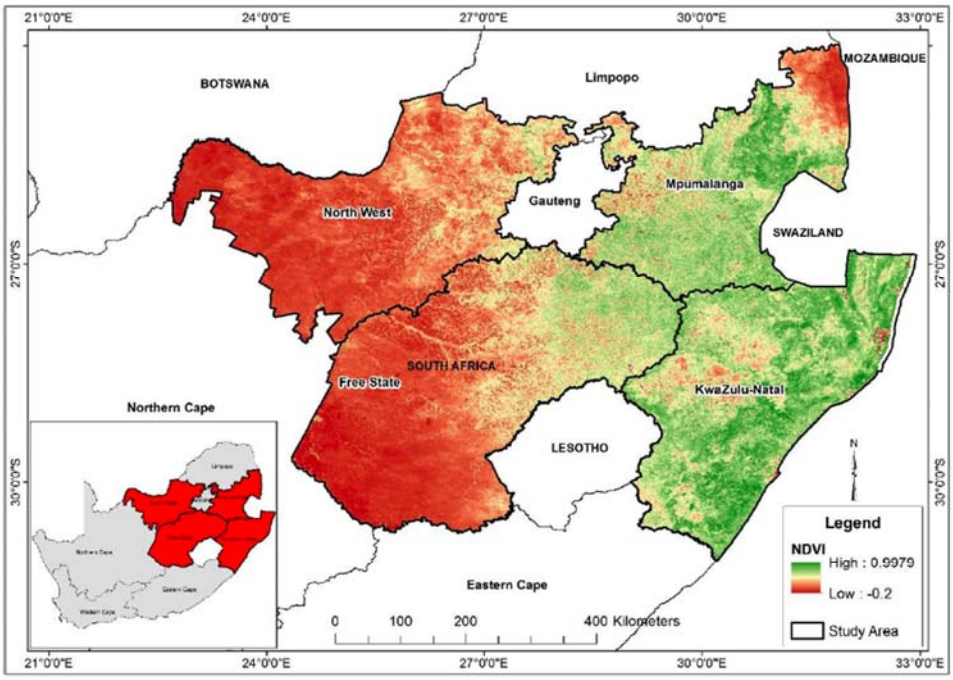

Figure 4-1: The Map of major maize producing Provinces of South Africa showing the Normalised Difference Vegetation Index (NDVI) for 51st week of the year 2016. NDVI values range from -1 to +1 indicating the response of vegetation to water availability. With high values tending towards 1 meaning healthy vegetation and lower values meaning barren, built land and negative as water surface

Figure 6. An example of a map with the legend title 'Legend' (Source: Adisa, 2019)

If and how doctoral students use software tools to communicate their research depends, amongst others, on the relationship with the supervisor and the context of the institution (Stein and Sim, 2020). Researchers have found that doctoral students require guidance and training for acquiring and developing skills in scholarly communication (White and King, 2020), and there is a need to provide explicit support to enable students to embed software within their own research processes (Stein and Sim, 2020). Supervisors should be sensitive to their students' needs in this regard, and provide them with guidance, which may include referring them to others if they do not have the expertise. There are many books that provide postgraduate students with guidance for conducting research and writing about it (e.g.,

Hofstee, 2006; Bryman et al., 2014; Christensen et al., 2015; Leedy and Ormond, 2015). Most universities also have an online guide for this. However, these resources tend to focus on ways to communicate the research in writing, on grammar, writing style and referencing, and increasingly also on data management. While there may not be space to include comprehensive guides on graphics and map making in books, online guides are ideal for directing students to additional resources on the internet.

Even though scientific maps aim to achieve objectivity and neutrality in their representations of data, this is close to impossible (Muehlenhaus, 2013). Nevertheless, an in-depth study of only those maps that present scientific results could reveal shortcomings, e.g. by reviewing the appropriateness of mapping techniques (Hay *et al.*, 2013; Schiewe, 2019) and cartographic representations (Schaab, Adams and Coetzee, 2021).

Cartography is defined as the art, science and technology of making and using maps (International Cartographic Association, 2021). To make a map that effectively communicates information, requires scientific knowledge about design and communication, skill in using tools and technologies for map making, but whether a map is beautiful or appealing is subjective and requires creativity. Very few PhD candidates will have been taught and trained in the preparation of maps (Schaab et al. 2021). Furthermore, map appreciation is difficult to teach and tends to come with experience. Since the educational background of the PhD candidates is not published in their thesis and because many of the doctoral students obtained their Bachelor and/or master's degree at a different university, it is impossible to know what level of graphics design or cartographic training may be in place. But even if this was known, Markauskaite and Wardak (2015) warn that one cannot assume that all research students have similar experiences, understandings and beliefs about the role

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of information and communication technologies in research. Kraak (2011) contends that today's plethora of data sources calls for better application of cartographic design knowledge (and not a new discipline altogether). When developing teaching material, one has to find an appropriate mix between age-old cartographic design principles and state-of-the-art technologies and trends for successfully stimulating creativity (Schaab, Adams and Coetzee, 2020).

