Legend-less Maps

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September 2017

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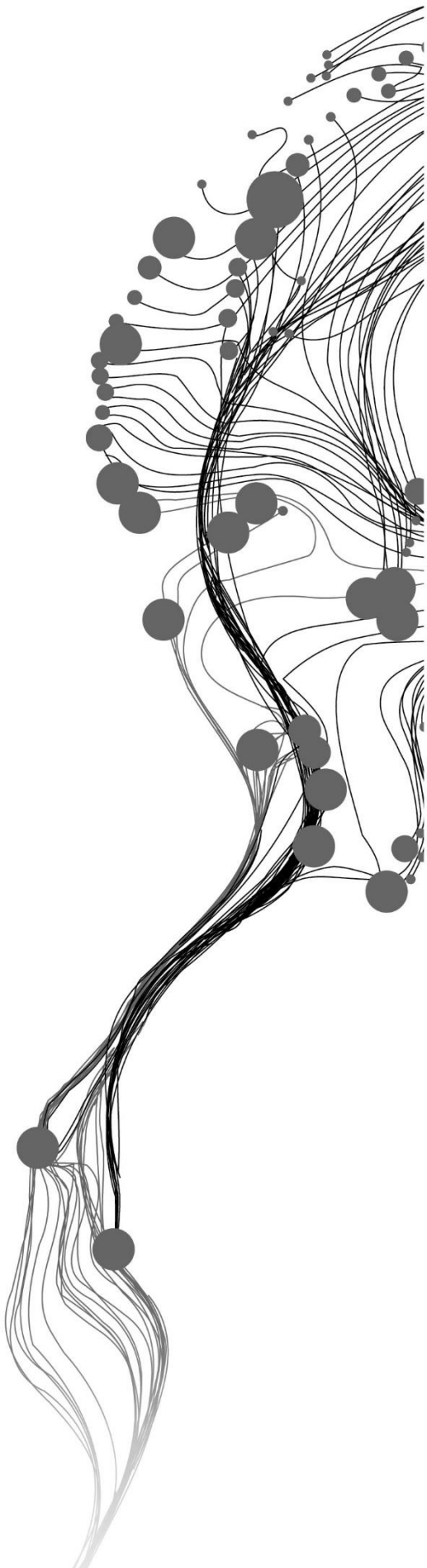

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Enschede, The Netherlands, September 2017

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ABSTRACT

Now a day we see many maps without legend. Academic literature on legend is limited and most of them dealing with the replacement of traditional legend with other form of legend. No scientific research has been done on legend-less maps although maps are available, particularly in news media.

In this research, maps have been designed with legend, replacing legend by annotation and putting legend in the title in case of three main thematic maps (chorochromatic, choropleth, isopleth and proportional symbol). Designed maps are tested to measure the usability of different version of maps in terms of effectiveness, efficiency and satisfactions. Stages of map reading process described by Bertin (1983) also have been tested.

Mixed methods have been used for usability survey including questionnaires, thinking aloud, eye tracking and video recording to conduct the tests. Designed maps with and without legend is presented as stimuli attached with three questions related to three level of map reading. Based on the answer, required time and attitude during the test, usability of maps with and without legend have been evaluated. Gaze plot have been analysed to evaluate the stages of map reading process.

It is found that none of the case matched with the successive stages of map reading described by Bertin (1983). In cases of legend-less maps, annotated and legend in title version of chorochromatic map appeared to be the best maps in terms of usability. In all other cases, maps with legend found as best maps in terms of effectiveness, efficiency and satisfaction.

Key word: Legend, Legend-less maps.

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1. INTRODUCTION

1.1 Motivation of the research

Once maps were mainly drawn or printed on paper. Nowadays maps are mostly shown on screens, on different size screens, varying from computer monitor, mobile phones to screens of smart watches. The Internet has resulted in an increase on maps, but many of those are created by non-cartographer, and their designs breach the cartographic conventions. Often basic elements of the map, like north arrows, graticules, legends and in some case even title are left out. One of the main reason for leaving out these basic element is the small size of the screen. "The use of any additional graphics in the map layout always requires extra space at cost of map body" (Kumar, 2004).

Very often we find maps without legend which might raise doubt by the reader on how to interpret these maps. For web maps many options like pop-up legends, activation of legends using pointer, are a solution but these options are not always available or feasible with all different types of devices. And often the maps need a single design for both paper and screen or for different size of screen. So, why not design a map in such a way we do not need a legend? Also, then we have to wonder how these maps are going to be read or interpreted?

"One can discern three phases in the map reading process: external identification, internal identification and map reading proper. External identification relates to the geographical framework and map theme normally captured in map title. Internal identification involves the decoding of the legends and this should involve a single stage transfer of data from the map to the reader. The more direct the transfer the more effective is the legends."(Williams, 1996)

Do we always need a legend in the map? Seigworth (2011) claims " a legend does not really add anything much to the map that is not already there; its purpose is more a matter of convinience or ready translation shorthand……" According to Dykes et al (2010) "If symbols are know and map task do not required precise indentification or acurate estimation then expensive map-to-legend reference may be removed by omitting the legend – the map sufficing as an indicator of content"

In his study Cybulski (2016) found that "very often (40%), animated maps do not have any sign explanations" . In these maps, sign explanations are replaced by annotation, sound narratives etc. Some news media have tried to design maps omitting legend, and those maps convey the information very well which makes the news article interesting to readers as these maps used there to tell stories. Maps from *The New York Times, The Bloomberg Review* are best examples where in some cases annotations are used instead of legend to explain map. The potential of a map is virtually unlimited to decipher and tell stories (Caquard & Cartwright, 2014). Annotation not only explain meaning; but also, could tell part of the story by providing additional information.

Many legend-less maps are available now-a-days. No research has been done on legend-less maps and its usability. In this research, the possibility of designing legend-less maps will be elaborated. Specific maps will be designed and evaluated.

1.2 Research identification

How we read a map? Before the actual map reading starts, two successive steps are required: "external identification (title) by which reader must identify the invariant and component involved in the information and internal identification (legend) by which the reader must recognize by what variables each of the components is represented in the graphic. These two stages of identification are indispensable and must be followed in any study of the information" (Bertin, 1983). The legend (internal identification) is a principal component of a map. According Cauvin et al (2010) a map cannot be used without it.

The question is if this is true. Is it possible to read a map skipping its internal identification? In this research, designing maps that are immediately understandable from its external identification or by bringing internal identification into the map or into the external identification, itself via the annotations will be examined and usability of those maps will also have to be tested.

1.2.1 Research objective

To design and evaluate legend-less maps.

1.2.2 Research sub-objectives

The main objective is split into three sub-objectives:

1. Examine the role of legend in map reading.
2. Find out if legend can be omitted or replaced, if so, for which map types.
3. Compare the usability of maps with and without a legend.

1.2.3 Research questions

Question related to objective 1:

Q1.1 How does the map reading process work?
Q1.2 What is the function of map legend?

Question related to objective 2:

Q2.1 How can the map reading process go without a legend?
Q2.2 How can title and/or map content replace a legend?
Q2.3 Are these options valid for all types of maps?

Question related to objective 3:

Q3.1 How to verify map reading process?
Q3.2 How do legend-less map alternative performed to compare to map with a legend?
Q3.3. How to evaluate the legend-less map?

1.3 Significance/Innovation

Maps on screens have limited space. So, if a map would be immediately readable and understandable without a legend, we need not have to save space for legend or think about other options (like pop-up legend etc.) as well we need not put the burden of the map to legend reference to the viewers.

Currently, legend-less maps are mostly used and designed by news media. Maps used in the newspaper were different cartographic genre (maps were simple in content and symbolization, understandable without specialized training as well sometimes ignorance in cartographic convention) and unique for its vast audience (Monmonier, 1999).

But the situation have been changed over time. Some news media are producing finest quality maps both in static and dynamic form (as for example *The New York Times*, *The National Geographic Magazine* etc) regularly. Now a days we have seen many maps that are designed leaving out-legend particularly in news media that

are well accepted and immediately understandable which raises the question that whether we must need a legend in all types of maps.

As maps without legend are availabe and well accepted but no academic research have been done on legend-less maps and it's usability. So, this study can fill up some of the research gap on this new trends of map designing.

1.4 Structure of the thesis

This thesis is structured into six chapters:

Chapter 1 (Introduction) deals with the motivation of the research, research identification (objectives, sub-objectives, and research questions), the significance of this research and the structure of the written thesis based on the research findings.

Chapter 2 (Methodology) deals with the methodology adopted for the research including research hypothesis.

Chapter 3 (Legend) has been written based on the first objective of the research. In this chapter, the definition of a legend, the role of legend in map reading process and the functions of the legend have been described. Previous research works on map legend have also been summarized in this chapter.

Chapter 4 (Legend-less maps) deals with the second objective of the research. In this chapter, designed maps omitting or replacing legends have been presented and described.

Chapter 5 (Usability of legend-less maps) has been written based on the third objective of the research. Stages in the map reading process and usability of (effectiveness, efficiency, and satisfaction) maps with and without legend have been tested by usability tests. In this chapter usability tests design, data analysis methods and results from the tests have been discussed.

Chapter 6 (Conclusion) discusses the conclusion of the research with recommendations for future work.

2. METHODOLOGY

2.1 Methodology

Mixed research methodologies have been used for this study using both qualitative and quantitative approaches. Review of literature, data collection, design of maps with and without legend and usability test for the designed maps have done for this study. Research objectives and questions wise methodology, data sources and used software have been described as follows:

Methodology for first objective:

It is important to know the role of legend in map reading process before thinking about omitting or replacing it. So, the first objective is examining the role of legend in map reading process. Research questions Q1.1 and Q1.2 related to first objective have been answered by reviewing and analysing existing literature and theory.

Methodology for second objective:

To find out how the map reading process would go without a legend (Q 2.1), it is necessary to known how the map reading process goes with a legend. The existing stages (Figure 2.1, a) of map reading process involves three steps: the external identification (what is the topic: title), the internal identification (how it is represented: legend), and the actual reading of the map view (Bertin, 1983). In this research two alternatives are suggested to replace the legend as Figure 2.1.b shows. One, the external and internal identification will be combined in title. Two, the internal identification will be merged into the map view annotations or specially designed symbology. This results the answer of Q2.2 How can map content or title replace a legend?

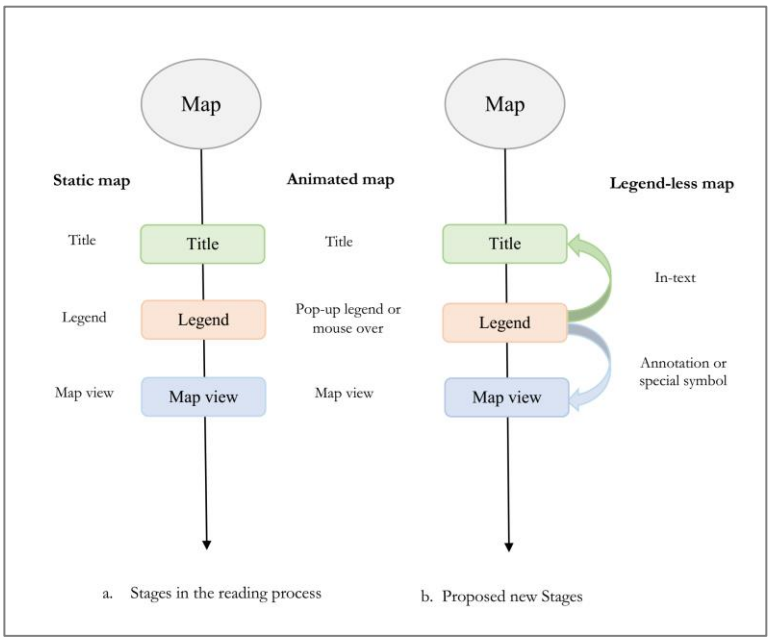


Figure 2-1: Stages in the map reading process (a), and proposed stages for legend-less maps (b).

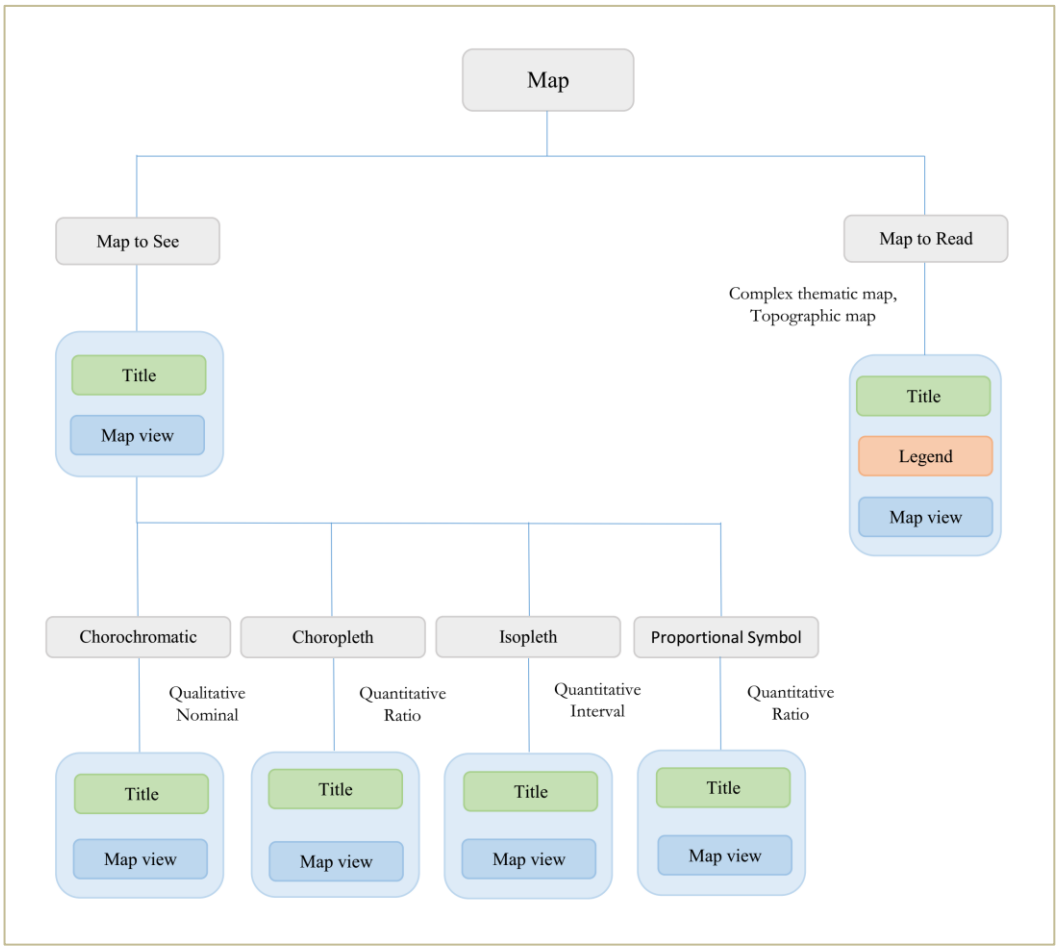


Figure 2-2: Methodology flow chart for designing legend-less maps

Maps can be classified into "map to see" and "map to read" (Figure 2.2). It is expected that omitting the legend might only be valid for so-called maps-to-see.

According to Bertin, who introduced these terms, a map-to-see is map that allow us to see, to immediately perceive about the distribution and it regionalize the image, thus provides information about entire set and a map to read is a map where immediate perception about the distribution is not possible by seeing the map, it involves reading of the symbol and at the level of overall set it shows only the examined points (Bertin, 1983).

Other authors also describe this phenome. Tufte the term "Macro reading or design" and define it as design/reading from where over all information (global comparison) is possible to gain by seeing it, on the other hand, "Micro reading or design" is design/reading where in-depth information (local comparison) can be gained by going in depth of any visual presentation, micro/macro design/reading means it is possible to get both overall and detail information from same design based on need of user or viewer which is recommended" (Tufte, 1992)

In map to see both macro reading (immediate perception or overall information or global comparison) and micro reading (detail perception or elementary information or local comparison) is possible at a time. Map to read only micro reading (detail perception or elementary information or local comparison) is possible, macro reading is not possible at a time in same map. So, Micro/Macro design is not possible in map to read. To design a map to see it can have only one variable (component) and the number of categories is limited Visual isolation (selectivity by Bertin 1983) defined by (Kraak & Ormeling, 2010) which indicate whether all

the relationship that can be perceived between the various categories discerned on the map can be perceived at a glance. As all graphical variable are not equally perceivable they defined number of categories for each graphic variable for basic feature geometry. (Table 2.1)

Table 2-1: The number of categories that can be perceived at a glance (Kraak & Ormeling, 2010)

	Dots	Dashes	Patches
Size	4	4	5
(Grey) Value	3	4	5
Texture	2	4	5
Colour Hue	7	7	8
Orientation	4	2	-
Shape	-	-	-

As per above discussion a "map to see" can be defined as a map from where an immediate perception of the entire data set and relationships between various categories presented on map can be achieved at a glance.

In other words, a "map to see" is a map of one theme (component) where graphic variable has a limited number of categories that vary in terms of basic feature geometry and it is not subjected to shape variation (table 2.1).

When the number of categories exeats this limit, it is not possible to perceive the relationship presented on map at a glance that means the map turns into a "map to read".

"The perception will be immediate and need not go through sign by sign when the variable is selective (selective perception), ordered (ordered perception) and quantitative (quantitative perception). So, When the perception will be immediate that's means maps are in category of "map to see". Selective perception is the perception when the eye must be able to isolate all the elements of the category, disregard all the other sign and perceived the image by given category. When a variable is ordered (ordered perception), it is not necessary to consult with the legend to be able to order the categories as well it not necessary to recourse legend to find out the numerical ratio between two signs when the perception is quantitative." (Bertin, 1983) A hypothesis has been formulated to find out if the legend-less alternatives are valid for all maps types (Q2.3).

Hypothesis: Legend of maps can be omitted or replaced only in "map to see".

To answer this question (Q2.3) maps have been designed based on the hypothesis and evaluated. The hypothesis has been verified in case of four main type of thematic maps (chorochromatic, choropleth, isopleth and proportional symbol) where number of categories or classes have been defined in a way as it can be perceived at a glance (Table 2.1).

Methodology for third objective:

Usability of maps with and with legend have been assessed in terms of effectiveness, efficiency and satisfaction (ISO 9241-11, 1998). To do so designed maps with and without legend have been provided to test person and asked to complete some task.

