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User preferences for world map projections

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Many small-scale map projections exist, and they have different shapes and distortion characteristics. World map projections are mainly chosen based on their distortion properties and the personal preferences of cartographers. Very little is known about the map projection preferences of map-readers; only two studies have addressed this question so far. This article presents a user study among map-readers and trained cartographers that tests their preferences for world map projections. The paired comparison test of nine commonly used map projections reveals that the map-readers in our study prefer the Robinson and Plate Carrée projections, followed by the Winkel Tripel, Eckert IV, and Mollweide projections. The Mercator and Wagner VII projections come in sixth and seventh place, and the least preferred are two interrupted projections, the interrupted Mollweide and the interrupted Goode Homolosine. Separate binominal tests indicate that map-readers involved in our study seem to like projections with straight rather than curved parallels and meridians with elliptical rather than sinusoidal shapes. Our results indicate that map-readers prefer projections that represent poles as lines to projections that show poles as protruding edges, but there is no clear preference for pole lines in general. The trained cartographers involved in this study have similar preferences, but they prefer pole lines to represent the poles, and they select the Plate Carrée and Mercator projections less frequently than the other participants.

Keywords: world maps; map-reader preferences; cartographer preferences; map projection selection criteria; Strebe projection

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Introduction

Cartographers have developed hundreds of small-scale map projections for over 2000 years, resulting in graticules with very diverse appearances. The shape of the graticule is defined by different components. Meridians can be represented as straight lines or they can be represented with different curve types that are concave toward the central meridian. Parallels can be straight or concave toward the nearest pole. Poles can be represented as points or as lines, and these lines can be either straight or curved. The corners where the pole lines and the bounding meridians meet can have a rounded or an edged appearance. With all of these graticule characteristics, there is a diverse plethora of ways that the world is represented in maps. For example, cylindrical projections show the world as a rectangle, while pseudocylindrical projections make the graticule more rounded. Or, graticules with poles as points are more rounded than those with a pole line. When the graticule is "cut" along specific meridians creating one or more lobes, the graticule is represented as an interrupted projection. Hence, the shape of the graticule is an important component of aesthetic criterion when selecting the projection for a world map.

John P. Snyder (1987) presented a systematic projection selection guide in which world map projections are chosen by their projection property (conformal, equivalent, equidistant, straight rhumb lines, or compromise distortion). Variations on Snyder's selection guide are included in various textbooks. Snyder is not specific in his recommendations for world maps, and he leaves cartographers considerable freedom to select projections for global maps. When selecting an appropriate projection, cartographers take a variety of criteria into account to adapt the projection to the purpose of the map. For example, the cartographer should select an equal-area projection for choropleth maps. However, there are multiple equal-area projections appropriate for world maps, and the cartographer then has to apply additional selection criteria. Among the many criteria, personal preference can be a major selection criterion. For example, a cartographer might prefer a rectangular projection; however, many agree that rectangular projections are not appropriate for small-scale maps mainly because they greatly distort the shape of Earth's features (Canters 2002, 263; American Cartographic Association et al. 1989). This article introduces additional selection criteria for world map projections based on a user study testing the projection preferences of map-readers. The goal of this study is to provide cartographers with additional criteria on which to base the selection of world map projections.

Previous user studies of map-reader projection preferences

Very little is known about the map projection preferences of map-readers. So far, two user studies have addressed

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map-reader preferences for world map projections. In 1983, Patricia P. Gilmartin published a user study testing what type of graticule map-readers prefer. She explored the preferred height-to-width ratio of the map and the most pleasing graticule shape. Her study was based on 50 students at the University of Victoria (BC, Canada), who were enrolled in an introductory geography class. Results showed a very strong preference for an elliptical map over a rectangular map, and in both cases projections with a distinctively longer width than height were preferred. Gilmartin (1983) also analyzed differences in preference according to participant demographics. The results were not significantly different based on the gender or major of the college student participants (Gilmartin 1983).

Robert J. Werner (1993) conducted another user study with 60 participants exploring map-readers' preferences for nine equator-centered world map projections. The following projections are listed from most favorable to least favorable by the map-readers that participated in this study: Voxland Hyperelliptic, Robinson, Winkel Tripel, Eckert IV, interrupted Mollweide, interrupted Goode Homolosine, Miller cylindrical, Mercator, and Peters. Werner's results showed that the most preferred projections are uninterrupted pseudocylindrical. They were followed by interrupted projections, and the least-favored projections were those with a rectangular shape. In this study, as well as in that of Gilmartin, there was no significant difference according to the age and education level of the participants. A significant difference in preference was found among geographers, who preferred the Robinson projection, while experienced cartographers ranked the Robinson and the Voxland Hyperelliptic map projections as their favorite. On average, cartographers also placed the Mercator as the second to least favorable (Werner 1993).

Gilmartin (1983) and Werner's (1993) studies were conducted using small groups of people, most from an academic setting. It seems doubtful that these results are truly representative of populations of map-readers. This leads us to the following question: Which world map projection do map-readers prefer?

Objectives and structure of the article

The main objective of this research and the user study presented in this article is to find the preferred world map projection among map-readers and to define what graticule characteristics map-readers prefer. These map-reader preferences may then provide additional criteria to Snyder's selection guidelines.

The same user study was also conducted among professional and academic cartographers, map projection experts, and GIS experts. The purpose of this second group of participants was to see whether there were any differences in preference between general map-readers and professionals. The user study also tested participant characteristics and their use of web maps (e.g., Google Maps) and virtual globe maps (e.g., Google Earth) to see whether these factors have any influence on their preferences.