Map readers form impressions of the spaces represented on a map, and they are influenced by the way in which a map was created (Peterson, 2014). Maps therefore have the power to lead (and mislead) readers (Robinson, 2019), intentionally or unintentionally (Monmonier, 2018). PhD candidates often spend a considerable amount of money on editors who improve the language and/or layout of the document so that examiners can better understand their research. Often, this is done on the recommendation of the supervisor, who should provide similar guidance on the graphics and maps in a dissertation. If maps convey an important aspect of their research, should they not also spend effort and money on maps?

4.6 Proposed PhD support program

Most universities provide research and scientific writing guidance and support for their postgraduate students, e.g., guidance on conducting ethical research and avoiding plagiarism, writing workshops and support for statistical data analysis. We propose that map making guidance and support for PhD candidates be integrated into such information provided by a university. This ensures that all PhD candidates have access to the map making guidance and it may also encourage more PhD candidates to include a map in their dissertations, if only of their study area. Topics in the Research Guide for postgraduate students at our university

include Library support, You and your supervisor, Literature review, Research Methods, Data collection techniques, Statistical support, Research Data Management, Referencing, Ethics, Plagiarism, Writing support and Emotional support (University of Pretoria, 2021), to which "Maps and geospatial data analysis" could be added.

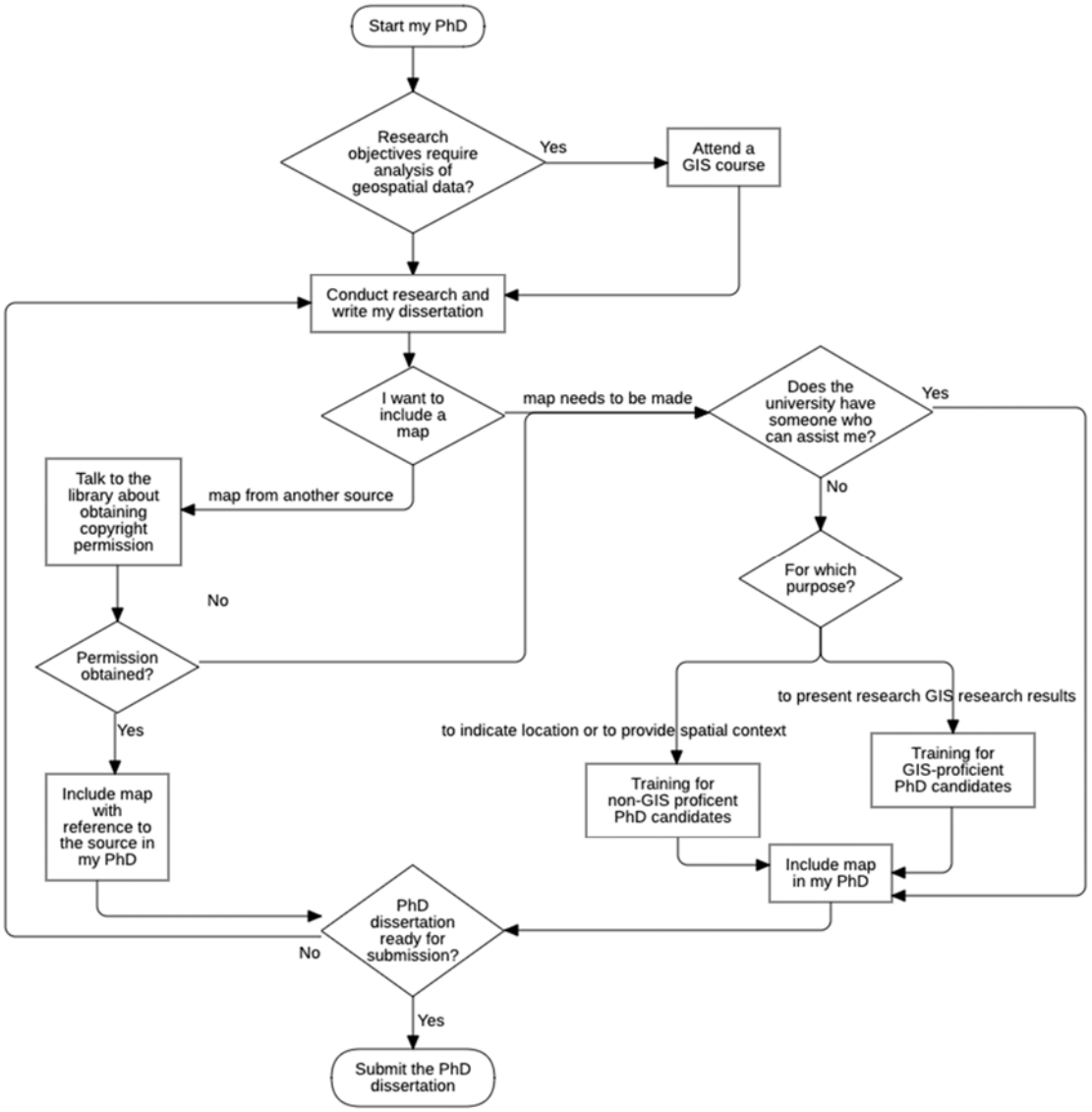

Figure 7. Proposed flow for guiding PhD candidates

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The process flow in Figure 7 shows the type of guidance to be provided to PhD candidates for including a map in their dissertation. Including the flowchart in the university's guide would alert PhD candidates to the fact that permission is required when using a map from another source; that GIS training is required for geospatial data analysis; and that there is support at the university for making maps. The flowchart indicates that two kinds of training are required, namely for PhD candidates who are familiar with GIS software and those who are not. The latter will have to start with the basics of geospatial data before moving on to the topic of map making and may well be better served by someone else making the map for them, while the former could jump straight into map design. Only a small group of PhD candidates may require training to prepare maps that show more complex spatial relationships and this could even be presented by face-to-face training on campus.

Additional information in the guide could include, e.g.,

- how maps can be used to communicate research results and why map design is important;
- where to find software for geospatial data analysis and/or making maps;
- map design tips (how to avoid distortion, how to check that the image resolution is appropriate, always let someone else review your map, etc.) and checklists or links to them (e.g., https://gisgeography.com/map-elements-how-to-guide-map-making/ and https://www.gislounge.com/ten-things-to-consider-when-making-a-map/);
- links to relevant books available (online) in the university library; and
- links to suitable free online training opportunities;
- face-to-face training opportunities available at the university; and
- contact details for geospatial data analysis and map making support at the university.

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5. Conclusion