Any question can have defined by its type and level, the level of the question or reading level can be grouped in to: the elementary level, the intermediate level and overall level (Bertin, 1983). In each map three questions or task have given involving three level of map reading.

Same map has been designed into three version (one with legend, one using annotation omitting legend and one using legend in title) and for all four main types of thematic maps (chorochromatic, choropleth, isopleth and proportional symbol) and the task are kept (the three level of map reading questions are kept similar) similar in three version of same thematic map.

Media elements on which the usability is tested is called stimuli. In this research, stimuli are static maps (designed maps with and without legend) in JPEG format. Stimuli have been designed and task (three level of map reading questions in each stimuli) have been prepared (Table 2.2) and attached on the stimuli for the test.

Table 2-2: Map use task in usability test (Elzakker, 2004)

Task level	Question Pattern	Task
Elementary	At a given place, what is there? How much is there? Where is certain geographic attributes?	To identify the object. To estimate the amount. To locate an attribute.
Intermediate	Where is the most/least? Is there any pattern identifiable in any certain parts?	To quantify spatial anomalies. To recapitulate the pattern with respect to other parts.
Overall level	Is there any overall pattern? Can any region be identifiable? Is there any trend observed?	To recapitulate the pattern. To regionalize. To recapitulate the trend.

For the usability test, mixed methods have been used involving eye tracking, questionnaires, and thinking aloud. Used methods, description of used methods and reason for selecting those methods are described in the table 2.3.

Table 2-3: Evaluation methods for usability test used in this research (Mengistu, 2015)

Methods	Description	Reason for selection
Eye Tracking	Collect the eye movement (eye gaze, time of gaze etc.) of the participants	To record and analyse eye gaze data of Test Person (TP) to find out whether reader follow the stages in map reading process (Figure 2.1 a.) and to calculate the duration of task completion time for efficiency measurement.
Questionnaires	Series of open and closed questions prepared for participants to answer.	To gather information about background and experiences of Test Person (TP) that is helpful to analyse test result in a proper context.
Thinking Aloud	Records of participants immediate thoughts and answer as vocal records.	To record the answers of the task performed by the participant during questionnaires survey to find out effectiveness and efficiency and satisfaction of designed maps.

Test Person (TP) for the test have been invited via a formal invitation letter (Appendix 6) by email to take part in the test. Instruction sheet (to explain how the test will be conducted to test person, see Appendix 7), questionnaire (see Appendix 8), test execution script (detail procedure of test execution for test conductor, see Appendix 9) have been prepared.

Hard copy of instruction sheet and questionnaire have been provided to test person before the actual test. Software solution have been used to present stimuli to test person and answer of task (think aloud), movement of the eye (eye tracking) and facial expression of TP have been recorded simultaneously during the test.

Effectiveness have been measured by assessing the correctness and completeness of task given to the test person, efficiency have been assessed based on the time required to completed the task and satisfaction by assessing the comments and facial expression of recorded thinking aloud data and video data.

The order/stages in the map reading process (Figure 2.1a) have been assessed from the gaze (eye movement) analysis of recorded eye tracking data from the map version that is designed "with legend" to find out the answer of the Q3.1 How to verify map reading process?

Based on the data from usability test, a comparative analysis has done between different version of maps for all four main types of thematic maps to find out the answer of the question Q3.2 How do legend-less map alternative performed to compare to map with a legend? and Q3.3 How to evaluate the legend-less map?

2.2 Data sources and used software

Data and cartographic boundary (ESRI Shape Files) for designing maps have been collected from different sources (Appendix 11: Table 1 and Appendix 12: Table 2). Maps are designed using ArcGIS 10.5 and Adobe Illustrator CC.

Usability tests have been designed and conducted using Tobii Studio 2.2, a comprehensive platform to collect eye gaze data (eye tracking), video, sound (Think aloud) simultaneously during test. Using Tobii Studio 2.2 stimuli (maps) with task (three level of map reading questions: elementary, intermediated and overall) have been provide to the test participant (TP). Usability (effectiveness, efficiency and satisfaction) of maps with and without legend have been assessed by analysing the recorded data. Analysis of data have done by using Microsoft Excel 2016.

3. LEGEND

3.1 Legend

A map legend is an extra layout on map body which explain the symbol presented on the map. A legend is considered as one of the basic elements of map. According to Li and Qin (2017) "In general, a legend consists of a legend title, a panel and features composed by symbol and its description". Theoretically, any map symbol that is not self-explanatory should be explained in legend and they should appear exactly as they look on the map (Robinson et al, 1995).

3.2 Function of map legend

The main function of map legend is to act as a key that help to decode the meaning of symbol presented on the map. "A legend defines all of the symbols that are not self-explanatory and includes a heading that further explains the map's themes" (Slocum et al, 2009). Schlichtmann (1997) identified five tentative functions of map legend:

1. Legend explain the symbol presented on map by establishing link between symbols and their meaning.
2. Groups the symbols according to their meaning based on substantive, temporal and spatial criterion.
3. Provide additional information in terms of units or structure.
4. Providing the information about data processing techniques.
5. Aid in interpretation process.

Brewer has described function of map legend specifically for thematic maps (see table 3-1)

Table 3-1: Functions of legend in thematic maps (Brewer, 2015)

Map types	Function of legend
Chorochromatic	Provide description about the qualitative data presented on map
Choropleth	Provide information about the data range for each colour used on the map
Isopleth	Define the Isoline interval
Proportional symbol	Symbol size in legend demonstrate the amount that presented on the map
Dot	Define the amount that a dot represents on the map

In flow maps, legend provide description about qualitative data presented on the map, in case of quantitative data, width of line states the amount presented by a linear symbol on the map.

3.3 Legend and map reading process

Map reading process involve two successive stages of identification (Figure 2.1 a). By external identification (title) reader identify the invariant and component represented by a map and by internal identification (legend) reader identify the thematic components (visual variable) represented in the map (Bertin, 1983).

3.4 Previous works on legend:

"The legend act as interpreter between the unique semiological system of the individual map and the culturally universally system of language" (Williams, 1996). Although legend is an important element of maps but it has long been neglected in cartographic research. According to Schlichtmann (1997) map legend deserve more care and attention than it received by cartographic literatures. Golebiowska, (2015) claim that academic research on the map legend was carried out at the end of the 1970s.

Delucia and Hiller (1982) tested whether efficiency of map reading performance could be improved using a 'natural legend' instead of conventional legend boxes but, their approaches were criticized by Paslawski, (1983).

Aspaas et al. (1989) tested legend design options for unclassed bivariate maps and concludes that readers' ability to identify the regional trends is not affected by presence or absence of the legend.

Kraak et al. (1997) describes potential legends for temporal animation, tested the validity of different legends and argues that choices among them should be made on the nature of the temporal data.

"As maps are part of exploratory data analysis, it is important to give the map-reader an equal insight into the underlying statistical distribution and spatial distribution of data" (Cromely and Ye, 2006). Kumar (2004) proposed frequency histogram legend as substitute of the traditional legend to display the statistical distribution into the legend in case of choropleth map. Cromely and Ye (2006) also advocates for replacing traditional legends, but they present an alternative legend design to the FHL that is based on ogive graphs rather than frequency graphs.

Reviewing traditional and digital map legends, seven functional components extracted by Dykes et al. (2010): visualization, navigation, analysis, dimensionality, thematic issues, general information, and layout, which should be considered in the design process of every interactive legend. Cybulski (2016) studied the design rules of animated map where he found that legend designed is not following conventional rules of the static map as well 40% of the map does not have any sign legend which is replaced by other form (sound, annotation etc.

From above literature review, it is clear that attention in the research for map legend had been neglected for long time. When researcher started working on legend, they particularly have given attention on replacement of traditional legend by some other forms. Li and Qin (2016) have studied that legend how researcher try to replace traditional legend with other form table (table 3.2).

Table 3-2: Previous studies on legend design (Li and Qin, 2017)

Design form	Methods used
Grid pattern diagram	Using curved lines and straight lines (by Brassel and Utano, 1979)
	Using matrix (by Aspaas and Lavin, 1989)
Statistical diagram	Frequency histogram (By Kumar, 2004)
	Cumulative frequency histogram (by Cromley and Cromley, 2009)
Using contour, charts, codes	Natural legend (using contour instead of traditional legend). (by Delucia and Hiller, (1982)
	Using charts (by Eyton, 1984)
	Using codes (by Ellehoj and Coulson, 1990)

Particularly, attention is paid by Li and Qin (2014) to the development of spacing and alignment rules for effective design of legends shown on screens (computer monitors and tablet screens) and results of their study indicate that a legend designed with proper consideration of the spacing and alignment rules is much more effective and efficient than ordinary legends. Li and Qin (2017) also study the building of grouping rules based on the Gestalt Laws.

Tufte (2006) discussed that "map show information with differentiated lines all the time, with greater richness than art history chart and network drawings. Many distinctions require contemplation of detailed encodings in the legend- although the correct reading many lines on maps, like words in a sentence, is often clear from the context."

Golebiowska (2015) from her study of different types of map legends found that users do not want to spend time studying a legend in order to understand an unfamiliar ordering of symbols; they would rather extract only the information they need and she suggested that use of map (whether it is for simple reading and analysis or solving more complex questions) should be taken into considered during legend design.

No scientific paper has been written about omitting legends until now. However, maps without legends have been created by some news media like *The New York Times* and animated maps are available online where legends are replaced by sounds or annotations etc.

4. LEGEND-LESS MAPS

4.1 Legend-less maps

In this chapter, maps with and without a legend desigend for this research are presented and described. Four thematic map types (chorochromatic, choropleth, graduated symbol and isopleth) have been chosen to design with and without a legend. For each of the four types of thematic maps, one map is designed with legend and one using annotation instead of a legend, and one by incorporating the legend in to the title. In chorochromatic "colour (hue)" choropleth and isopleth maps "value", has been chosen as visual variable and for graduated symbol maps 'size' has been chosen.

4.2 Designing legend-less maps

According to the hypothesis of this research, legend only can be omitted or replaced in "map to see". Kraak & Ormeling (2010) described the number of categories (table 2.1) that can be perceived at a glance (map to see) in terms of visual variables. For designing legend-less maps number of classes have been chosen 3 for graduated symbol maps where classes have been determined in terms of size variation and for other map types 5 categories have been chosen where classes have been determined in terms of colour (hue/ saturation/value) (see table 3.1).

Table 4-1: Map types, Visual variable and number of category used in map design

Map types	Data	Visual Variables	Symbols	Number of classes
Chorochromatic	Nominal	Colour (Hue)	Patches	5
Choropleth	Ratio	Value/saturation	Patches	5
Isopleth	Interval	Value/saturation	Patches	5
Graduated symbol	Ratio	Size	Dot (circle)	3

For chorochromatic maps, five classes have been selected. The colour (hue) has been chosen as variable to represent these five classes. Maps are designed into three version: with legend, annotated map omitting legend and legend incorporating in the title where text used for the description of the category coloured according to the category it is representing on the map. (figure 4.1)

For choropleth map, like a chorochromatic map, five class has been selected and variable "value" has been chosen to represent five classes. Maps are designed as well in three version: with legend, annotated maps where legend is omitted and description of category (range) is presented on map body as annotation. In title version where legend is incorporated into tile, ranges (class) are presented with number and coloured according to the range it is presenting on the map. (figure 4.4)

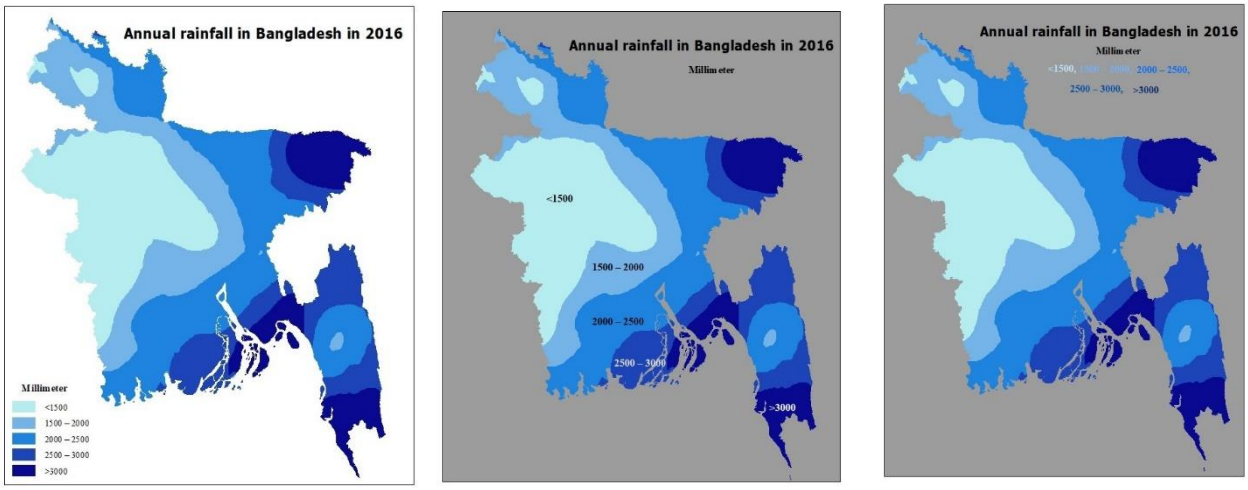
For isopleth map, as well 5 classes have been chosen to represent by five "values" and designed in three version like chorochromatic and choropleth maps (figure 4.2).

In graduated symbol maps, three sizes have been chosen as representing variables, in annotated maps ranges are represented by using annotation on the map and in title version ranges represented by number are varied in three sizes to represent the size of symbol presented on the maps (figure 4.3).

Simplification of the ranges (number) has been done in all three version of maps (in case of choropleth, isopleth and graduated symbol maps) to make it easier to read. For usability test of maps with and without legend more maps have been designed and represented as an appendix in the thesis.

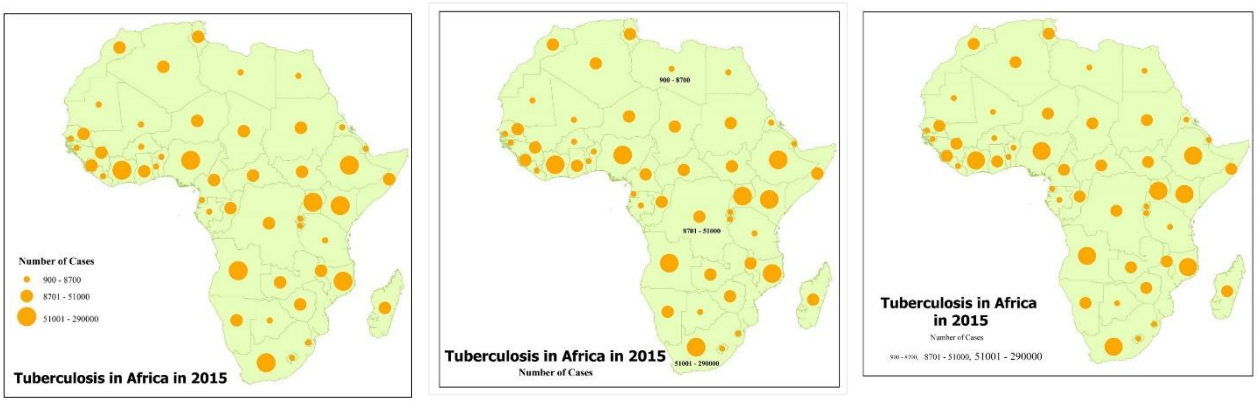
a. b. c.

Figure 4-1: Choropleth maps (a. with legend, b. annotated c. legend incorporated in the title)



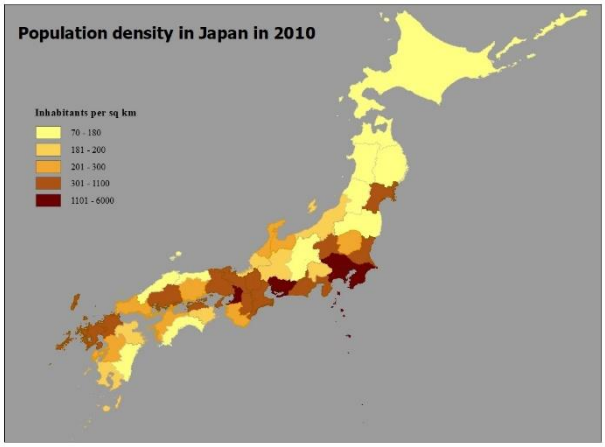
a. b. c.

Figure 4-2: Isopleth maps (a. with legend, b. annotated c. legend incorporated in the title)

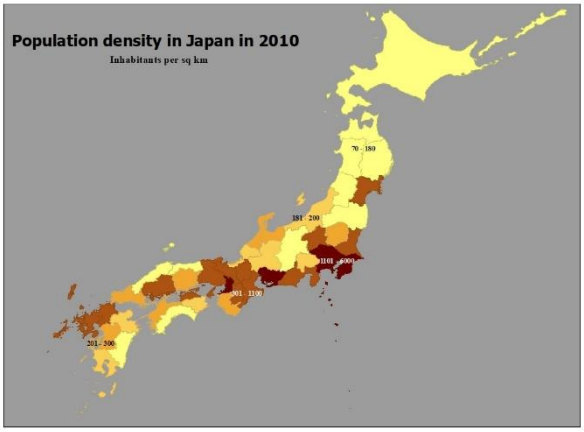


a. b. c.

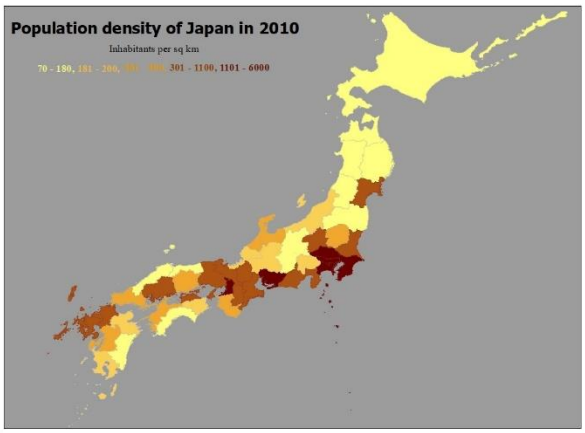
Figure 4-3: Proportional symbol maps (a. with legend, b. annotated c. legend incorporated in the title)



a.



b.



c.

Figure 4-4: Choropleth maps (a. with legend, b. annotated c. legend incorporated in the title)

5. USABILITY OF LEGEND-LESS MAPS

In methodology chapter (chapter 2) overall methodology and used methods in usability tests have been discussed. In this chapter elaborated methodology of usability tests, test design, data analysis methods, results and discussion have been presented.