The article first documents the research questions and hypotheses of the user study. In the methods section, the user study design, user study survey process, recruiting, and statistical methods are explained. The results and discussion section then describe the study results. In the conclusion, map-reader preferences are listed, user study results are summed up, and directions for future studies are pointed out. This article has two appendices. Appendix 1 details the design of two new projections created for the purpose of this user study (the Wagner VII and the Miller projections with rounded corners of pole lines), and Appendix 2 details user study participants' characteristics for the two participant groups.

Research questions and hypotheses

Map-reader preferences

In order to derive map-reader preferences, a user study was conducted to answer the following question: *Which of nine commonly used small-scale map projections do map-readers prefer?* This question tries to determine which graticule is the most pleasing for map-readers overall. Since both previous user studies (Werner 1993; Gilmartin 1983) show a map-reader preference for rounded over rectangular shapes, it is expected that this study will confirm their results.

This study addresses four more specific questions.

(1) Do map-readers prefer elliptical or sinusoidal shapes for meridian lines?

Sinusoidally shaped meridians follow a part of a sine curve. The best-known example graticule is probably the sinusoidal projection. Meridians with an elliptical shape are based on the formula for a semiellipse (e.g., the Eckert IV projection). The curves of both meridians result in very distinctive graticule shapes. Sinusoidal meridians result in a more pronounced horizontal extension of map features in the vicinity of the equator than elliptical meridians. The first question attempts to test preferences for sinusoidal and elliptical curves since this question has not been tested in previous studies.

(2) Do map-readers prefer curved or straight parallels?

A slight bending of the parallels toward the poles reduces distortion in peripheral parts of the map, especially when the projection is equal-area. For this reason, cartographers select projections with bent parallels. Therefore, the

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second question tests map-readers' preferences for curved parallels.

(3) Do map-readers prefer pole points or pole lines?

Based on the good performance of the Voxland Hyperelliptic, Werner (1993, 35) concluded that "map-readers prefer to see the poles represented as points, not lines." The third specific question addresses this hypothesis.

(4) Do map-readers prefer edged or rounded corners of pole lines?

While designing the Natural Earth projection, Tom Patterson, the author of this projection, preferred rounded corners for aesthetic reasons – "curves convey classic elegance" (Jenny, Patterson, and Hurni 2008, 21; Šavrič et al. 2011). The fourth question addresses Patterson's assumption and tests whether map-readers find rounded corners more pleasing than edged corners.

Participants' characteristics

This user study also addresses the question: *Do map-reader preferences change with different map-reader characteristics and with the use of web maps and virtual globe maps*? The two previous studies by Gilmartin (1983) and Werner (1993) did not find that gender, age, or highest education level had any influence on map-reader preferences. The only characteristics that have been shown to have an effect are cartographic background and experiences, as exemplified in Werner's (1993) study.

In the past, there was a concern that continued exposure to the Mercator projection distorts the general audience's cognitive map of the world (Robinson 1990; Saarinen, Parton, and Billberg 1996; Chiodo 1997; Jenny 2012). The Mercator projection, or to be more precise, the web Mercator projection, is in general used mainly for web mapping and other web map services (Battersby et al. 2014). Yet Battersby (2009) and Battersby and Montello (2009) could not confirm the existence of the so-called "Mercator effect." Battersby (2009) wondered "what long-term impact the popularity of these online mapping tools could have on map-reader notions of space" (Battersby 2009, 43). We test whether the use of web maps or virtual globe maps has any influence on map-reader preferences.

Methods

User study design

Comparing multiple small-scale projections at once is a difficult task for study participants and even for trained cartographers. The task is even more difficult if there are only small differences between graticules and one must focus on minute details to notice differences between small-scale maps. Therefore, this user study is designed in a way so that participants compare projections only in pairs. Two approaches were used in this user study: (1) a paired comparison test and (2) binominal tests with repeated measures.

Paired comparison test

To test user preferences for nine commonly used small-scale map projections, a paired comparison test was used. The paired comparison test compares each element (map projection) with every other element (map projection) in the set. For the purpose of this study, a set of nine small-scale map projections was prepared, which included the Mollweide, Robinson, Eckert IV, Winkel Tripel, Wagner VII, interrupted Mollweide, interrupted Goode Homolosine, Plate Carrée, and Mercator projections (see Figure 1). A complete paired comparison experiment was designed with 36 pairs in total.

The nine projections in the set are commonly used in atlases. Fritz C. Kessler and Daniel R. Strebe (personal communication with F. C. Kessler, Frostburg State University, October 2014) counted the number of projections in 11 English-language atlases and one Russian atlas published between 2000 and 2011. Eight of the nine projections used for our study are among the 11 most commonly used world map projections identified by Kessler and Strebe (the only exception being the Eckert IV projection). Werner's (1993) user study included the Voxland Hyperelliptic, the Miller cylindrical, and the Gall-Peters projections. These projections are not included in our study because they have been comparatively rarely used in atlases in recent years (personal communication with F. C. Kessler, Frostburg State University, October 2014; Monmonier 2004, 128). Instead, we added the more commonly used Eckert IV, Mollweide, Wagner VII, and Plate Carrée projections. The popularity of the Eckert IV projection is confirmed by Monmonier (2004, 128), who found that – besides the Robinson projection – it is the most commonly used projection in 12 world atlases published between 1997 and 2002. Additionally, Kessler and Strebe found the Wagner VII and the Mollweide among the most often used projections. The Plate Carrée projection is added to the set of study projections because it is commonly used for exchanging and visualizing geospatial data.