In this study, we searched for maps in 575 PhD dissertations and subsequently evaluated 192 maps in 65 PhD dissertations. 38% of the maps were created by PhD candidates, 48% were inserted from other sources and 14% adapted from other sources. We found that maps prepared by PhD candidates had more shortcomings than other maps, nevertheless, the number of problems with maps from other sources suggests that guidelines on how to incorporate maps from other sources into a PhD dissertation could be useful. This could support PhD candidates so that their maps are worth the proverbial 1000 words.

Very few PhD candidates receive training in preparing maps. Our results show that using GIS software helps them to design maps, but that there is also room for improvement in refining software that guides users towards appropriate design choices. Since they are not trained cartographers, one would not expect a PhD candidate to create the perfect map and to have advanced knowledge about creating meaningful scientific visualizations (Stofer, 2016). However, without much additional effort, PhD candidates can significantly improve their maps by paying attention to cartographic design rules, e.g., related to contrast and visual hierarchy, which are readily accessible in textbooks, online tutorials and blog posts. As a simple solution, universities and/or supervisors can direct their PhD candidates to such available training material. This is especially important if the maps convey the scientific results of the PhD research.

The results of this study confirm that there are shortcomings in maps in PhDs and they give an indication of the nature and extent of the challenge. A more in-depth investigation of only those maps that convey scientific results would also be useful for planning support. While it will be difficult to interview PhD candidates whose dissertations

have already been published, semi-structured interviews with current postgraduate students could help us to understand the level of graphics design or cartography training in place, which tools and resources they use to prepare the maps, the reasons for using those, as well as the reasons behind their design choices. This would also be an opportunity to investigate whether gender, age and educational background are relevant. It would be especially useful to understand this for PhD candidates who plan to present scientific results in their dissertations. The results of such a study would allow planning targeted interventions to make sure that relevant PhD candidates receive appropriate training in graphics and map making.

While our results are based on PhD dissertations published by a single university, they have wider applicability because they are an important reminder for supervisors and university authorities that research communication needs to be supported, not only in the context of scientific writing, but also for graphics and maps. Our paper contributes a method for assessing maps in PhD dissertations that can be repeated or adapted at other universities. The results show that there are opportunities for developers of mapping software to better guide users towards appropriate design choices. The results also raise additional questions for further research. How would these results compare to those of PhD dissertations at (other) universities or in other countries? Would the results differ by discipline? Does a cartographic support service at a university result in better maps in PhD dissertations? Are there good practices at universities with a strong cartographic teaching component from which other universities could learn? Generally, how many PhD dissertations include maps, and is there an upward or downward trend? Finally, the results of PhD research are often published in peer-reviewed journals; the question arises whether maps are changed (improved) for

publication in journals, and if, how, and whether maps are changed in response to reviewer comments or based on the supervisor's recommendation before submission.

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