5.1 Test design

Test design includes selection of the test methods, preparation of stimuli for the test, test person invitation, preparation of invitation letter, preparation of questionnaire, instructions for test person and test execution script etc (see chapter 2: Methodology). All necessary materials (stimuli, questionnaires etc) have been prepared before the actual test. Test set up procedures have been discussed in following sections:

Stimuli design

For finding out how map reading process works (order of map reading process) and comparing usability (effectiveness, efficiency and satisfaction) of map with legend and without legend (annotated map and map with legend in title) a usability survey has been designed and conducted where four main type of maps (chorochromatic, choropleth and isopleth and proportional symbol) has been designed in three version (with legend and using annotation instead of legend and with legend in title). In every map three questions of each level of map reading (elementary, intermediate and overall level) has been incorporated.

Avoiding bias in the test

All test participant has provided with identical instruction sheets before the actual test started. test person (TP) have been asked to practice thinking aloud (instruction provided in the instruction sheet, see appendix 10) during completion of questionnaire to ensure that test taker need not to intervene during the test to address this issue. It is also ensured that during the test only test person and test taker will be at the "usability lab" where the test have been conducted, no interaction made between TP and test taker during actual test (task completion).

If reader is given same stimuli (same map with same geographic boundary and same theme) in three version, and are being asked same questions, there is possibility that reader can remember from previous stimuli and complete the task easily that will bias results of the test. To prevent these in case of each thematic map three different theme and geographical area has been chosen and designed in three different version. Three tests have been designed in a way that it can prevent this biasness (see table 5-1). The three level of task also randomize in way that if in one stimuli first task involve elementary level in another the first task star with overall level in case of same type of maps. Test parson are invited through invitation letter (see appendix 9) and three tests has been distributed into 15 test persons sequentially (see table 5-2). Overall effectiveness, efficiency and satisfaction have been measured three tests.

Pilot testing

After completion of test design, a pilot usability test has been done with a test person (TP). Necessary changes made on the test materials (stimuli of the test, questionnaire, instructions etc.), test procedure based on the pilot test.

Table 5-1: Description of tests and stimuli for usability survey

Map type	Map Version	Stimuli (maps)		
		Test 1	Test 2	Test 3
Topographic Map	With legend	Topographic map of Massachusetts	Topographic map of Massachusetts	Topographic map of Massachusetts
Chorochromatic	With legend	Parental involvement in abortion of minors in the USA	Official languages in Africa	Schengen countries in Europe
	Annotated	Official languages in Africa	Schengen countries in Europe	Parental involvement in abortion of minors in the USA
	Legend in title	Schengen countries in Europe	Parental involvement in abortion of minors in the USA	Official languages in Africa
Choropleth	With legend	Population density in Japan in 2010	Population density in New Zealand 2013	Population density in Africa 2016
	Annotated	Population density in New Zealand 2013	Population density in Africa 2016	Population density in Japan in 2010
	Legend in title	Population density in Africa 2016	Population density in Japan in 2010	Population density in New Zealand 2013
Isopleth	With legend	Annual rainfall in Bangladesh in 2016	Mean temperature in the Netherlands on 1st January 2017	Annual rainfall in Sri Lanka in 2015
	Annotated	Mean temperature in the Netherlands on 1st January 2017	Annual rainfall in Sri Lanka in 2015	Annual rainfall in Bangladesh in 2016
	Legend in title	Annual rainfall in Sri Lanka in 2015	Annual rainfall in Bangladesh in 2016	Mean temperature in the Netherlands on 1st January 2017
Proportional Symbol	With legend	Tuberculosis in Africa in 2015	Claim for work related injuries in New Zealand in 2015	Fire incidents in Japan in 2013
	Annotated	Claim for work related injuries in New Zealand in 2015	Fire incidents in Japan in 2013	Tuberculosis in Africa in 2015
	Legend in title	Fire incidents in Japan in 2013	Tuberculosis in Africa in 2015	Claim for work related injuries in New Zealand in 2015

Table 5-2: Test person (TP) tests

TP	Test
TP 1	Test 1
TP 2	Test 2
TP 3	Test 3
TP 4	Test 1
TP 5	Test 2
TP 6	Test 3
TP 7	Test 1
TP 8	Test 2
TP 9	Test 3
TP 10	Test 1
TP 11	Test 2
TP 12	Test 3
TP 13	Test 1
TP 14	Test 2
TP 15	Test 2
TP 16	Test 3

Table 5-3: Time required to complete the test

Participant (TP)		Required time for the test (Minutes: Seconds)
Test 1	TP 1	19:54
	TP 4	21:40
	TP 7	20:35
	TP 10	20:22
	TP 13	36:42
Test 2	TP 2	18:47
	TP 5	21:40
	TP 8	12:02
	TP 11	19:05
	TP 15	21:24
Test 3	TP 3	20:55
	TP 6	22:48
	TP 9	22:39
	TP 12	27:54
	TP 16	16:24

Limitation of the test design

During the survey, it is found that TP14 (see table 5-2) have colour-blindness, that was not asked in the questionnaire and maps are not designed in consideration of this issue. As in 3 out of 4 map types, value or hue have been taken into visual variable to classify maps. Colour-blindness would influence the test results. That's why collected data from TP14 have not been included in the test.

Most of the TP are M Sc students and have cartographic knowledge except few. Due to limitations, it was not possible to include TPs from diverse background.

TP 8 have taken less time than average and TP 12 and TP 13 have taken longer time than average. In efficiency measurement outlier can be identified as box and whisker plot have been used but in effectiveness measurement it was not possible to separate their results that may affect overall results as TP 8 have completed only 85% task correctly and TP 12 only 78 percent correctly. TP 13 have taken longer time but answered 98% task correctly (see table appendix-3). TP 8 and TP 12 both from different background rather than Geography or Cartography and TP 12 have never attended any cartography lessen, whereas TP 13 is from Geography background (see table 5-4 and table 5-5)).

5.2. Personal information and background of test person (TP)

A questionnaire survey has been conducted to finding out the background of test person and there previous knowledge on cartography to evaluate test results in proper context. As test persons are dominated by male. They are from different parts of the world. Their age ranges between 21-54 years. Most of the TP are M Sc student having geography or geoinformation background.

Almost all test person having cartography lessons except one, TP12 and they use map weekly or daily and all have experience of making maps.

Table 5-4: TPs' personal information and background

Test Person	Gender	Age	Country	Occupation	Field of study
TP 1	Male	26	India	M Sc student	Physics
TP 2	Female	30	China	PhD student	Geography,
TP 3	Male	30	Indonesia	M Sc Student	Geodetic engineering
TP 4	Male	35	Bangladesh	M Sc Student	Geography
TP 5	Male	28	Kenya	M Sc Student	Geography
TP 6	Female	23	China	M Sc Student	Environmental science
TP 7	Female	28	Tanzania	M Sc Student	Geoinformatics
TP 8	Female	25	India	M Sc Student	Urban planning
TP 9	Male	54	The Netherlands	ITC/UT Staff	Data visualization
TP 10	Male	25	Mexico	M Sc student	Geoinformatics
TP 11	Male	29	Egypt	M Sc Student	Civil engineering
TP 12	Male	27	Ethiopia	M Sc Student	Water resource
TP 13	Male	39	Rwanda	M Sc Student	Geography
TP 15	Male	21	Russia	M Sc Student	Human geography
TP 16	Male	22	The Netherlands	M Sc student	Human geography

Table 5-5: TPs' cartography knowledge and map use in daily life

Test Person	Cartography lesson	Map use in daily life	Make making
TP 1	Yes	Daily	Yes
TP 2	Yes	Weekly	Yes
TP 3	Yes	Daily	Yes
TP 4	Yes	Daily	Yes
TP 5	Yes	Daily	Yes
TP 6	Yes	Weekly	Yes
TP 7	Yes	Weekly	Yes
TP 8	Yes	Weekly	Yes
TP 9	Yes	Weekly	Yes
TP 10	Yes	Weekly	Yes
TP 11	Yes	Daily	Yes
TP 12	No	Weekly	Yes
TP 13	Yes	Weekly	Yes
TP 15	Yes	Weekly	Yes
TP 16	Yes	Daily	Yes

5.3. Evaluation of the stages of the map reading process

The map reading process (figure 2.1 a.) an according to Bertin (1983) involve two successive stages: external identification (title) and internal identification (legend) followed by actual reading process (reading map view).

Eye tracking data during the task completion have been analysed to evaluate the stages of the map reading process. The sequence and position of fixation (represented by dot) can be analysed by the gaze plot visualization on static media (stimuli maps) and size of the dots indicate the fixation duration and number in the dot represent the order of the fixation (see figure 5-5) (Tobbi Studio, 2010).

In the three usability tests, each TP provide with 5 maps that designed with legend (four main thematic maps – "map to see") and one (topographic map- "map to read"). Gaze plot data from total 75 maps tested by 15 TPs have been used to evaluate the stages of map reading process. Questionnaire survey data related to map reading process also compared with the data found from the gaze plot analysis.

For analysis, sequence of recorded gaze by eye tracker are observed from the starting of map reading process until the reader looks three (title, legend and map view) elements of the maps.

5.3.1. Evaluation of map reading process: TPs' opinion

In questionnaire survey of TP explain how they start map reading. About 13% answered that they random scan the map rather following any ordered stages during map reading. About 40% of the participant says that they look at the title first and rest 47% looks on the map view first (see figure 5-1).

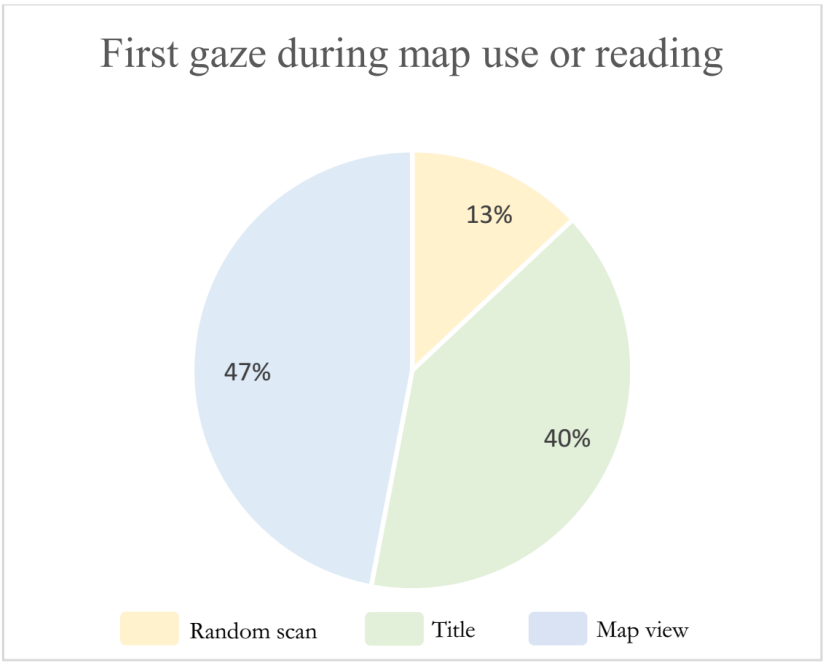


Figure 5-1: TPs' responds to the question: Which parts they look first during map reading?

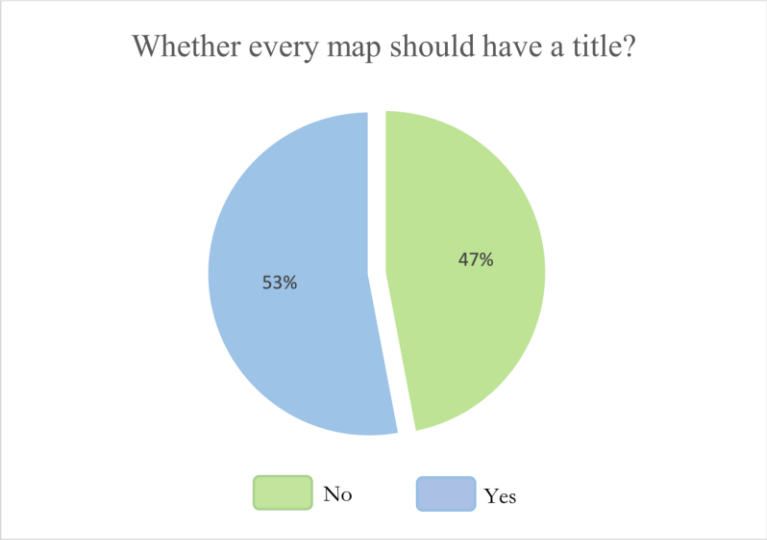


Figure 5-2: TPs' responds whether every map should have a title

About 47% of test person express that if the maps are self-explanatory or intuitive for reader, a title is not necessary (figure 5-2). Necessity of a title depends on map types (Google maps doesn't have any title), it's design, information its delivering and the purpose it designed for. The explanation in their words are as follows: "Sometimes context will make a map title unnecessary"; "If the symbol is good enough it can be self-descriptive" "But the map itself very intuitive for the reader".

A title is necessary in every map according to 53% TPs' opinions (figure 5-2). It is necessary to have a title in every map to know the theme it is presenting, the geographical area as well it is representing directly during reading process. TP explain the necessity of a title in every map as: "It gives an introduction and what can be found in the map"; "Need to know the topic of map directly"; "It is easy to comprehend what the map is about".

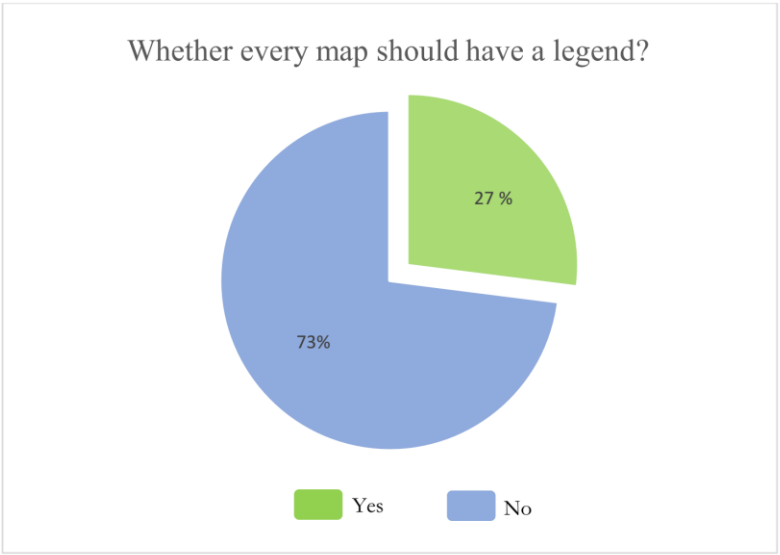


Figure 5-3: TPs' responds whether every map should have a legend

In the answer of the questions Do they think that every map should have a legend? Only 27% answered "yes" and explain that every map should have legend to explain meaning of the symbol presented on the map (figure 5-3). In their word legend is necessary in every map because: "Need to know the meaning of symbol, colour"; "For better delivery of information"; "I agree, from my view, symbol is what makes map a map (in contrast to a photo). So, they need to be explained"

About 73% participant think that every map should not have a legend (figure5-3). From their view, why every map should not have a legend can be categories into two aspects as map can be designed in a way where legend is not necessary and some others think that it depends on the complexity of the maps and simple maps might be self-explanatory without legend (table 5-6). It can be summarized from their opinions as a map that is simple (in terms of theme, information it is conveying, etc.) can be design in a way where legend is not necessary.

Table 5-6: Test persons' explanation why legend is not necessary in every map

Category (opinions)	Explanation of the participant
Map design	"But the map should have well explained the content of the map itself" "Good map design can make a legend unnecessary" "Not in web map but in static map necessary" "If the symbol is good enough it can be self-descriptive"
Map complexity	"If not, enough information presented on map, but need a legend if lot of information is presented in the map" "It depends, if there are more item, it may have needed" "Some maps are intuitive enough to understand without a legend"

5.3.2. Evaluation of map reading process: from eye tracker data

Analysing gaze plot data, four predominate order/ stages of map reading process fund (figure 5-4) that collectively represent 79% of cases (table 5-7). Five other pattern of reading process found from the data that represent only 21 % of cases (table 5-7). Only 13% cases map reading started from reading title (table 5-7). where as in questionnaire 40% says that they first look at title. (questionnaire have been providing to TP before the actual test: eye tracking, task completion). This discrepancy indicate that reader might unconsciously look at certain parts but when they asked they are being asked they answer consciously and they might also don't know from where they start reading.

Table 5-7: Pattern of reading process found from the test

Reading stages	Number of cases (%)
Map View – Title – Map View – Legend	33
Map View – Legend – Title	20
Map View – Title – Legend	17
Title – Map View –Legend	9
Legend – Title – Map View	5
Map View – Title – Map View – Title – Legend	5
Map View – Legend – Questions/Questions – Legend – Map View	4
Title – Map View – Title – Map View – Legend	4
Legend – Map View – Title	1

Predominant stages of map reading:

Most dominant pattern of stages in reading process found that reader start from map view, then moved to map title, after reading map title again goes to map view and then map legend and the process continue until s/he finished map reading (figure 5-4: a. and figure 5-5). This pattern found in about 33% of cases in the test.