Binominal tests with repeated measures

Binominal tests were designed to directly measure map-reader preference for the shapes of meridians and parallels, the representation of poles, and the representation of pole line corners. Each user study participant compared two or

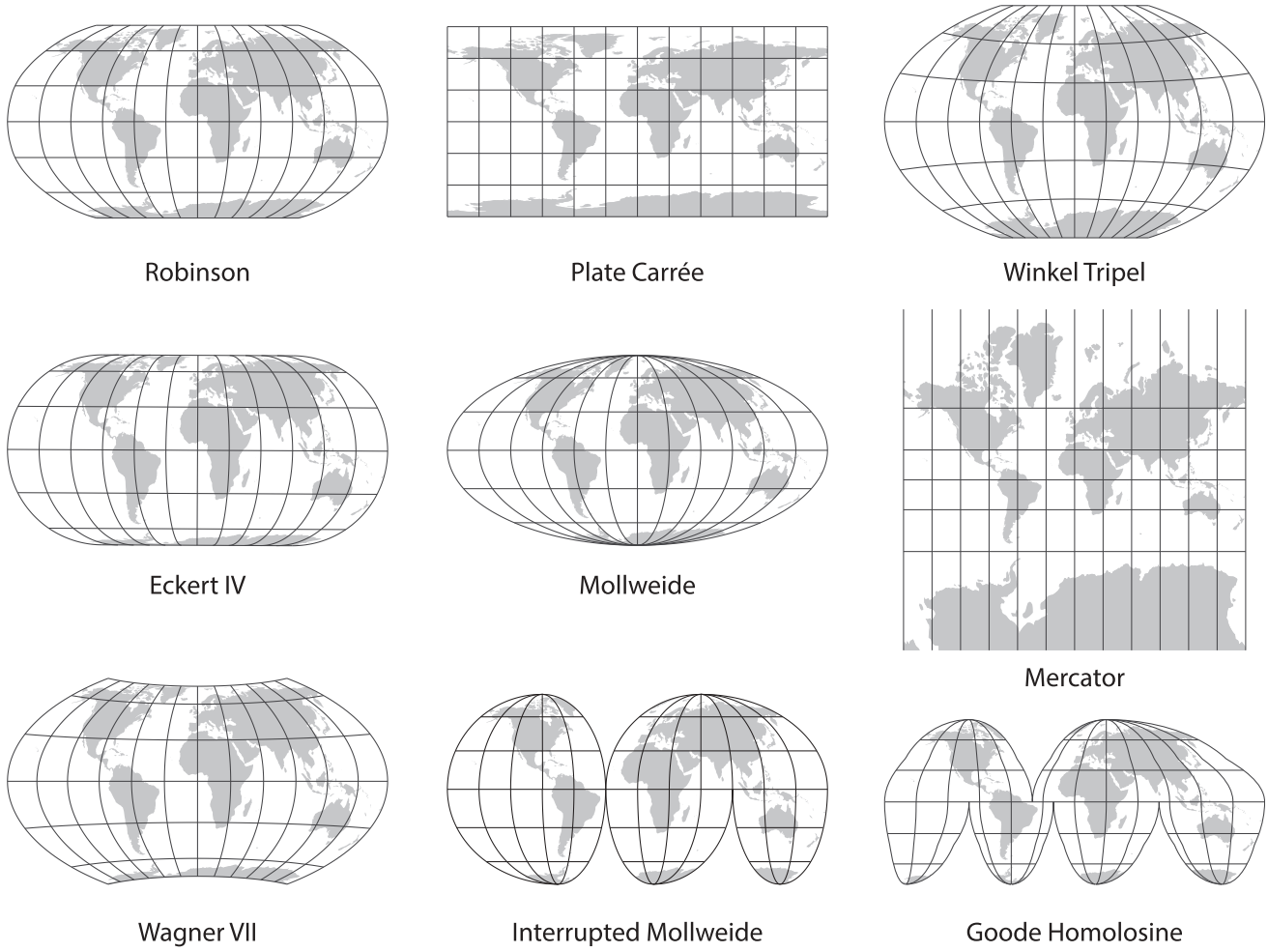

Figure 1. The nine small-scale map projections used in the paired comparison test, arranged by descending map-reader preference from top-left to bottom-right.

more pairs of graticules, all with very similar, if not identical, characteristics – except for one varied, tested characteristic. For each tested characteristic, 2–5 such pairs were prepared for each participant.

To test whether map-readers prefer elliptical over sinusoidal shapes for meridian lines, participants were asked to compare two pairs (Figure 2, top-left pairs): the Mollweide vs. the Boggs Eumorphic (both graticules are equal-area, have straight parallels, and poles represented as points) and the Wagner IV vs. the McBryde-Thomas Flat-Polar Sinusoidal (both graticules are equal-area, have straight parallels, and pole lines).

There were three pairs used in order to test whether map-readers prefer straight or curved parallels (Figure 2, top-right pairs): the Mollweide vs. the Hammer (both are equal-area, represent poles as points, and graticules have elliptical shape), the Robinson vs. the Wagner VII (both have pole lines with edged corners), and the Natural Earth vs. the Wagner VII with rounded corners (both have pole lines with rounded corners).

To test whether map-readers prefer pole points vs. pole lines, the following four pairs were used (Figure 2, bottom-right pairs): the Mollweide vs. the Wagner IV (both graticules are equal-area, have straight parallels, and elliptical shape of meridians), the Boggs Eumorphic vs. the Eckert VI (both are equal-area, have straight parallels, and moderate sinusoidal shape of meridians), the Sinusoidal vs. the McBryde-Thomas Flat-Polar Sinusoidal (both are equal-area, have straight parallels, and sinusoidal shape of meridians), and the Hammer vs. the Wagner VII (both are equal-area and have curved parallels).

There were five pairs used in order to test whether map-readers prefer edged or rounded corners of pole lines (Figure 2, bottom-left pairs): the Robinson vs. the Natural Earth (both are compromise projections with straight parallels), the Wagner IV vs. the Eckert IV (both are equal-area projections with straight parallels), the Wagner VII vs. the Wagner VII with rounded corners (both are equal-area projections with curved parallels), the Winkel Tripel vs. the A4 (both are compromise

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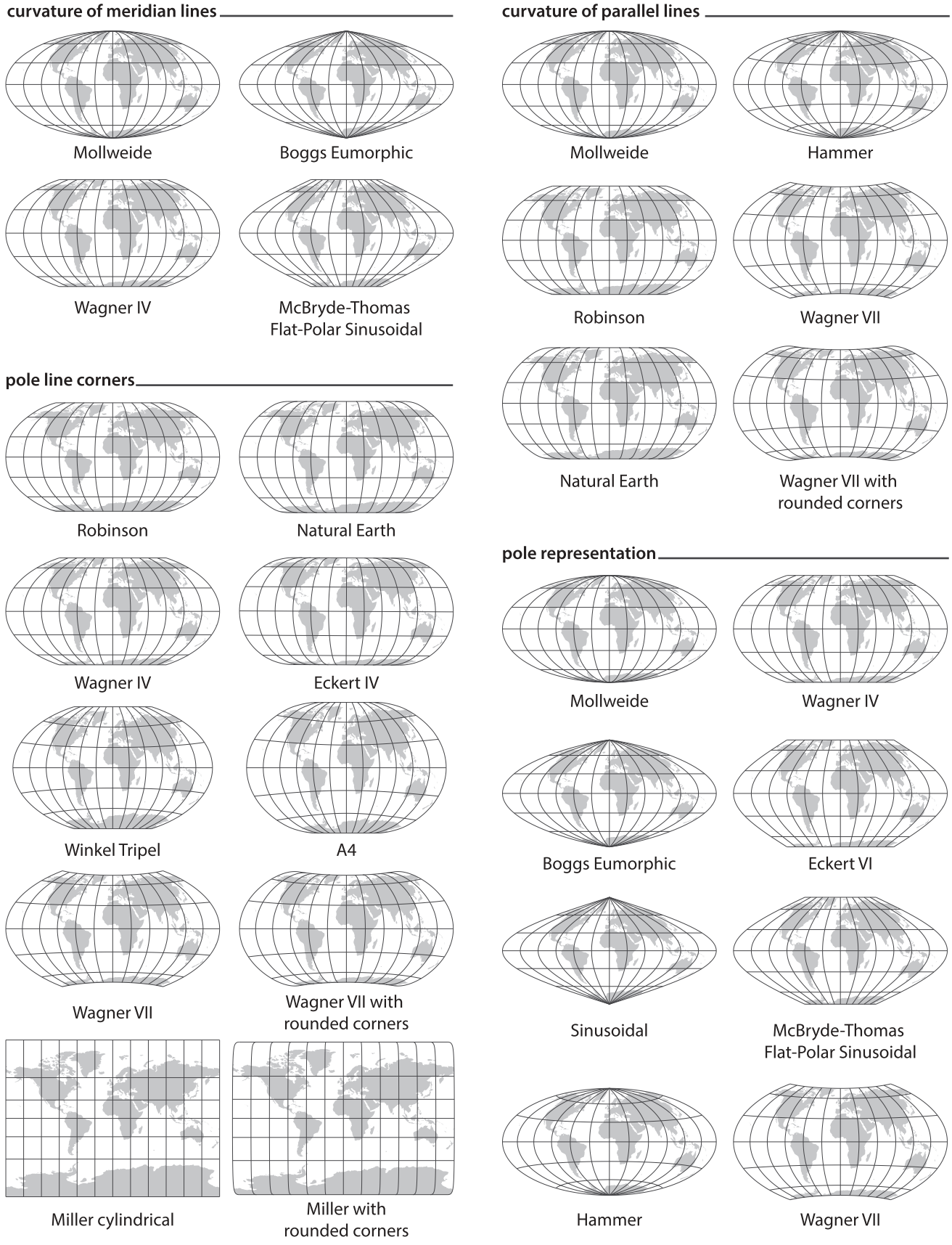

Figure 2. Fourteen map projection pairs used in binominal tests with repeated measures.

projections with curved parallels and straight pole lines; for A4, see Jenny, Patterson, and Hurni 2008), and the Miller cylindrical vs. the Miller with rounded corners (both are compromise projections with a cylindrical appearance).

The Wagner VII with rounded corners and the Miller with rounded corners were designed for the purposes of this study. For the details of their design, see Appendix 1. Similar to the paired comparison test, each figure for the binominal tests had a similar world visualization, and it was scaled so that the map area was visually constant between two graticules for each pair. In total, 14 pairs were used in all four binominal tests with repeated measures.

User study survey process

The user study was designed and conducted via a web-based survey system. Participants evaluated map projection pairs by selecting one of the two presented maps that they personally preferred. They evaluated only one pair at a time and they could not return to previous questions to check or change their answers. Ten pairs of map projections were repeated over the whole user study to measure how consistent participants were in their answers. The order of the graticule pairs and the order of the choices per each pair were randomized. The only exceptions were the repeated pairs; these questions appeared at random order in the survey flow, but the left-right order of the repeated maps was inverted. In the final stage of the study, participants were asked what type of maps they use most often, how frequently they use web maps and virtual globe maps, and demographic questions regarding their gender, age, education level, country of residency, background in cartography, and cartographic experience. Response categories are detailed in Tables A1 and A2.