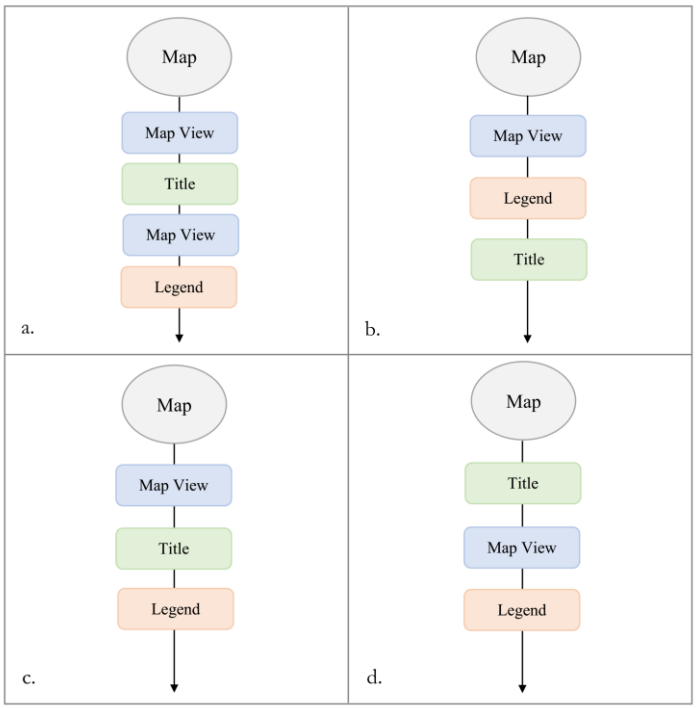


Figure 5-4: Predominant of map reading process found from the test

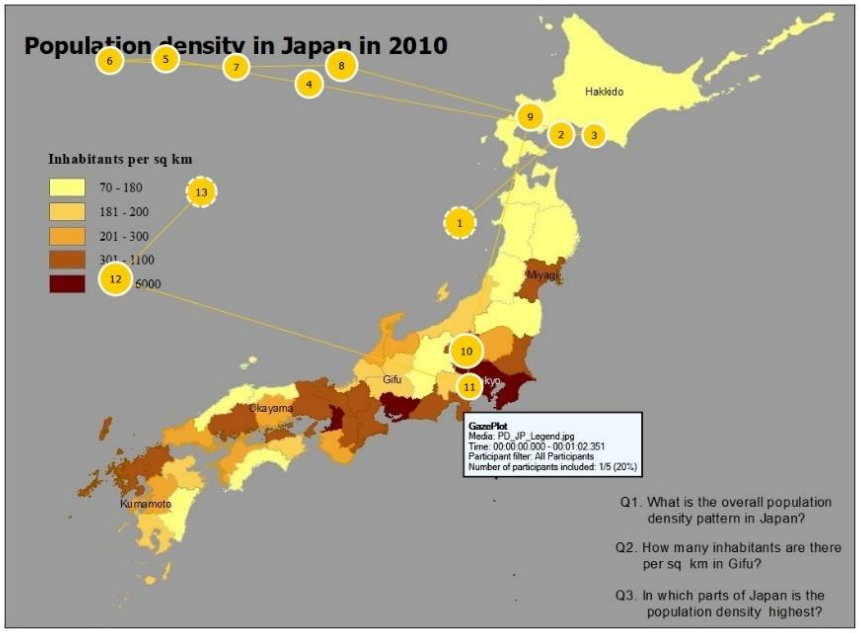


Figure 5-5: Gaze plot of most predominant reading order/stages

The second dominant map reading stages found that reader start from map view, then map legend and followed by title and the process continues until task completion (figure 5-4: b.). It can be assumed that, as in these 75 stimuli some maps are not designed according to conventional design methods where title normally placed on the upper most left side of the maps may results in these kind of pattern, but maps those are designed according to conventional design rules also generated similar pattern (figure 5-6: a. and b.)

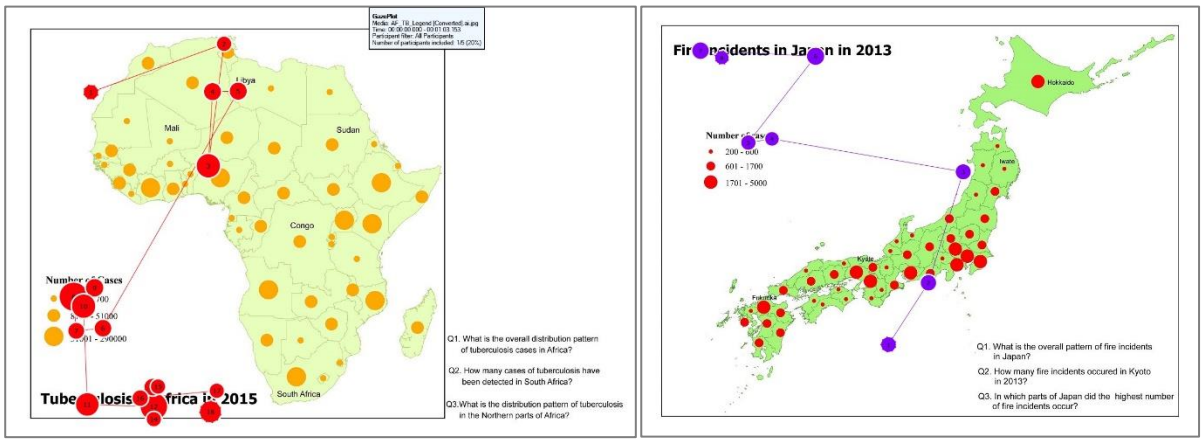


Figure 5-6: Gaze plot of map reading stages (a) Map title designed in nonconventional manner and (b) designed according to traditional convention

The third most predominant pattern fount from the test data analysis that map reader started reading from map view, followed by title and then legend and again the process continue in different order until s/he finished map reading (figure 5-7). In 17% cases map reading started following this pattern (table 5-7)

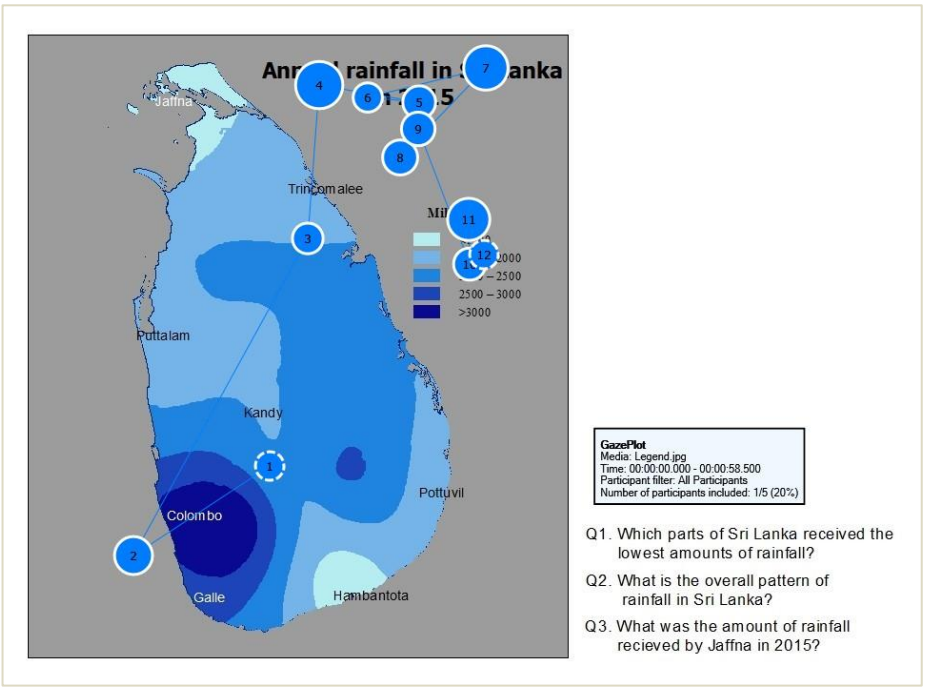


Figure 5-7: Gaze plot of third most predominate pattern of map reading

Another predominant pattern where map reader started reading maps from title, followed by map view, then legend. This pattern occurred in 9% cases although when participant is being asked which parts they first look during map reading, about 40% have written that they first looks at title.

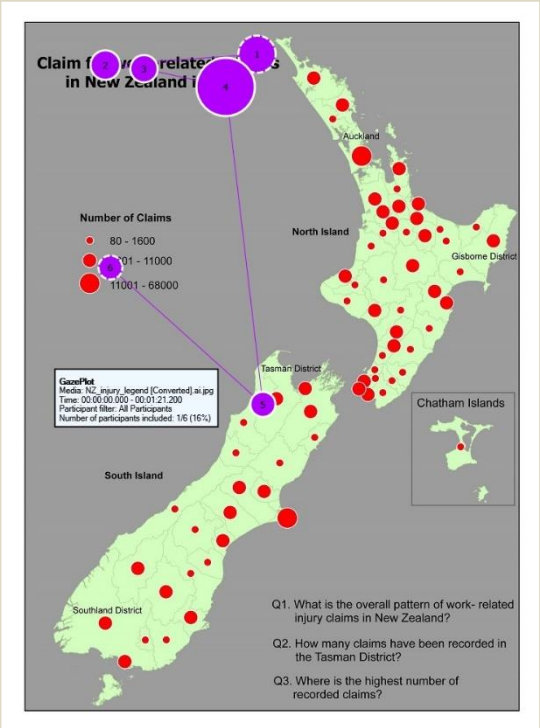
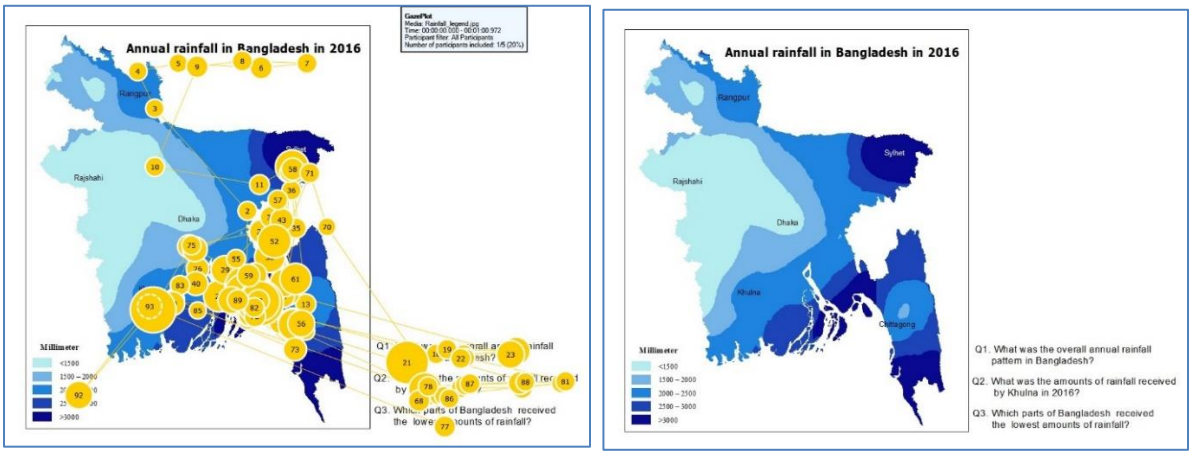


Figure 5-8: Gaze plot of fourth most predominate reading pattern

In some cases, TP have answered both overall and intermediate level questions correctly without consulting with legend, they look for legend when they need to answer elementary level questions. In figure shows that gaze 92 (figure 5-9 a.) deals with legend and TP consult with legend only during answering Q2 (figure 5-9 b.). as other two questions have not asked any exact amount.



. Figure 5-9: Eye movement order (number) and duration (dot size) during test

Even in some cases, TP have completed task looking at the legend, map view and the provided question and have not even looked at the title at all. It is also can be a case of investigation if these stimuli were not attached with questions what pattern would be found from the test.

It is also found that if intermediate and overall questions asked not to mention exact amount, the answer can be given correctly without discuss with legend (for example: inferring from the value change in case of choropleth and isopleth maps).

"The eye tracking methods utilizes eye tracker that collects data on eye movements, which are the reflection of humans' inner processes of map interpretation" (Dong). Whether the stages/order of map reading process influenced by readers' country of origin or any spatial attachment of the geographical area presented on the maps, and reader look at that parts first during reading that is also not clear and can be tested.

Analysing the pattern of map reading stages from gaze plot visualization of 3 tests, it is found that map reading process need two stages of identification in most cases but it is not following the successive order according to theory. As well in many cases readers are not aware or unconscious from where they star reading map. None of the pattern matched with theoretical map reading stages/order (figure 2.1a) described by Bertin (1983). It is hard to say that whether there is a flaw in the test design, map design or in the theory of map reading stages.

5.4. Usability of legend-less maps

Usability of maps with and without legend measured in terms of effectiveness, efficiency and satisfaction.

5.4.1. Effectiveness

Effectiveness generally measured based on task completion successes, particularly the correctness and the completeness of task completed. In this research, for measuring effectiveness task completion successes measured in three terms: correct- the task is completed and it is correct, incorrect- the task is completed but incorrectly, and not answered: either TP have missed the ask unconsciously or have not attempted (table 5-8). If any task is incorrectly completed due to problem of understanding the task questions provide in the stimuli, is considered as not answered as this research is not subjected to find out the effectiveness of the questions, rather the effectiveness of map design.

Table 5-8: Measurement criteria of effectiveness

Measurement of effectiveness	Explanation
Correct (C)	Provided task have been completed by TPs' and is correct
Incorrect (I)	Provided task have been completed by TPs' but incorrect
Not Answered (N)	TPs' unconsciously missed the questions or not attempted or incorrectly answered not understanding the provided task questions correctly.

Effectiveness data have been summarized from the recording of think aloud data of test participant. Data from three tests have been summarized and analysed to compare the overall effectiveness of maps with and without legend (table 5-9).

Overall effectiveness in answering different level of questions: elementary level (table 5-10), intermediate (table 5-11), and overall (table 5-12) also have been calculated from summarizing recorded data from three tests.

Table 5-9: Overall effectiveness from three tests

OVERALL (All level task)	Effectiveness (%)								
	With legend			Annotated			Legend in title		
Map types	C	I	N	C	I	N	C	I	N
Chorochromatic	94	2	4	85	13	2	96	4	0
Choropleth	98	2	0	96	2	2	89	7	4
Isopleth	98	0	2	93	2	5	91	9	0
Graduated symbol	91	9	0	89	11	0	96	2	2
C = Correct, I = Incorrect, N = Not answered									

Table 5-10: Overall effectiveness for elementary level task from three tests

Elementary level task	Effectiveness (%)								
	With legend			Annotated			Legend in title		
Map types	C	I	N	C	I	N	C	I	N
Chorochromatic	93	7	0	80	20	0	93	7	0
Choropleth	93	7	0	93	7	0	74	13	13
Isopleth	100	0	0	100	0	0	87	13	0
Graduated symbol	87	13	0	87	13	0	86	7	7
C = Correct, I = Incorrect, N = Not answered									

Table 5-11: Overall effectiveness for intermediate level task from three tests

Intermediate level task	Effectiveness (%)								
	With legend			Annotated			Legend in title		
Map types	C	I	N	C	I	N	C	I	N
Chorochromatic	93	0	7	80	13	7	100	0	0
Choropleth	100	0	0	100	0	0	100	0	0
Isopleth	100	0	0	100	0	0	100	0	0
Graduated symbol	93	7	0	87	13	0	100	0	0
C = Correct, I = Incorrect, N = Not answered									

Table 5-12: Overall effectiveness for overall level task from three tests

Overall level task	Effectiveness (%)								
	With legend			Annotated			Legend in title		
Map types	C	I	N	C	I	N	C	I	N
Chorochromatic	93	0	7	93	7	0	93	7	0
Choropleth	100	0	0	93	0	7	93	7	0
Isopleth	93	7	0	80	7	13	87	13	0
Graduated symbol	93	7	0	93	7	0	100	0	0
C = Correct, I = Incorrect, N = Not answered									

Effectiveness of chorochromatic maps

In case of chorochromatic maps, test data analysis shows that most effective designed map is the map with legend in title in terms of correctness and in terms of correctness and completeness map with legend is the most effective one (see figure 5.10). Annotated chorochromatic maps appears as the least effective.

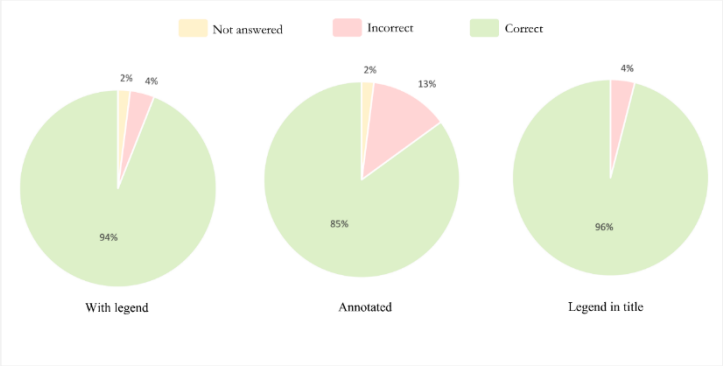


Figure 5-10: Overall effectiveness of different versions' chorochromatic map

Effectiveness of choropleth maps

In choropleth maps, most effective maps are the maps is map designed with legend in terms of both task completeness and correctness followed by annotated maps (see figure 5.11). Maps designed by incorporated legend on title appeared as least effective maps. In maps, "legend in title" version class/ranges are coloured according to the class it is representing in the maps, and it appears that it was hard to decode information from this type of legend design particularly for choropleth maps still the effectiveness of title version quite high around 89%.

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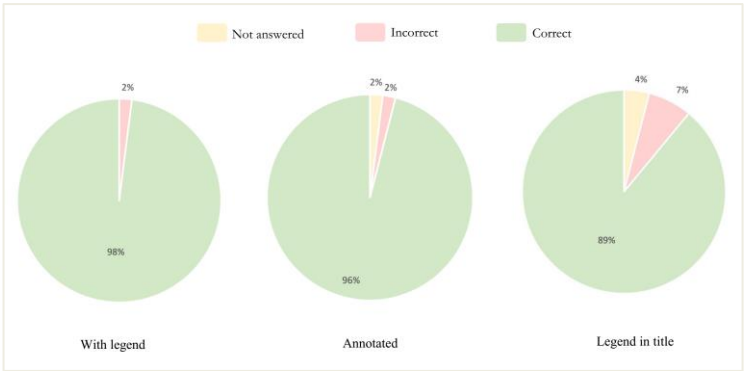


Figure 5-11: Overall effectiveness of different versions' choropleth map

Effectiveness of isopleth maps

Like chorochromatic and choropleth maps, isopleth maps' class varies on values and in annotated version, classes are presented on maps and title version class are incorporated with title and coloured according to the class it represents in the maps. In isopleth maps with legend is most effective followed by annotated maps and the least effective is map where legend is incorporated in the title (figure 5-12).

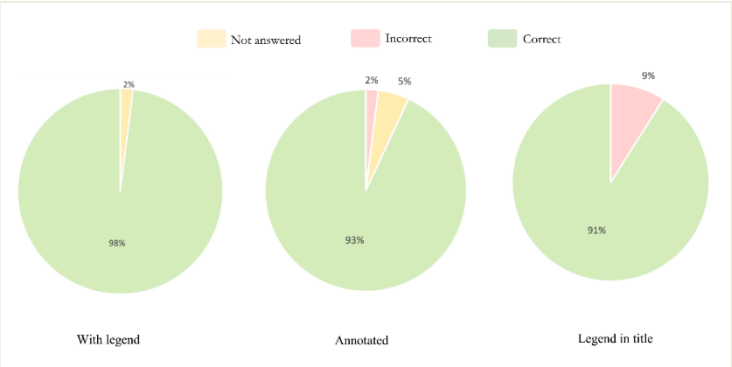


Figure 5-12: Overall effectiveness of different versions' isopleth map

Effectiveness of graduated symbol maps

In graduated symbol maps data have been classified into three classes and only in this maps size is the visual variable. In annotated version description of classes presented by numbers represented on map as annotation and title version class representing number vary in size to represent different size of circle in the maps. From tests, it is found that title version is most effective version even better than the legend version and least effective is the annotated version as reader have to search whole map to find out annotated symbol and then match with similar symbol to complete the task presented on the test (see figure 5-13).

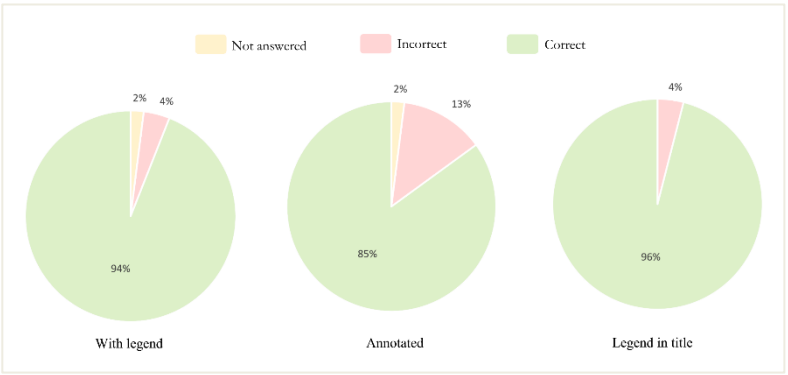


Figure 5-13: Overall effectiveness of different versions' graduated symbol maps

5.4.2. Efficiency

Efficiency is defined as resourced (time, cost etc) used during achieving any specific goal. In case of usability of legend-less maps, efficiency is measured in terms of time required to complete a certain task correctly. Required data extracted from recorded think aloud and eye movement data of test person. In calculation of the time required for specific task, time required to read question is excluded. In some cases, test person looks for answer in map during reading question. In that case, when reader moves eye to find out answer, during reading question included as it is possible to see all gaze record from the test and as well reading question can be heard from think aloud and video recording simultaneously.

Required time for each level of task in each version of maps have been extracted in case of every TP (table appendix-4 to table appendix-18) and box and whisker plot have been generated to visualize data as outliers can be easily identified the spread of data as well, mean, median time required to complete task can be shown at a time. Less time required to complete any task correctly in any map, considered more efficient compared to others.

Chorochromatic maps

For chorochromatic map, most efficient is maps with legend in title and least efficient is maps with legend for answering elementary level of questions. For answering intermediate and overall level questions most efficient maps are annotated maps (figure 5-14).

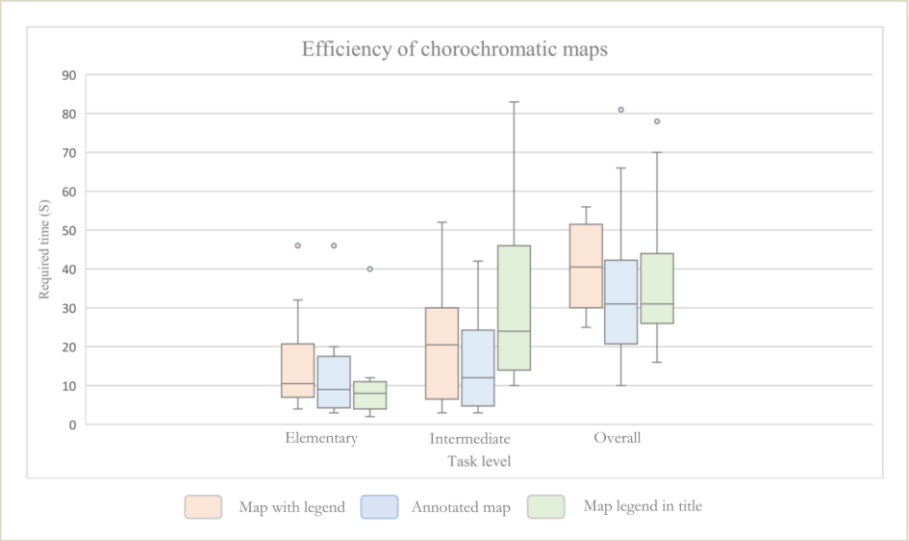


Figure 5-14: Overall efficiency of chorochromatic maps from three tests

Choropleth maps

In choropleth, most efficient is maps with legend particularly in case of answering elementary level of questions as within 10-12 seconds all TP have completed task where in that time in annotated map only 25% participant can complete the task. For elementary level task, annotated choropleth maps appear to be the least efficient may be because TP have to match similar "value "that representing the answer of the task with another geographic area where range (classes) have been annotated (figure 5-19).

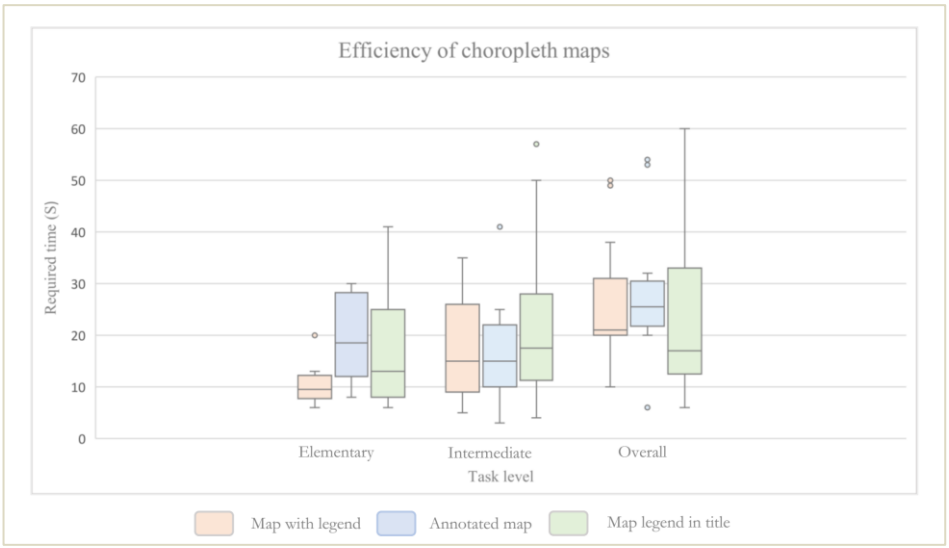


Figure 5-15: Overall efficiency of choropleth maps from three tests

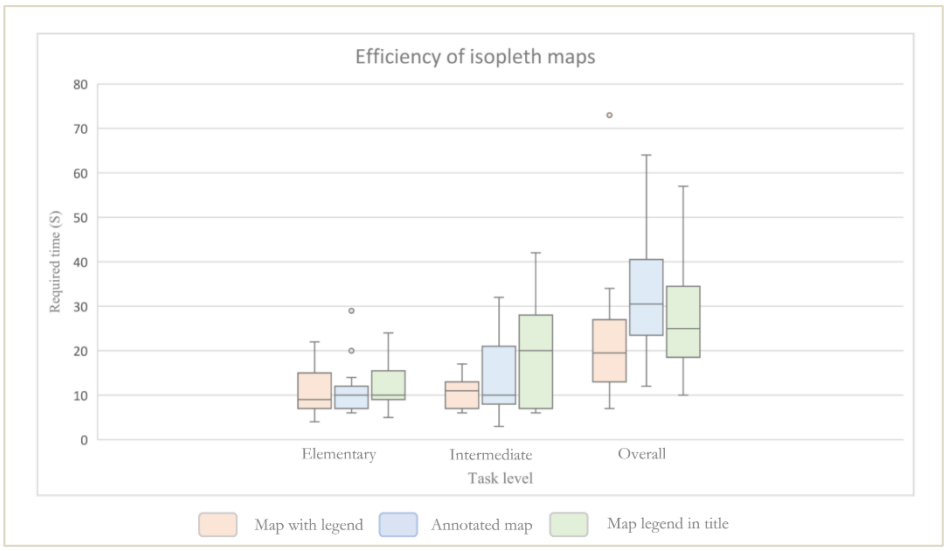


Figure 5-16: Overall efficiency of isopleth maps from three tests

Isopleth maps

Most efficient maps are maps with legend, then annotated maps and least efficient is legend it title version (figure 5-16).

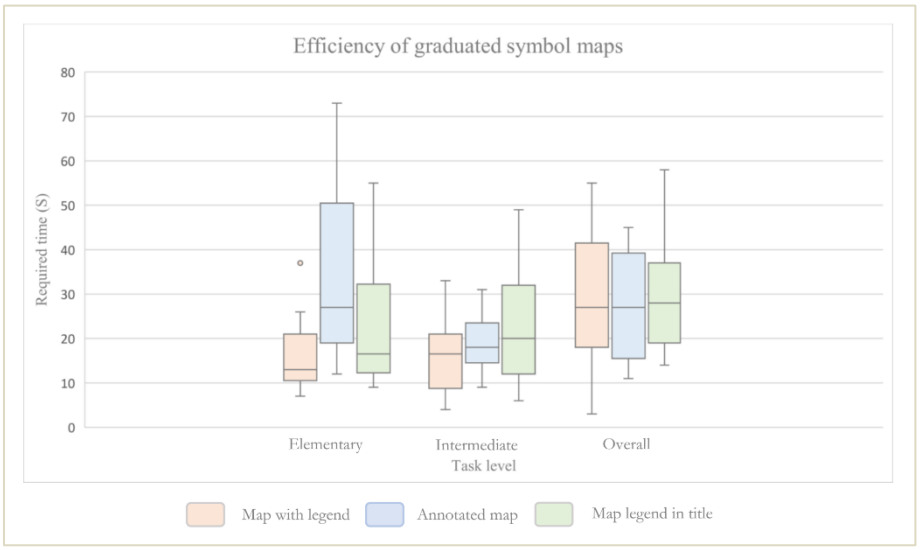
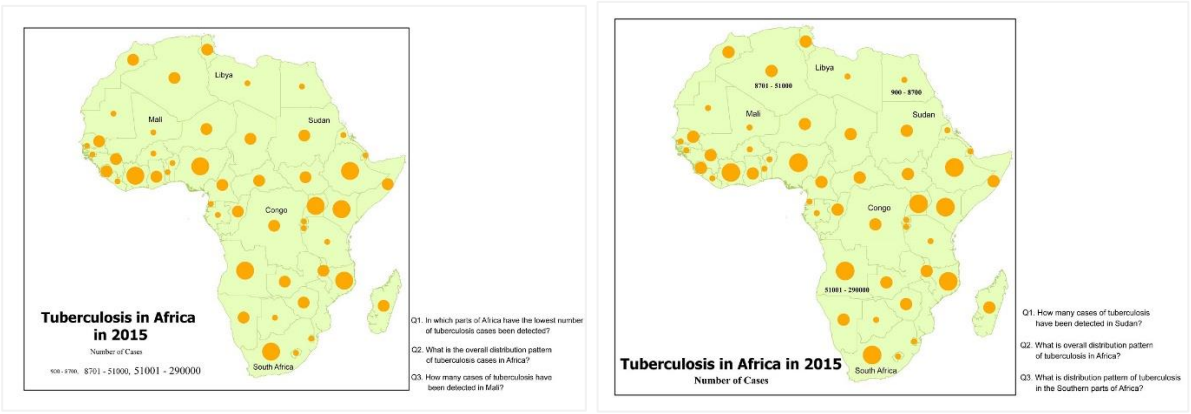


Figure 5-17: Overall efficiency of graduated symbol maps from three tests

Graduated symbol maps:

In graduated symbol maps, most efficient is maps with legend and annotated maps appears to be the least efficient particularly in case of elementary level task. In annotated maps when 25% of participant can complete the task within in 25-28 S. In case of choropleth maps all participants (100) have completed the task and in the same time in title version about 70% participant can be able to complete the task (figure5-17). The reason is for finding answer elementary level task, TP have to compare similar level circle in the questions asked for with another geographical boundary that required time less time required in title version although legend is presented by the size of the range it is representing in the maps (figure 5-18). This is happened when only the data is classified in to three, if the class number increase, the map will be more complex and efficiency will be decreased. So, graduated symbol maps most efficient is maps with legend, then legend in title and least efficient is annotated maps.



a. b.

Figure 5-18 Annotated (a) and "legend in title" (b) version of graduated symbol map

5.4.3. Satisfaction

Satisfaction defined as the positive attitudes or discomfort towards any product or services sometimes expressed by emotional or psychological effects (Bevan, 2015). For measuring satisfaction emotional expression, positive and negative comments have been extracted from the recording of the tests.

Maps with legend

No specific comments come from TP in case of maps with legend. From their facial expression, it can be assumed that maps with legend is convenient for map reading. Some TPs expresses dissatisfaction in case of absence of legend as "I guess a legend would be even better" during task completion of annotated choropleth maps.

Annotated maps

No negative attitude or discomfort found in the annotated chorochromatic maps.

Most of the cases annotated choropleth maps receives negative attitudes. TP has to compare value of geographical area (question asked for) with another geographical area included into same class annotated with class description. It is confusing as well as time consuming as categories have been done based on "value". The negative attitude and discomfort expressed by TP as: "It could have a legend! it is very hard" during the task completion of annotated population density map (Population density of the New Zealand). During answering the elementary level questions (figure 5-19) discomfort expressed by TP as "This is a kind of annoying! I have to look for one with same colour".

No discomfort or negative attitude found in case of annotated isopleth maps.

Some positive comments found in case of annotated graduated symbol maps as the techniques seems interesting to some of the TP: "This is interesting!"; "This is also good idea!". Some other test person found it hard to answer the questions as they have to compare dot size of the geographic area (questions asked) with another area representing same class and annotated with class description.

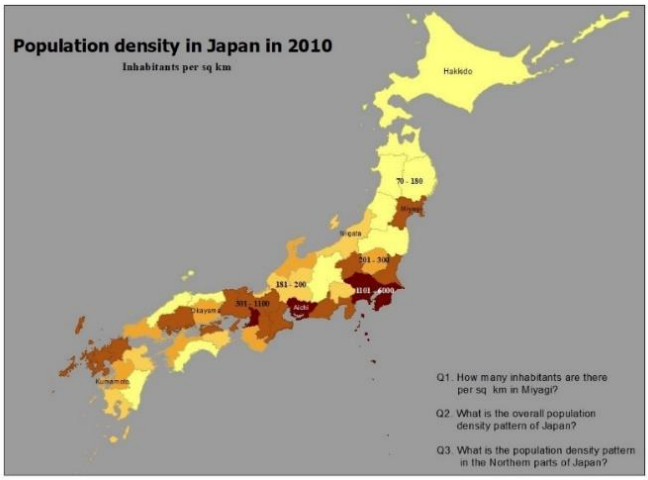


Figure 5-19: Annotated choropleth map

Maps with legend in title

Positive comments or attitude shown by TP in case of chorochromatic maps designed with legend in the title: "Oh! This is interesting! I thought there will be a legend at the bottom but it is in title". The colour choice received negative attitude ("the colour is shocking") in all version of map presented in figure 5-20.

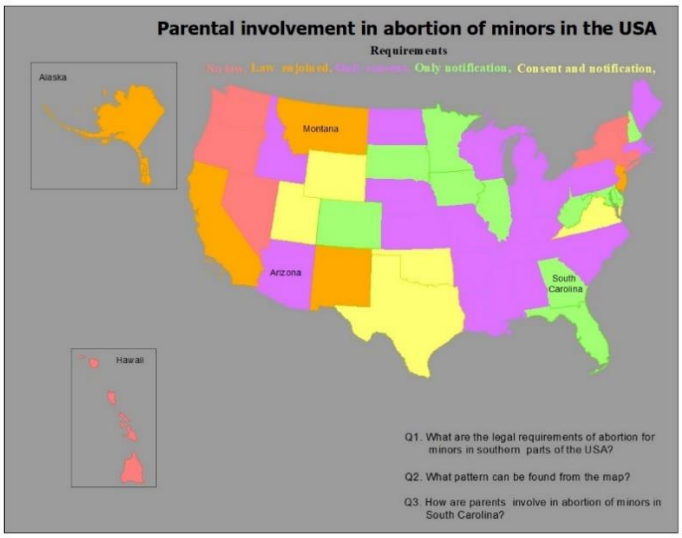


Figure 5-20: Chorochromatic maps with legend in title

No negative attitudes or discomfort found in case of isopleth maps designed with legend in title. Negative attitudes discomfort expressed in case of graduated symbol. Graduated symbol maps using number size to represent circle size in the map discomfort some TPs ("there is no relation between symbol and the number……."; "I would love if there is a legend with size……") during task completion of "Title version" of graduated symbol maps.

5.5. Summary of the usability test

In annotation and in title version of choropleth maps received discomfort as well negative attitude by TPs. Positive attitudes observed in case of legend version. In terms of overall efficiency choropleth maps with legend is most effective, then annotated one and least effective is legend in title (figure 5-11). In case of elementary level task, with legend and annotated perform same way in terms of effectiveness and title version is the least effective one. In terms of efficiency, maps with legend is most efficient followed by annotated maps but in elementary level task annotated least efficient than other two version (figure 5-15). So, in case of choropleth maps in terms of usability best one is maps with legend. The second best in terms of effectiveness, and satisfaction annotated one and in terms of efficiency the title version.

Negative and positive both attitude observed in case of proportional symbol maps designed using annotation and putting legend in the title. In terms of effectiveness, title version was most effective and annotated one is least effective (figure 5-13). In efficiency, again annotated version is least efficient and legend version is most efficient (figure 5-17). No negative attitude and discomfort fund in case of maps with legend, but for maps without legend both positive and negative attitude observed. In the case of graduated symbol maps only three classes have been chosen, if the number of class increase, map complexity will be increase and in terms of usability legend-less maps perform least. So, for graduated/proportional symbol maps map with legend is the best options.

No, negative attitude or discomfort found in all three version of isopleth maps. In overall effectiveness, best option is maps with legend (figure 5-12), in terms of overall (from three tests) effectiveness in case of elementary task both annotated and legend version perform same (table 5-10). In terms of efficiency, maps with legend is most efficient, then annotated maps. Legend in title is less efficient and effective (figure 5-16). So, maps with legend will be the best option, in case of designing legend-less maps annotated map will be best solution.