In some cases, the survey system displayed maps with a short delay due to slow network latency or CPU (central processing unit) in the computer. If this occurred, the participant saw the name of the map projections for a short fraction of time. While this shortcoming probably did not affect the answers of general map-reader participants, it may have allowed some of the cartographers, map projection experts, and GIS experts to base their decisions on the names of the projections.

Recruiting methods

Recruitment for this user study was done via Amazon Mechanical Turk, the CartoTalk forum (CartoTalk.com 2014), email, and social media sites (e.g., Facebook and Twitter). Amazon Mechanical Turk (Amazon.com 2014) is a web-based crowdsource service where study participants (Turkers) complete one or more small tasks (HITs) in exchange for a small reward (micro-payment). Several studies (e.g., Heer and Bostock 2010; Kosara and Ziemkiewicz 2010; Mason and Watts 2010) found that crowdsourcing is viable for testing graphic perception, provides high-quality responses, is time effective, and reduces user study costs. While many user studies are carried out in a university setting, Mechanical Turk enables a much wider demographic, which is more representative of the general population than that of people in an academic setting (Heer and Bostock 2010). Mechanical Turk also offers the ability to filter out Turkers that have taken part in earlier studies or to constrain the study only to Turkers with a high success rate for completing tasks. For this research, there were three constraints for Turkers to participate in the user study: (1) they had to be over 18 years old, (2) their HIT approval rate had to be equal to or greater than 98%, and (3) Turkers' number of HITs approved had to be equal to or greater than 1000. Each Turker was compensated between $0.5 and $1, and they were allowed to participate only once. Compensation was based on the number of consistent answers on the repeated questions.

The survey link was distributed to cartographers, map projection experts, and GIS experts via email. The link was also posted on the CartoTalk forum and distributed via social media. These user study participants were not compensated, but their consistency was also tested.

Statistical methods

Since the user study has two groups of participants, map-readers and professionals, all statistical tests are performed for each group separately. Two different kinds of statistical methods are used to test differences in participants' responses. For the paired comparison experiment, two nonparametric tests of significance, proposed by H. A. David (1988), were used. The overall test of equality (David 1988) was used to determine whether any of the map projections has a significantly different score compared to all the other projections. The multiple comparison range test (David 1988) was the test used in post hoc analysis to determine which graticules were significantly different in preferences from each other.

For binomial data (e.g., pole point vs. pole line), three different tests suggested by McCrum-Gardner (2008) and Motulsky (2014) were used. To test the significance of each compared pair to the hypothetical values, a χ^2 test was used. McNemar's (1969) and Cochran's Q (1950) tests were used to analyze whether there was any difference between the pairs. Both tests are nonparametric tests and used for repeated measures; McNemar's test was used to compare two pairs (McNemar 1969), and Cochran's Q test was used to compare three or more pairs (Cochran 1950). All post hoc analyses of Cochran's Q tests were performed using McNemar's tests to compare all possible combinations of two pairs.

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The χ^2 test for the $2 \times C$ table (C represents number of categories) is used to compare binominal data between two or more independent groups of participants. This test was performed on all 50 map projection pairs separately for each group of participants. The purpose of this test was to determine whether map-readers' demographic information and their use of maps had any effect on their preferences. The significance level was 0.01 for all statistical tests in this user study.

User study results and discussion

In total, 496 people participated in the user study. Via Mechanical Turk, 303 responses were collected. The consistency of participants' responses was relatively high: 448 responses had six or more matching answers on repeated questions. These responses are included in the statistical analysis presented in this section. The remaining 48 less-consistent responses were discarded. All responses are split into two groups: (1) *general map-readers*, 355 participants consisting of map-readers recruited via social media and Mechanical Turk; and (2) *professionals*, 93 participants, consisting of professional and academic cartographers, map projection experts, and GIS experts. Demographic and participants' characteristics for both groups are detailed in Appendix 2.

Preferences for nine world map projections

Preferences of general map-readers

General map-readers most often selected the Robinson and Plate Carrée projections over the other projections. These projections were followed by the Winkel Tripel, Eckert IV, and Mollweide projections. The Mercator and Wagner VII projections were in sixth and seventh place, and the least preferred were the interrupted projections: the interrupted Mollweide and the interrupted Goode Homolosine. Table 1 summarizes preferences for each of the compared pairs. Figure 1 displays all nine projections arranged according to these preferences. An overall test of equality ($\chi^2_{8,0.01} = 20.09$, $D_n = 3395.58$) showed that differences in map-reader preferences for projections did exist, and a post hoc analysis with the multicomparison range test is displayed in Figure 3 (left). In this figure, projections are arranged according to preference, and any projection that is not circled by the same line is significantly different based on these preferences.

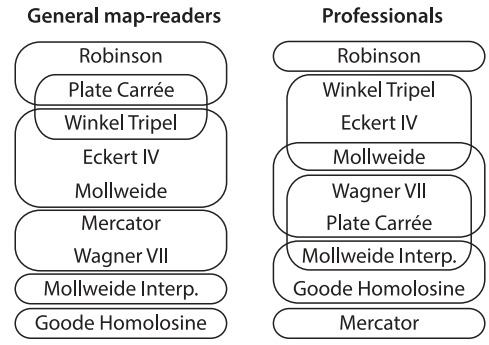

Figure 3. Significant differences in the preferences between the projections in paired comparison test for each participants group. The projections are arranged with most preferred at the top. Any projection that is not circled by the same line is significantly different in preferences.