As no negative attitude, or discomfort observed for legend less version of chorochromatic maps. In terms of efficiency, legend less (annotated, and legend in title) is more efficient than maps with legend (figure 5:14). In terms of effectiveness title version appear to be more effective than maps with legend (figure 5-10). In annotated version, overall effectiveness is low. It is found that of two test participants, TP 12 and TP 2 (table appendix-9) is collectively contributing about 11% of incorrect answer out of 13% where TP 12 alone contributing 7% (table appendix-17). With further investigation from thinking aloud data it is observed that TP 12 is trying to quantify annotated chorochromatic maps, it seems s/he is not known to maps with nominal data. Then it appears that TP 12 is from different background rather than cartography and geography and have never taken part any cartography lessons before. The effectiveness of the annotated maps could be different if these case is not included.

So, in terms of usability chorochromatic maps are the best map that can be designed without legend by annotation or by legend in title. The second options for legend-less maps are isopleth maps using annotation.

6. CONLCUISON

Legend's main functions is to decode the meaning of the symbol. It is found from this research that only elementary level task always requires some form of legend. If intermediate and overall level task doesn't ask for any exact amount, correct answer can be given form the value change in case of choropleth and isopleth maps and in case of graduated/proportional symbol maps answer can be inferred from size of the symbol. For answering any level of questions need some form of legend/key either by annotation or putting in title or traditional legend in case of chorochromatic maps.

None of the pattern found from gaze plot analysis from the test matches stages of reading process described by Bertin (1983). In most cases, two stages of identification are observed but the successive order/stages have not found in any cases. It is not clear whether there is flaw in test design, map design or in theory itself. Further research can be done to prove it.

From usability test it is found that in case of choropleth maps best option is maps with legend and legend in title are the least suitable maps. In cases of graduated symbol maps, best option is maps with legend, annotated maps are least suitable one. In case of isopleth maps, best option is maps with legend, followed by annotated maps in terms of usability. Legend in title is least suitable one for isopleth maps.

Legend-less map is best option, either annotated or title version compared to maps with legend in case of chorochromatic maps. The second best option (after maps with legend in case of isopleth maps) if maps are designed without legend can be annotated isopleth maps.

In the test, maps have been designed with 5 categories in case of chorochromatic, choropleth and isopleth maps and for proportional symbol 3 categories. The test can be repeated increasing or decreasing category. As the category increase, map complexity increase. Relationship between legend/legend-less option in relation to map complexity also can be tested.

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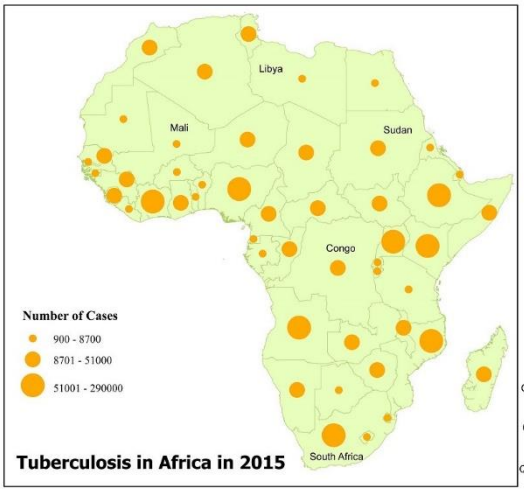
APPENDIX

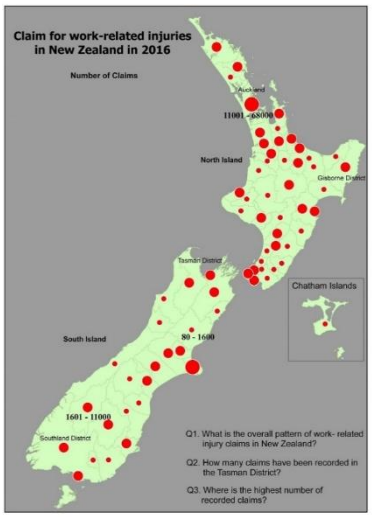
Appendix 1: Stimuli (Test 1)

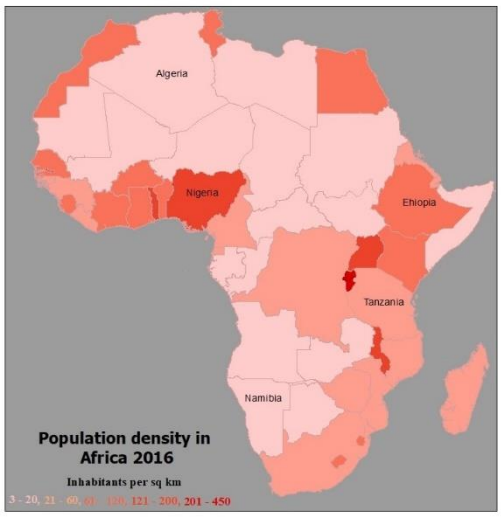


Q1. What is the overall distribution pattern of tuberculosis cases in Africa?

Q2. How many cases of tuberculosis have been detected in South Africa?

Q3.What is the distribution pattern of tuberculosis in the Northern parts of Africa?

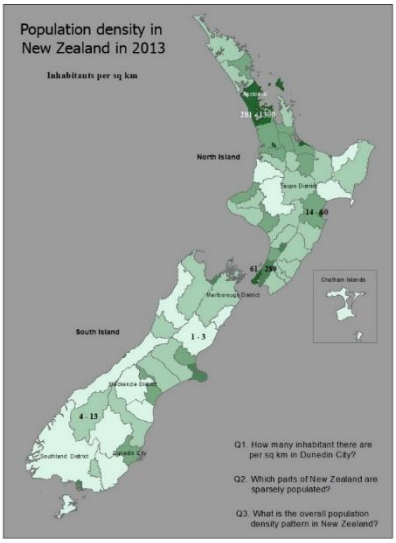


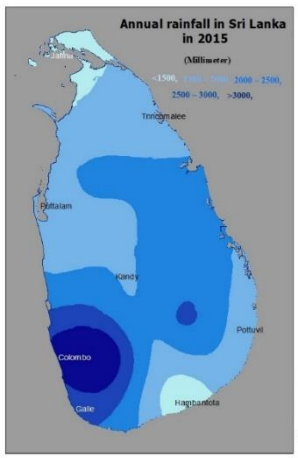


Q1. What is the population density pattern in the Southern parts of Africa?

Q2. Define regions in Africa based on population density?

Q3. How many inhabitants are there per sq km in Nigeria?

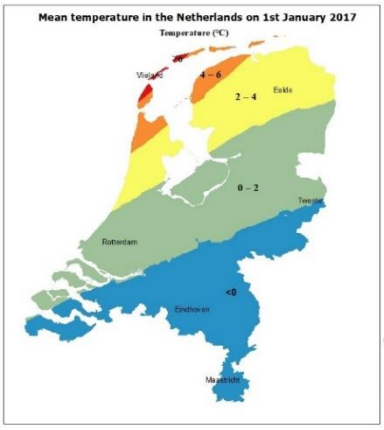




Q.1 What was the amount of rainfall received by the middle parts of Sri lanka?

Q2. What was the overall pattern of rainfall in Sri Lanka?

Q3. What was the amount of rainfall received by Colombo in 2015?

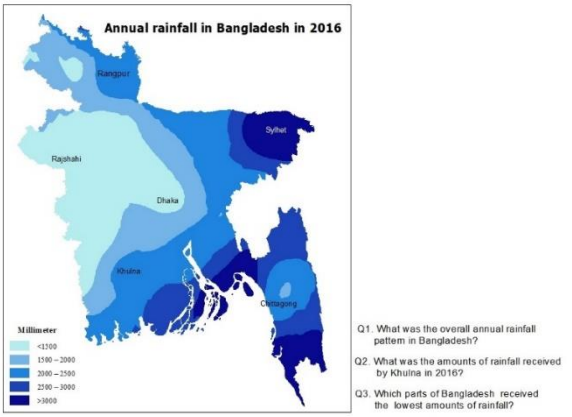


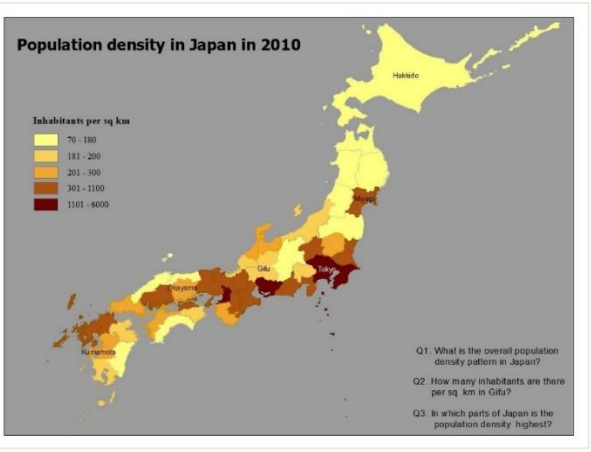
Q1. What was the mean temperature in Rotterdam on 1st January 2017?

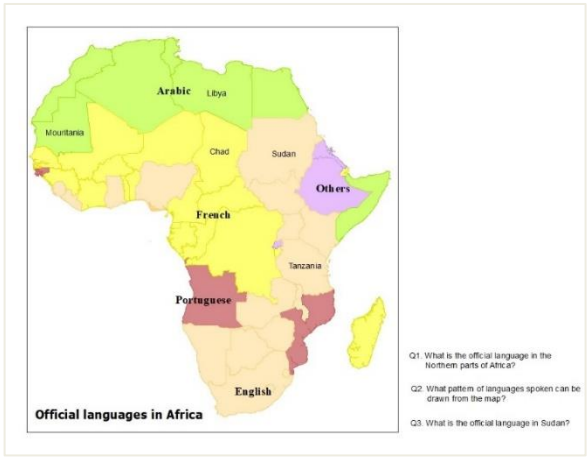
Q2. What was the overall mean temperature pattern over the Netherlands on 1st January 2017?

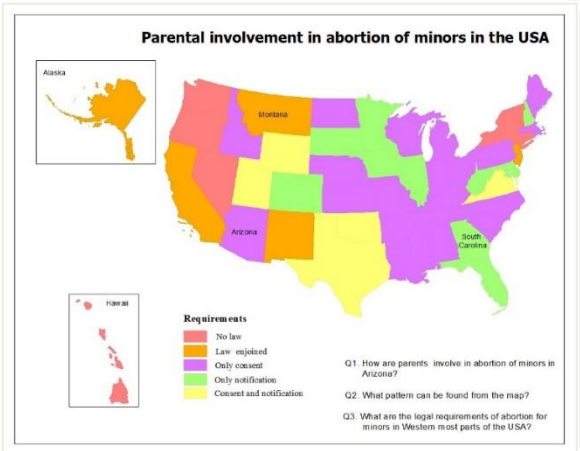
Q3. What was the mean temperature pattern in the Northern parts of the Netherlands?

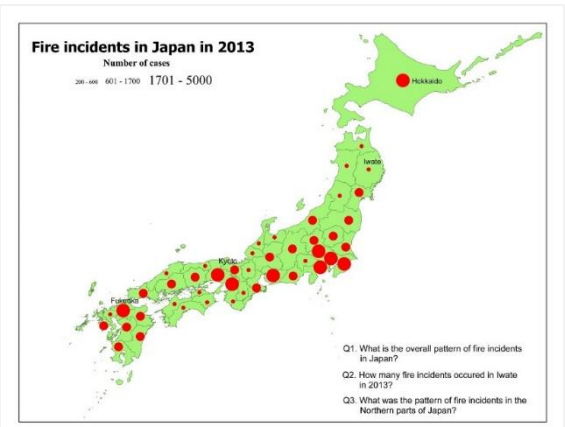
Appendix 1: Stimuli (Test 1)

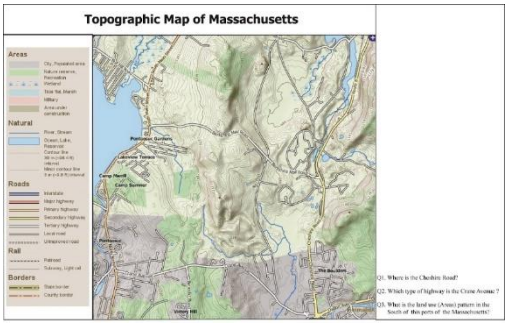




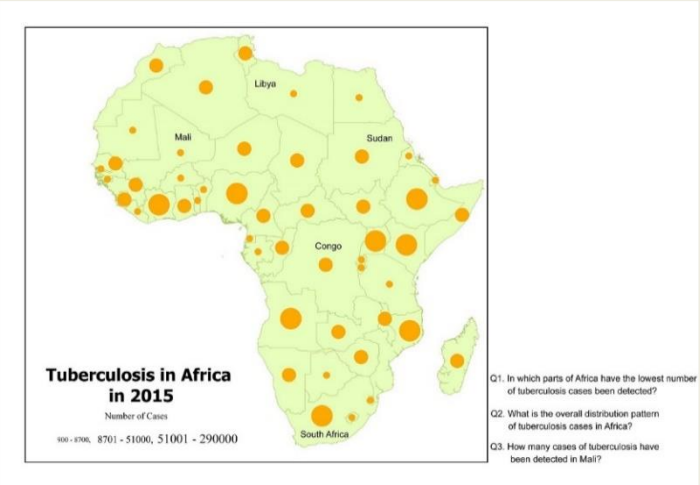


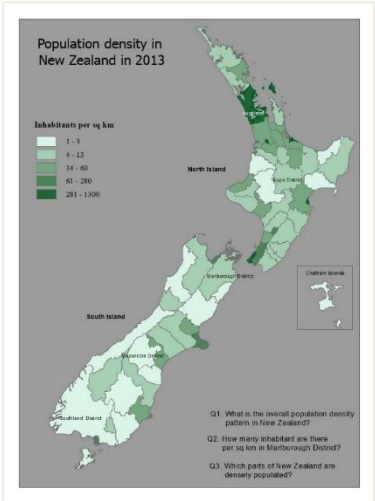


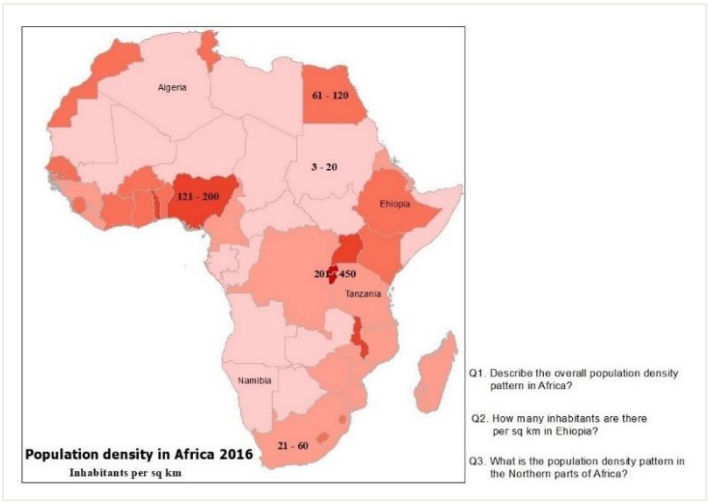


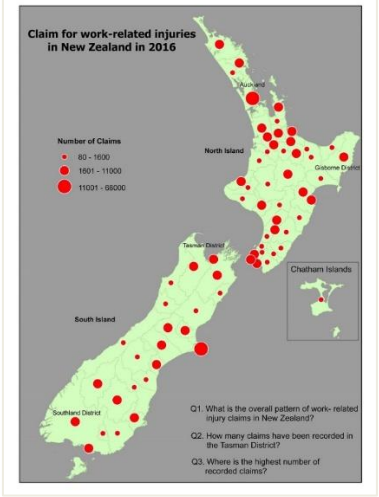


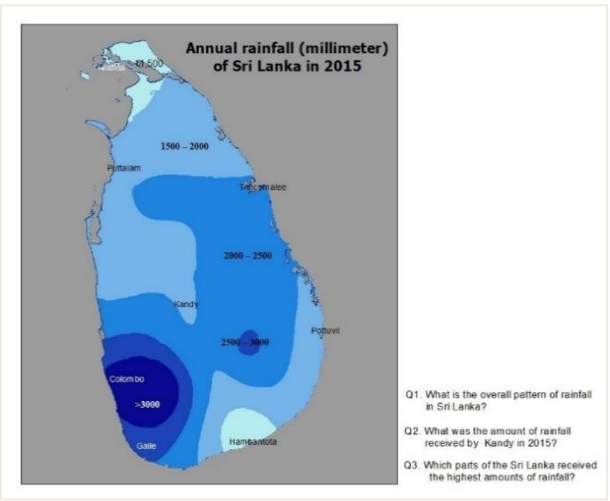
Appendix 2: Stimuli (Test 2)