While the high rating of the Robinson projection is not surprising, the close second rating of the Plate Carrée projection is. Both projections were preferred over the other seven projections presented in the test. Projections with straight pole lines (the Robinson, the Plate Carrée, the Winkel Tripel, and the Eckert IV) were preferred over the ellipse-shaped Mollweide projection, which represents the poles as points. The results showed a strong indication that general map-readers disliked any interrupted projections; both interrupted projections were in last place and their scores were significantly different from all of the other projections. The Mercator and Wagner VII projections were similarly less preferred, but map-readers liked them more than the interrupted projections.

Table 1. Preferences for the nine most commonly used world map projections by general map-readers.

	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	6 (%)	7 (%)	8 (%)	9 (%)
1. Robinson		50	56	68	59	67	85	93	93
2. Plate Carrée	50		54	58	56	83	67	84	86
3. Winkel Tripel	44	46		54	56	66	79	87	90
4. Eckert IV	32	42	46		50	65	77	90	90
5. Mollweide	41	44	44	50		63	70	86	89
6. Mercator	33	17	34	35	37		48	72	75
7. Wagner VII	15	33	21	23	30	52		83	87
8. Mollweide Int.	7	16	13	10	14	28	17		79
9. Goode Homolosine	7	14	10	10	11	25	13	21	

Note: The names of the projections are arranged in both rows and columns according to the total scores. Each row shows the percentages of participants that have a preference for the projection in the row over other projections listed in the column.

Since the Plate Carrée projection performed well, one cannot assume that map-readers prefer rounded over rectangular map projections. In contrast to Werner's (1993) user study, both rounded and rectangular graticules were preferred over any interrupted map projections.

Preferences of professionals

Professionals strongly preferred the Robinson projection, followed by the Winkel Tripel, Eckert IV, Mollweide, Wagner VII, and Plate Carrée projections. They placed both interrupted projections before the Mercator projection, which ended up in last place. Table 2 summarizes preferences for each compared pair. The overall test of equality ($\chi^2_{8,0.01} = 20.09$, $D_n = 665.51$) showed that differences in preferences for projections existed, and Figure 3 (right) shows the post hoc analysis.

Compared to general map-readers, professionals more strongly preferred the Robinson projection. The biggest difference in their preferences was for the Plate Carrée and Mercator projections. They selected them less often than general map-readers. Professionals preferred rounded projections to the Wagner VII, rectangular, and interrupted projections. These results aligned with the findings of Werner's (1993) user study.

Curvature of meridian lines

In comparing elliptical vs. sinusoidal shapes for meridian lines, binomial tests showed a strong indication that general map-readers preferred elliptical shapes for meridians (the Mollweide vs. Sinusoidal pair, $\chi^2 = 279.5$, $p < 0.01$; the Wagner IV vs. McBryde-Thomas Flat-Polar Sinusoidal pair, $\chi^2 = 262.0$, $p < 0.01$). McNemar's test did not find any differences between both pairs ($Q = 1.087$, $p \approx 0.297$), which showed that both projection pairs yielded the same results.

The results of the professionals were not different from those of the general map-readers. In both projection pairs, they also preferred graticules with elliptical shapes (the Mollweide vs. Sinusoidal pair, $\chi^2 = 74.1$, $p < 0.01$; the Wagner IV vs. McBryde-Thomas Flat-Polar Sinusoidal pair, $\chi^2 = 67.1$, $p < 0.01$). McNemar's test also did not find any differences between the two pairs ($Q = 0.67$, $p \approx 0.414$).

Curvature of parallel lines

General map-readers, as well as professionals, preferred straight over curved parallels. All three projection pairs revealed strong preferences: the Mollweide vs. Hammer pair: $\chi^2 = 82.4$, $p < 0.01$ for map-readers and $\chi^2 = 21.8$, $p < 0.01$ for professionals; the Robinson vs. Wagner VII pair: $\chi^2 = 169.1$, $p < 0.01$ for map-readers and $\chi^2 = 28.0$, $p < 0.01$ for professionals; and the Natural Earth vs. Wagner VII with rounded corners pair: $\chi^2 = 116.1$, $p < 0.01$ for map-readers and $\chi^2 = 30.2$, $p < 0.01$ for professionals.

Cochran's Q test did not show any differences in results between the projection pairs for professionals ($Q = 0.765$, $p \approx 0.682$), but it did show differences for general map-readers ($Q = 14.7$, $p < 0.01$). Post hoc analysis with McNemar's test showed that general map-readers more strongly preferred straight parallels in the case of the Robinson vs. Wagner VII pair.

Pole representation

In the case of the Sinusoidal vs. McBryde-Thomas Flat-Polar Sinusoidal pair ($\chi^2 = 197.8$, $p < 0.01$) and the Boggs Eumorphic vs. the Eckert VI pair ($\chi^2 = 111.6$, $p < 0.01$), general map-readers preferred pole lines for representing the poles. While the χ^2 test of the Mollweide vs. Wagner IV pair was not significant ($\chi^2 = 5.2$, $p \approx 0.023$), the Hammer vs. Wagner VII pair values illustrated the opposite preference for pole points ($\chi^2 = 10.5$, $p < 0.01$). Cochran's Q test ($Q = 11.3$, $p < 0.01$) showed differences between the results, and post hoc analysis with McNemar's test revealed that each projection pair gave different results.