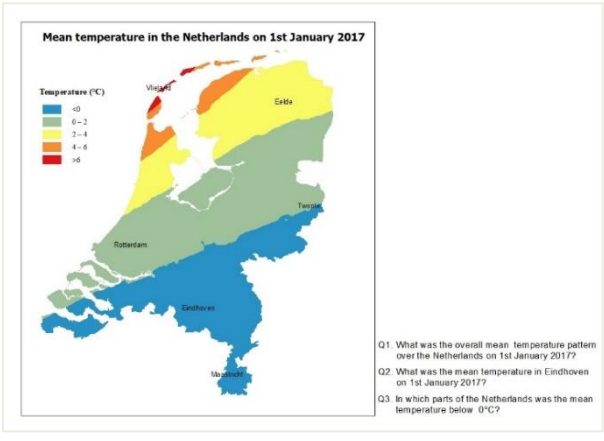




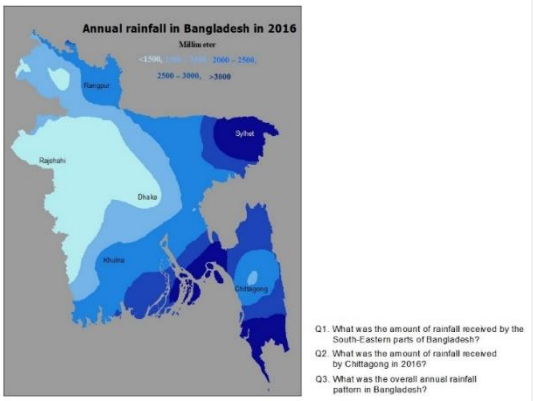


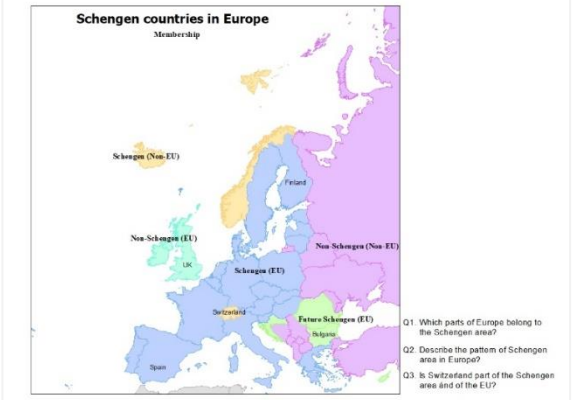


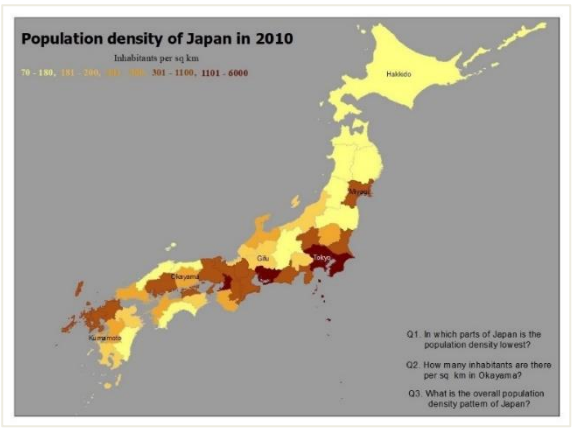


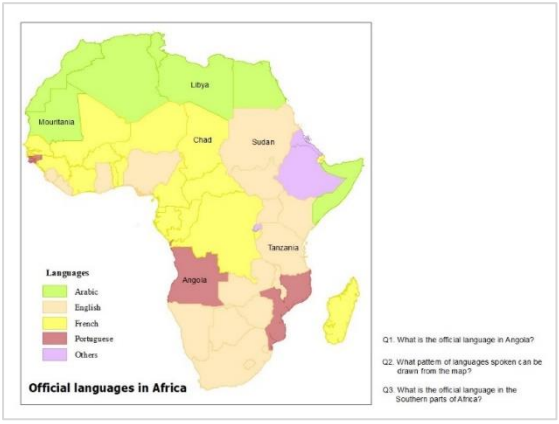


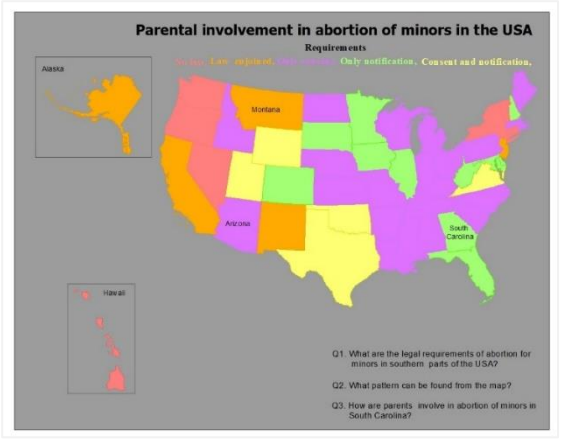
Appendix 2: Stimuli (Test 2)

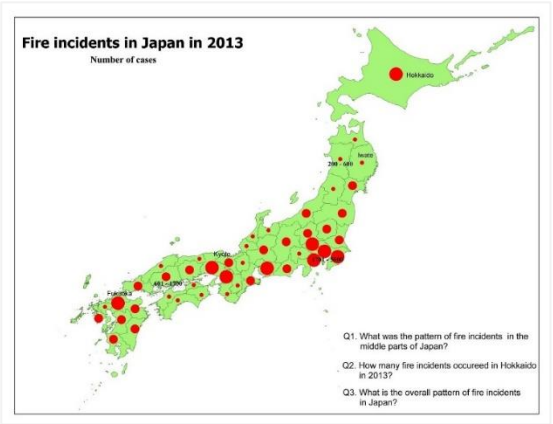


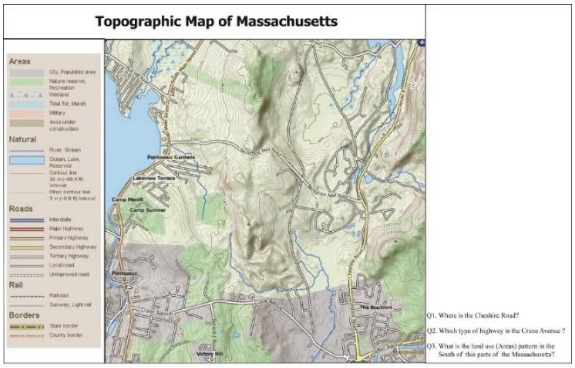




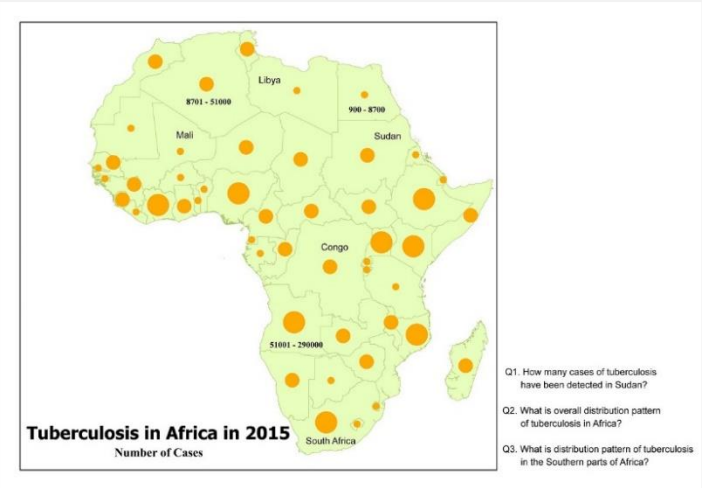


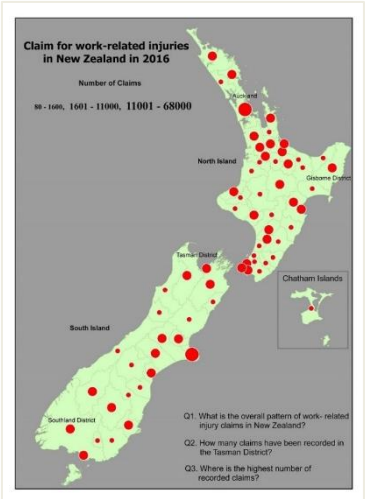


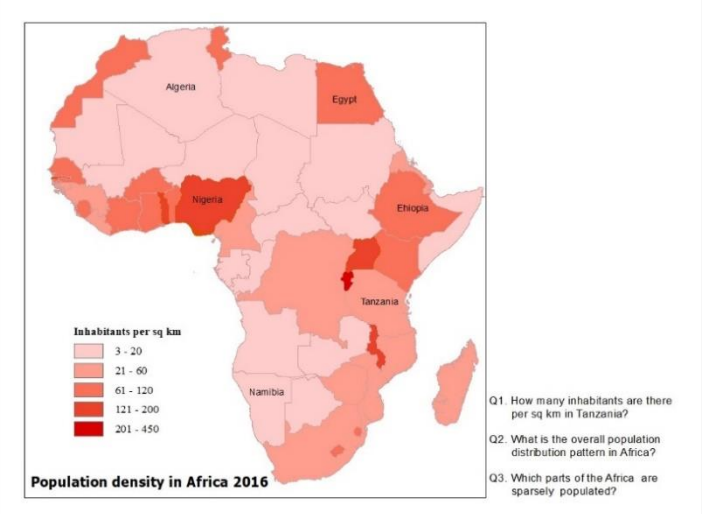


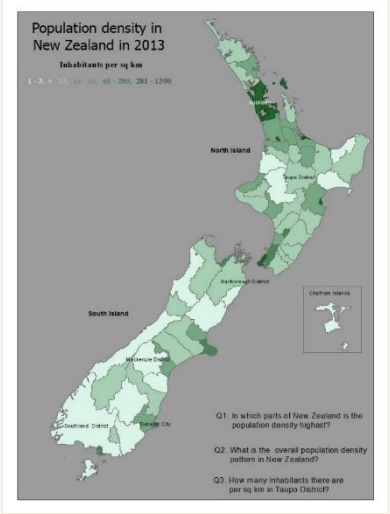


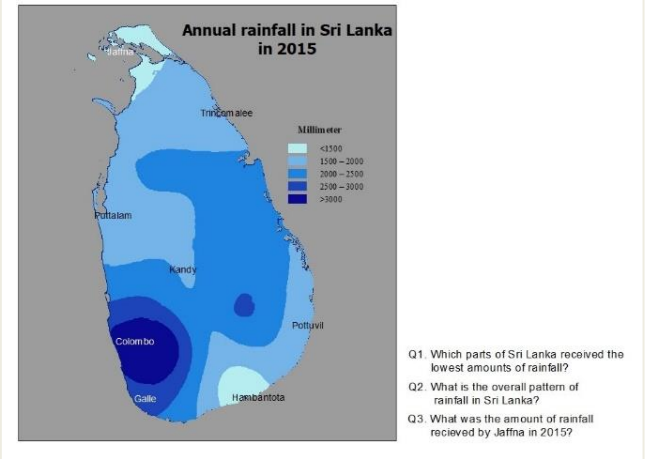
Appendix 3: Stimuli (Test 3)

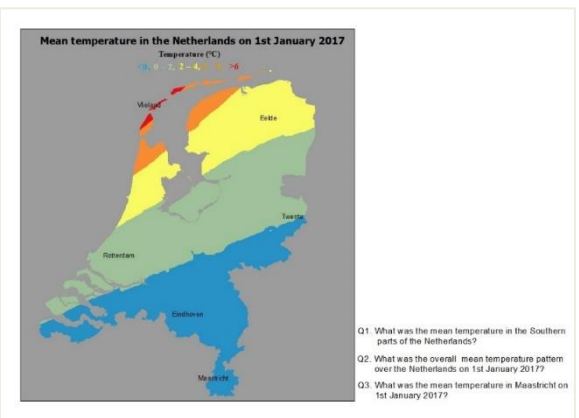




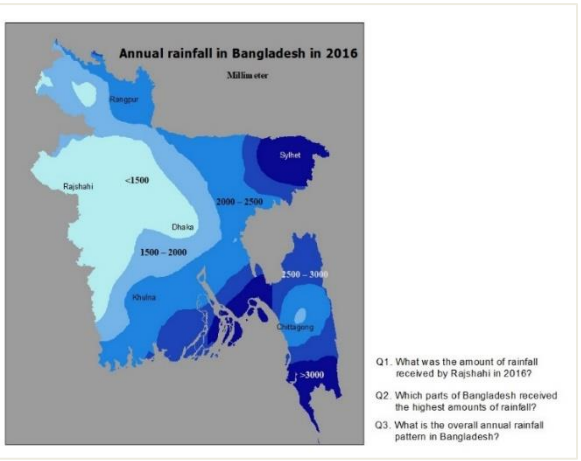


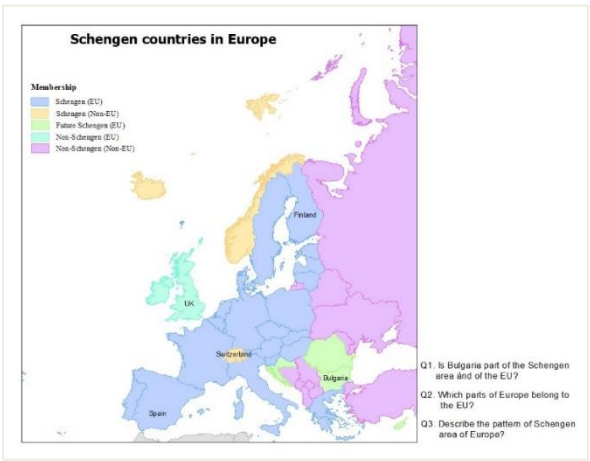


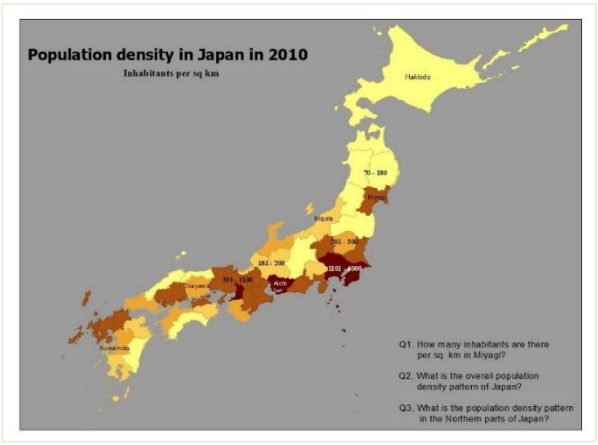


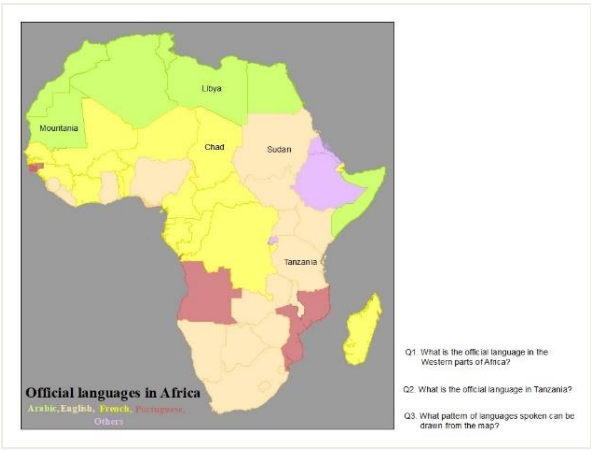


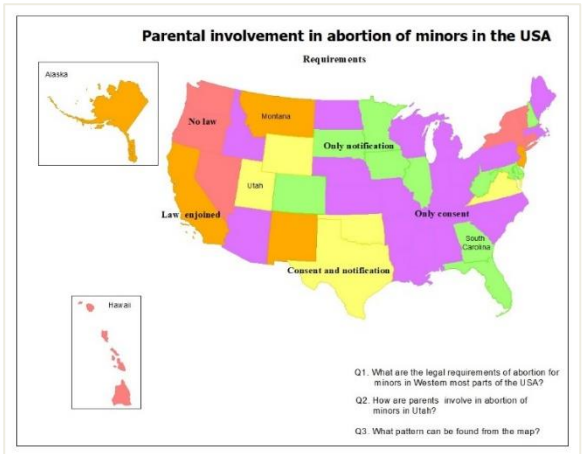
Appendix 3: Stimuli (Test 3)

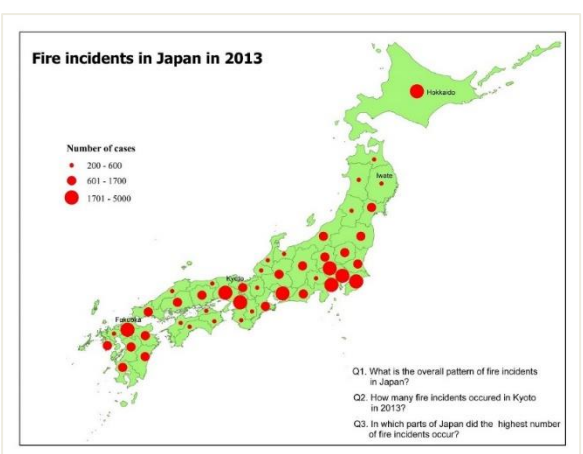


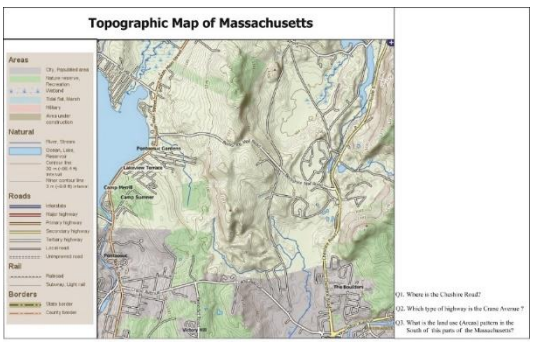












Appendix 4: Data source

Table appendix-1: Data used for designing stimuli

Stimuli title	Data sources
Topographic map of Massachusetts	OpenStreetMap Wiki (2017). *Toposm with legend.* Retrieved July, 14, 2017 from http://wiki.openstreetmap.org/wiki/File:Toposm_ with_legend.jpg
Schengen countries in Europe	Political Geography Now (2017). Retrieved July, 14, 2017 from http://www.polgeonow.com/2016/03/map-schengen-temporary-border-controls.html European Commission (2017). Retrieved July, 14, 2017 from https://ec.europa.eu/home-affairs/sites/homeaffairs/files/e-library/docs/schengen_brochure/schengen_brochure_dr3111126_en.pdf
Official languages in Africa	Nations Online Project: Your Guide to the World (2017). *Official and Spoken Languages of African Countries.* Retrieved July, 7, 2017 from http://www.nationsonline.org/oneworld/african_languages.htm
Parental involvement in abortion of minors in the USA	Guttmacher Institute (2017). *Parental Involvements in Minors' Abortion.* Retrieved July, 7, 2017 from https://www.guttmacher.org/state-policy/explore/parental-involvement-minors-abortions
Population density in Japan in 2010	Statistics Bureau of Japan (2017). *Japan Population Year book 2016: Population and Households, Table 2-3 Population by Prefecture*. Retrieved July, 7, 2017 from http://www.stat.go.jp/english/data/nenkan/65nenkan/1431-29.htm
Population density in Africa 2016	African Economic Outlook (2017). *Statistics: Table 1 – Basic Indicators, 2016*. Retrieved July, 7, 2017 from http://www.africaneconomicoutlook.org/en/statistics
Population density in New Zealand 2013	Local Councils NZ (2017). *Council Profile by Types.* Retrieved July, 7, 2017 from http://www.localcouncils.govt.nz/lgip.nsf/wpg_URL/Profiles-Councils-by-Type-Index
Annual rainfall in Bangladesh in 2016	Bangladesh Meteorological Department (BMD)
Annual rainfall in Sri Lanka in 2015	Department of Census and Statistics-Sri Lanka (2017). *Statistical Abstract 2016: Area and Climate.* Retrieved July, 7, 2017 from http://www.statistics.gov.lk/Abstract2016/index.asp?page=chap National Center for Environmental Information (NOAA) (2017). Retrieved July, 7, 2017 from ftp://ftp.ncdc.noaa.gov/pub/data/noaa/isd-history.txt
Mean temperature in the Netherlands on 1st January 2017	Royal Netherlands Meteorological Institute (2017). *Climatology: Daily weather data for the Netherlands – Download.* Retrieved July, 7, 2017 from http://www.sciamachy validation.org/climatology/daily_data/selection.cgi
Fire incidents in Japan in 2013	Statistics Bureau of Japan (2017). *Japan Population Year book 2016: Disasters and Accidents, Table 29-5 Cases and Damage of Fires by Prefecture.* Retrieved July, 7, 2017 from http://www.stat.go.jp/english/data/nenkan/65nenkan/1431-29.htm
Tuberculosis in Africa in 2015	African Economic Outlook (2017. *Statistics: Table 17 – Major Diseases.* Retrieved July, 7, 2017 from http://www.africaneconomicoutlook.org/en/statistics
Claim for work related injuries in New Zealand in 2015	Statistics New Zealand (2017). *2013 Census (Injury): Table 5: All claims for work-related injury by industry and territorial authority 2009 – 2016 (P).* Retrieved July, 7, 2017 from http://nzdotstat.stats.govt.nz/wbos/Index.aspx