Table 2. Preferences of the nine most commonly used world map projections by professionals.

	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	6 (%)	7 (%)	8 (%)	9 (%)
1. Robinson		68	77	71	77	74	84	78	95
2. Winkel Tripel	32		49	57	72	65	70	76	90
3. Eckert IV	23	51		55	62	66	68	76	84
4. Mollweide	29	43	45		54	61	70	70	81
5. Wagner VII	23	28	38	46		53	67	67	81
6. Plate Carrée	26	35	34	39	47		56	57	89
7. Mollweide Int.	16	30	32	30	33	44		69	71
8. Goode Homolosine	22	24	24	30	33	43	31		68
9. Mercator	5	10	16	19	19	11	29	32	

Note: The table has the same ordering and units of measure as Table 1.

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Our study could not determine a clear preference for pole representation by general map-readers. In the two tests, where projections were represented with more sinusoidal curves for meridians and poles were represented with protruding edges, map-readers preferred pole lines (the Sinusoidal vs. McBryde-Thomas Flat-Polar Sinusoidal pair and the Boggs Eumorphic vs. the Eckert VI pair). The Hammer vs. Wagner VII pair with the opposite preference result showed that there were possible factors (e.g., curved parallels) that impacted map-reader preferences for the pole representation. These results do not confirm Werner's (1993) conclusions that map-readers prefer projections with pole points.

The group of professionals was more unanimous than general map-readers and was clearly more in favor of pole lines. The Mollweide vs. Wagner IV pair ($\chi^2 = 14.7$, $p < 0.01$), the Sinusoidal vs. McBryde-Thomas Flat-Polar Sinusoidal pair ($\chi^2 = 40.0$, $p < 0.01$), and the Boggs Eumorphic vs. Eckert VI pair ($\chi^2 = 19.9, p < 0.01$) showed preferences for pole lines, while the Hammer vs. Wagner VII pair was not significant ($\chi^2 = 3.9$, $p \approx 0.049$). Yet, Cochran's Q test ($Q = 21.4, p < 0.01$) indicated differences between the projection pairs due to the Sinusoidal vs. McBryde-Thomas Flat-Polar Sinusoidal pair, which had a stronger preference for pole lines.

Pole line corners

Binomial tests comparing projections with edged vs. curved pole line corners did not show any preferences by general map-readers or by professionals. For general map-readers, the Wagner IV vs. Eckert IV pair showed weak preference for edged corners of pole lines ($\chi^2 = 6.8$ and $p \approx 0.009$) while the Wagner VII vs. Wagner VII with curved corners pair showed weak preference for curved corners ($\chi^2 = 7.9$ and $p \approx 0.005$). All other pairs for both groups of participants were not significant. Both of the Cochran's Q tests indicated differences between the projection pairs.

Participants' characteristics

The most obvious participant characteristic, which has an impact on participants' preferences, is their prior cartographic experiences and knowledge. Comparing both groups of participants revealed that professionals selected the Plate Carrée and Mercator projections less frequently than did the other participants. The χ^2 tests showed differences in preferences for the Plate Carrée vs. Robinson pair ($\chi^2 = 18.0$, $p < 0.01$), the Plate Carrée vs. Eckert IV pair ($\chi^2 = 16.9$, $p < 0.01$), the Plate Carrée vs. Mollweide pair ($\chi^2 = 8.9$, $p < 0.01$), the Plate Carrée vs. Wagner VII pair ($\chi^2 = 12.7$, $p < 0.01$), the Plate Carrée vs. Winkel Tripel pair ($\chi^2 = 10.5$, $p < 0.01$), the Mercator vs. interrupted Mollweide pair ($\chi^2 = 59.7$, $p < 0.01$), and the Mercator vs. interrupted Goode Homolosine pair ($\chi^2 = 58.9$, $p < 0.01$). In the case of these pairs, general map-readers preferred the Plate Carrée or Mercator projections to the other projection in the pair, while professionals preferred the opposite. In other projection pairs with the Plate Carrée and the Mercator projections, professionals less frequently selected those two rectangular projections over the others. Another difference between both groups of participants was found in the Hammer vs. Wagner VII pair ($\chi^2 = 10.5$, $p < 0.01$). In this pair, general map-readers selected the Hammer projection as their preferred world map while professionals preferred the Wagner VII projection.

Gender, age, and education did not appear to impact participant preference. There was also no difference in the groups based on the frequency of their use of web maps and virtual globe maps. However, some preferences were different based on the type of map most often utilized. Participants that most often used physical and virtual globes (73 participants) preferred the Plate Carrée projection less than participants using paper maps (71 participants) and web maps (211 participants). These differences were apparent in the Plate Carrée vs. the Eckert IV pair ($\chi^2 = 11.6$, $p < 0.01$), the Plate Carrée vs. the Mollweide pair ($\chi^2 = 9.9$, $p < 0.01$), and the Plate Carrée vs. the Robinson pair ($\chi^2 = 17.5$, $p < 0.01$). Differences were also found for the Mollweide vs. Wagner IV pair ($\chi^2 = 9.4$, $p < 0.01$). General map-readers that use web maps often preferred the Wagner IV projection. These differences do not apply to the group of professionals.