Appendix 5: ESRI Shape files sources

Table appendix-2: Shapefile sources

Geographic boundary	Source
Africa	Map Library (2017). *Africa: Country outlines ESRI Shape file format (Africa_SHP.zip 1890.8 kb.* Retrieved July, 14, 2017 from http://www.maplibrary.org/library/stacks/Africa/index.htm
Bangladesh	Natural Earth (2017). *1:10m Cultural Vectors: Admin 0-Countries.* Retrieved July, 11, 2017 from http://www.naturalearthdata.com/downloads/10m-cultural-vectors/
European Union	Natural Earth (2017). *1:10m Cultural Vectors: Admin 0-Countries.* Retrieved July, 13, 2017 from http://www.naturalearthdata.com/downloads/10m-cultural-vectors/
Japan	Geospatial Information Authority of Japan (GSI) (2017). *Global map Japan version 2 vector data (Released in 2011): gm-jpn-bnd_u_2.zip (3.4 MB).* Retrieved July, 13, 2017 from http://www.gsi.go.jp/kankyochiri/gm_japan_e.html
New Zealand	Statistics New Zealand (2017). *Census based ESRI shapefiles: New Zealand 2013 (NZTM) (246MB).* Retrieved July, 27, 2017 from http://www.stats.govt.nz/browse_for_stats/Maps_and_geography/Geographic-areas/digital-boundary-files.aspx
Sri Lanka	Global Administrative Areas (2017). *Sri Lanka: ESRI file geodatabase.* Retrieved July, 13, 2017 from http://www.gadm.org/country
The Netherlands	University of Groningen Open Data (2017). *Dutch Provinces.* Retrieved July, 13, 2017 from http://opendata.rug.nl/datasets/834ad40886214e1b9f0cf1995029bb26_0
USA	United States Census Bureau (2016). *Cartographic boundary shapefiles-states 2016.* Retrieved July, 7, 2017 from https://www.census.gov/geo/maps-data/data/cbf/cbf_state.html

Appendix 6: Invitation letter for the test

Dear ITC Staff/Student,

I am a student in the Department of Geoinformation Processing of ITC-UT. Currently, I am doing my thesis under the supervision of Prof. Dr. M. J. Kraak. My thesis topic is "Legend-less maps". In my thesis one-part deals with the usability of "Legend-less maps" and I am working on this part under the supervision of Dr. Corné van Elzakker.

I have prepared some maps with and without a legend and I want to test the effectiveness of these maps. For this purpose, I am conducting a test using eye tracking methods.
The test will be like a "Geography Game". In it, I will present to you a number of maps and ask you to answer some questions with the help of these maps. During your task execution, we will record your eye movements in order to find out at which parts of the screen you are looking. All the data collected from the test will be used only for my research purpose and will be anonymized before reporting.

I would like to request you to participate in the test which will only last 30 minutes. The test will be held on 6th and 7th September 2017 in the "Usability Lab" (Room No. 1-066) of the ITC Building.

If you want to participate, and I really hope you do, please confirm your participation by visiting the following link and indicate when you are available for doing the test on Wednesday 6 or Thursday 7 September:

https://doodle.com/poll/244i27myzfzpw672

Early next week you will receive a confirmation of the date and time of your test.

Thanks in advance

Best regards,
Md. Marufur Rahman
MSc. Student (Cartography)
Department of Geoinformation Processing
ITC-University of Twente

Appendix 7: Instruction for test person

Instruction for test person

Thank you for giving your valuable time for the test. Our test is divided into three parts. Now you are reading the "Instruction" sheet. After reading the instruction sheet, we would like you to fill up a questionnaire, followed by our final test.

In this test, we will present to you a number of maps and ask you to answer three questions with the help of these maps. Both the maps and the questions to be answered will appear at the same time on the computer screen in front of you. After answering all three questions per map, please click on mouse button to display the next map and questions. Please continue doing this until the test will be finished. Please answer the questions with each verbally (speaking aloud) because the answer will be recorded.

During your task execution, we will record your eye movements in order to find out at which parts of the screen you are looking. At the same time, we ask you to THINK ALOUD during your task execution, so that we will also understand why you are looking at certain parts of the screen. Please say out loud everything that comes up in your mind.

All the data collected from the research will be used only for my research purpose and will be anonymized before reporting.

I now kindly ask you to start with completing the printed questionnaire. In doing so, I would like to ask you to already start thinking aloud, so that you can practice with that before you actually start with the test.

Appendix 8: Questionnaires

Questionnaires

We would like you to answer few questions related to your background and experiences. Your answers will help us to analyze our test result in a proper context.
Please complete the questionnaire by writing your answers in the space provided, or –in the case of multiple choice questions- by encircling the correct answer.
Please do THINK ALOUD when completing the questionnaire.

1. Your name: ……..
2. Gender
    a. Male
    b. Female

3. Your Age: ……..
4. Your country of origin: ……..
5. What is your current occupation?
    a. ITC/UT staff
    b. PhD candidate
    c. M Sc student
    d. Others
    (specify…….)

8. What is your current / previous field of study (e.g. geography, computer science, etc.)?
    ……
……..
7. Have you ever studied/attended Cartography classes?
    a. Yes
    b. No

8. How often you use maps in your daily life?
    a. Never
    b. Seldom
    c. Daily
    d. Several times in a week
    e. Several times in a month
    f. Several times in a year

9. Have you ever made maps yourself?
    a. Yes
    b. No

10. When you use or read a map for the first time, at which part will you normally look first?
    a. Title
    b. Legend
    c. Map body
    d. Random scan of the whole map

11. Do you think that every map should have a title? Explain your answer.

……
……..

12. Do you think that every map should have a legend? Explain your answer.

……
……..

Appendix 9: Test execution script for the test day

Test execution script for the test day

Before the test

1. Turning on the "eye tracker" and "sound recorder".
2. Turning on the computer.
3. Putting instruction sheet and questionnaires (hard copy) on the table.
4. Checking out whether the eye tracker and sound recorder are functioning properly.
5. Checking out whether the "test set up" on Tobii studio is working properly.

Welcoming test person

1. Test person will be welcomed and offered a seat.
2. Test person will be provided with the instructions sheet for reading.
3. Test taker asks test person to practice "THINK ALOUD" during fill up of questionnaires.
4. Test person will be asked whether s/he have any further questions.

During the test

1. The test will be started by pressing "START RECORDING".
2. Adjustment of the table and computer screen height and angle suitable for the test person.
3. Test person will be asked to follow the "RED DOT" with eyes during calibration of eyes.
4. Finally, the test will be started.

After the test

1. Expressing gratitude by thanking to test person.
2. Preparing for the next session of test with another test person and checking out whether sequence of tests (Test 1, Test 2, Test 3) are maintained properly according to test persons.

Appendix 10: Test results

Table appendix-3: Required time and TP wise effectiveness

Participant (TP)		Required time for the test (Minutes: Seconds)	Effectiveness (%)		
			Not Answered	Incorrect	Correct
	TP 1	19:54	2	7	91
	TP 4	21:40	5	0	95
	TP 7	20:35	0	0	100
	TP 10	20:22	0	0	100
	TP 13	36:42	2	0	98
Test 2	TP 2	18:47	0	7	93
	TP 5	21:40	0	0	100
	TP 8	12:02	7	8	85
	TP 11	19:05	2	2	96
	TP 15	21:24	0	5	95
Test 3	TP 3	20:55	0	0	100
	TP 6	22:48	2	11	87
	TP 9	22:39	0	0	100
	TP 12	27:54	2	20	78
	TP 16	16:24	0	2	98

Table appendix-4: Effectiveness and efficiency of TP 1

TP 1		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	9	C	4	C	11
	Intermediate	C	4	C	4	C	20
	Overall	C	43	C	42	C	24
Choropleth	Elementary	I	3	I	33	N	5
	Intermediate	C	14	C	22	C	20
	Overall	C	31	C	6	C	41
Isopleth	Elementary	C	20	C	6	C	9
	Intermediate	C	7	C	9	C	28
	Overall	C	12	C	27	C	18
Graduated Symbol	Elementary	C	10	I	18	C	10
	Intermediate	C	9	C	17	C	12
	Overall	C	25	C	14	C	33
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Appendix 10: Test result

Table appendix-5: Effectiveness and efficiency of TP 4

TP 4		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	7	C	3	C	6
	Intermediate	C	25	C	4	C	24
	Overall	C	42	C	35	C	26
Choropleth	Elementary	C	10	C	18	N	-
	Intermediate	C	15	C	25	C	16
	Overall	C	23	C	30	C	60
Isopleth	Elementary	C	8	C	7	C	5
	Intermediate	C	10	C	9	C	17
	Overall	C	13	C	31	C	24
Graduated Symbol	Elementary	C	11	C	67	N	13
	Intermediate	C	19	C	31	C	28
	Overall	C	37	C	43	C	51
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Table appendix-6: Effectiveness and efficiency of TP 7

TP 7		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	9	C	4	C	4
	Intermediate	C	52	C	15	C	10
	Overall	C	54	C	40	C	44
Choropleth	Elementary	C	8	C	28	C	6
	Intermediate	C	5	C	18	C	26
	Overall	C	38	C	23	C	27
Isopleth	Elementary	C	15	C	6	C	10
	Intermediate	C	7	C	10	C	13
	Overall	C	23	C	42	C	39
Graduated Symbol	Elementary	C	13	C	19	C	17
	Intermediate	C	17	C	12	C	17
	Overall	C	3	C	43	C	37
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Appendix 10: Test result

Table appendix-7: Effectiveness and efficiency of TP 10

TP 10		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	18	C	6	C	12
	Intermediate	C	30	C	7	C	50
	Overall	C	25	C	66	C	25
Choropleth	Elementary	C	12	C	19	C	13
	Intermediate	C	16	C	15	C	50
	Overall	C	21	C	26	C	31
Isopleth	Elementary	C	22	C	12	C	10
	Intermediate	C	13	C	10	C	21
	Overall	C	30	C	23	C	25
Graduated Symbol	Elementary	C	23	C	48	C	36
	Intermediate	C	21	C	12	C	20
	Overall	C	29	C	31	C	19
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Table appendix-8: Effectiveness and efficiency of TP 13

TP 13		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	46	C	5	C	40
	Intermediate	C	26	C	3	C	83
	Overall	C	56	C	29	C	70
Choropleth	Elementary	C	20	C	29	C	32
	Intermediate	C	26	C	41	C	57
	Overall	C	49	C	32	C	127
Isopleth	Elementary	C	22	C	9	C	12
	Intermediate	C	16	C	32	C	34
	Overall	C	73	N	-	C	57
Graduated Symbol	Elementary	C	26	C	40	C	50
	Intermediate	C	32	C	18	C	49
	Overall	C	46	C	45	C	39
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Appendix 10: Test result

Table appendix-9: Effectiveness and efficiency of TP 2

TP 2		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	10	I	7	C	11
	Intermediate	C	7	I	14	C	46
	Overall	C	27	C	23	C	33
Choropleth	Elementary	C	13	C	12	C	13
	Intermediate	C	28	C	12	C	9
	Overall	C	25	C	28	C	17
Isopleth	Elementary	C	9	C	20	C	24
	Intermediate	C	8	C	13	C	21
	Overall	C	34	C	39	C	18
Graduated Symbol	Elementary	C	19	C	22	I	28
	Intermediate	C	9	C	9	C	32
	Overall	C	25	C	11	C	20
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Table appendix-10: Effectiveness and efficiency of TP 5

TP 5		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	7	C	26	C	11
	Intermediate	C	13	C	22	C	31
	Overall	C	51	C	27	C	28
Choropleth	Elementary	C	12	C	9	C	17
	Intermediate	C	9	C	25	C	19
	Overall	C	10	C	53	C	29
Isopleth	Elementary	C	9	C	12	C	22
	Intermediate	C	9	C	3	C	34
	Overall	C	7	C	64	C	35
Graduated Symbol	Elementary	C	13	C	15	C	24
	Intermediate	C	33	C	26	C	35
	Overall	C	7	C	38	C	32
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Appendix 10: Test result

Table appendix-11: Effectiveness and efficiency of TP 8

TP 8		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	4	I	12	C	9
	Intermediate	C	3	C	9	C	19
	Overall	N	9	C	14	C	16
Choropleth	Elementary	C	8	C	8	C	6
	Intermediate	C	15	C	12	C	8
	Overall	C	21	N	13	I	12
Isopleth	Elementary	C	6	C	7	I	3
	Intermediate	C	6	C	9	C	20
	Overall	N	14	I	6	C	19
Graduated Symbol	Elementary	C	9	C	19	C	9
	Intermediate	C	4	C	20	C	19
	Overall	C	12	C	12	C	15
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Table appendix-12: Effectiveness and efficiency of TP 11

TP 11		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	4	C	18	C	7
	Intermediate	N	-	C	14	C	27
	Overall	C	39	C	10	C	78
Choropleth	Elementary	C	8	C	20	C	9
	Intermediate	C	17	C	19	C	12
	Overall	C	20	C	21	C	35
Isopleth	Elementary	C	5	C	14	I	11
	Intermediate	C	17	C	16	C	42
	Overall	C	26	C	15	C	25
Graduated Symbol	Elementary	C	15	C	12	C	9
	Intermediate	C	12	C	17	C	23
	Overall	C	55	C	27	C	22
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Appendix 10: Test result

Table appendix-13: Effectiveness and efficiency of TP 15

TP 15		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	11	C	13	I	17
	Intermediate	C	5	C	25	C	25
	Overall	C	50	C	24	C	53
Choropleth	Elementary	C	7	C	18	C	25
	Intermediate	C	12	C	19	C	27
	Overall	C	15	C	54	C	14
Isopleth	Elementary	C	9	C	11	C	16
	Intermediate	C	12	C	4	C	21
	Overall	C	18	C	30	C	10
Graduated Symbol	Elementary	I	40	C	36	C	13
	Intermediate	C	17	C	28	C	37
	Overall	C	32	C	19	C	18
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Table appendix-14: Effectiveness and efficiency of TP 3

TP 3		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	11	C	46	C	10
	Intermediate	C	19	C	42	C	24
	Overall	C	26	C	81	C	3
Choropleth	Elementary	C	13	C	16	C	17
	Intermediate	C	6	C	8	C	9
	Overall	C	26	C	22	C	13
Isopleth	Elementary	C	10	C	9	C	10
	Intermediate	C	12	C	7	C	9
	Overall	C	17	C	25	C	30
Graduated Symbol	Elementary	C	12	C	53	C	16
	Intermediate	C	8	C	21	C	6
	Overall	C	40	C	27	C	28
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Appendix 10: Test result

Table appendix-15: Effectiveness and efficiency of TP 6

TP 6		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	32	C	7	C	4
	Intermediate	C	30	N	20	C	14
	Overall	C	53	C	33	C	40
Choropleth	Elementary	C	9	C	30	I	23
	Intermediate	C	26	C	12	C	16
	Overall	C	20	C	20	C	12
Isopleth	Elementary	C	7	C	29	C	9
	Intermediate	C	6	C	22	C	6
	Overall	C	21	C	41	C	34
Graduated Symbol	Elementary	C	37	I	41	C	55
	Intermediate	I	28	I	6	C	12
	Overall	C	20	I	31	C	33
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Table appendix-16: Effectiveness and efficiency of TP 9

TP 9		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	29	C	11	C	3
	Intermediate	C	52	C	10	C	58
	Overall	C	37	C	43	C	32
Choropleth	Elementary	C	7	C	26	C	41
	Intermediate	C	35	C	3	C	13
	Overall	C	18	C	28	C	11
Isopleth	Elementary	C	10	C	8	C	11
	Intermediate	C	13	C	30	C	6
	Overall	C	23	C	32	C	27
Graduated Symbol	Elementary	C	7	C	73	C	31
	Intermediate	C	21	C	18	C	19
	Overall	C	55	C	35	C	58
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Appendix 10: Test result

Table appendix-17: Effectiveness and efficiency of TP 12

TP 12		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	I	70	I	17	C	4
	Intermediate	C	10	I	18	C	13
	Overall	C	36	I	31	C	31
Choropleth	Elementary	C	11	C	12	I	16
	Intermediate	C	32	C	10	C	31
	Overall	C	50	C	25	C	17
Isopleth	Elementary	C	9	C	10	C	15
	Intermediate	C	13	C	21	C	7
	Overall	C	21	N	-	I	33
Graduated Symbol	Elementary	I	48	C	19	C	27
	Intermediate	C	7	I	12	C	29
	Overall	I	56	C	26	C	24
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							

Table appendix-18: Effectiveness and efficiency of TP 16

TP 16		Map with Legend		Annotated map		Map with legend in Title	
Task level		Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)	Effectiveness	Efficiency (s)
Chorochromatic	Elementary	C	18	C	20	C	2
	Intermediate	C	22	C	25	C	12
	Overall	C	31	C	13	C	28
Choropleth	Elementary	C	6	C	30	C	8
	Intermediate	C	9	C	3	C	4
	Overall	C	21	C	23	C	6
Isopleth	Elementary	C	4	C	12	C	7
	Intermediate	C	11	C	8	C	6
	Overall	C	17	C	12	I	14
Graduated Symbol	Elementary	C	16	C	27	C	16
	Intermediate	C	16	C	17	C	10
	Overall	C	22	C	16	C	14
Effectiveness: C= Correct, I = Incorrect, N= Not answered; Efficiency in seconds (S)							