Ross et al. (2010) analyzed demographics in Mechanical Turk. Their results show that most Turkers come from the United States (57%) and India (32%). The general map-reader group of participants mainly consisted of participants recruited via Mechanical Turk and most participants in this group were from those two countries (107 are from India and 175 are from the United States, see Table A2). Their answers were extracted from the group and were separately analyzed for each country's participants with a χ^2 test for each projection pair. There were differences in five projections pairs: the Eckert VI vs. Mollweide ($\chi^2 = 16.4$, $p < 0.01$), the Eckert VI vs. Winkel Tripel ($\chi^2 = 11.0$, $p < 0.01$), the Robinson vs. Mollweide ($\chi^2 = 17.9$, $p < 0.01$), the Robinson vs. Winkel Tripel ($\chi^2 = 6.8$, $p < 0.01$), and the Mollweide vs. Wagner IV pair ($\chi^2 = 6.9$, $p < 0.01$). In all of these projection pairs, the Indian participants preferred the Mollweide or the Winkel Tripel projections, while the American participants were more in favor of the Eckert IV, Robinson, or Wagner IV projections.

Conclusions

Snyder's selection guidelines can now be extended with map-reader preferences, derived from the user study

presented in this article. Results indicate that the general map-readers participating in this study had three basic preferences: (1) uninterrupted graticules, (2) elliptical meridians, and (3) straight parallels.

Results also showed that professionals are in favor of straight parallels, even though curved parallels generally reduce distortion in peripheral parts of the map. The Robinson projection was the most preferred world map projection in the study. Map-readers and professionals both selected this projection most frequently as their favorite.

In addition, the general map-readers preferred projections that represent poles as lines to projections that show poles as protruding edges. However, this user study did not show a clear preference for pole lines in general. The results of the binominal tests between projections with pole points and pole lines showed the existence of other possible factors that might exert influence on map-reader preferences, for example, curved parallels or sinusoidal curves for meridians. To see whether those graticule properties influence map-reader preferences, future user studies need to be conducted. Among the professionals in this study, projections with straight pole lines are preferred.

Our user study results suggest that gender, age, and education do not influence map-reader preferences, but cartographic knowledge and experiences do. Some differences in preferences were found between participants that most often use virtual globes and/or web maps. To confirm these differences, future studies could address this particular topic more precisely.

This user study mainly included participants from the United States and India, who did not necessarily come from an academic setting (i.e., students, faculty). This study has a larger sample of participants than previous studies by Werner (1993) and Gilmartin (1983), and more variability in the characteristics of the sampled population than Gilmartin's (1983) study. Therefore, it can be argued that this study is more representative than previously conducted studies. Yet, extending and modifying the user study to map-readers of other nationalities would make the findings more universally true. Also, differences in preferences between map-readers of other nationalities could then be examined in more detail.

Another user study could test globular projections that show the entire globe in a circle. Those projections were not included in the study presented in this article. All of the maps in our user study visualize landforms and the graticule. As another way to extend and modify what we know about map-reader preferences, it would be interesting to see how preferences change when map-readers base their decision only on projected landforms.

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Appendix 1. Wagner VII and Miller with rounded corners

For the purpose of the user study, two new map projections were designed: (1) the Wagner VII with rounded corners and (2) the Miller with rounded corners. These new projections were designed because no similar projections could be found in the literature. Both projections were used in a binominal tests, exploring whether map-readers prefer edged or rounded corners of pole lines. The Wagner VII with rounded corners was also used for testing the preference concerning curved or straight parallels. This appendix first presents Strebe's transformation, a method used for designing the projections. The second and third sections then detail the design for each projection.

Strebe's transformation

Daniel R. Strebe used a combination of equal-area scaling, forward, and inverse projections to create his Strebe 1995 projection. He presented a map in this projection, along with the theory behind it, at the joint Canadian Cartographic Association and North American Cartographic Information Society meeting in 1994 (Strebe 1994). Strebe's method consists of five steps: (1) selecting and applying the projection to be modified (e.g., the Eckert IV); (2) scaling the x and y coordinates by some factor chosen so that the range fits within the bounds of a second projection (e.g., the Mollweide); (3) transforming the projected coordinates back on the sphere with the inverse of the second projection; (4) transforming from the sphere to the new projected coordinate system with a third projection (e.g., the Hammer); and (5) scaling the x and y coordinates by the reciprocal of the factor from step 2 (Strebe 2011).

One can modify the appearance of the projection by selecting the scale factors in steps 2 and 5. When all three projections (two forward and one inverse) are equal-area transformations, the resulting projection is equal-area, such as with the Strebe 1995 projection (Strebe 2011).

The Wagner VII with rounded corners

The Wagner VII with rounded corners was created from the Eckert IV projection (step 1). The projection was scaled with a factor of 1.15 (steps 2 and 5) and projected back to the sphere with the inverse Eckert IV projection (step 3). The final forward projection was the Wagner VII (step 4). Since all three projections are equal-area, the resulting graticule (Figure 4) is also an equal-area projection.

The Miller with rounded corners

The Miller with rounded corners (Figure 5) was created in similar way, except the scale factor was 1.002 and the final forward projection was the Miller cylindrical. Since the last projection is not equal-area, the resulting Miller with rounded corners is a compromise projection.

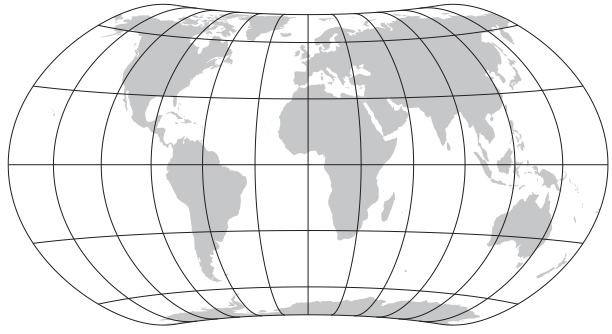

Figure 4. Wagner VII with rounded pole line corners.

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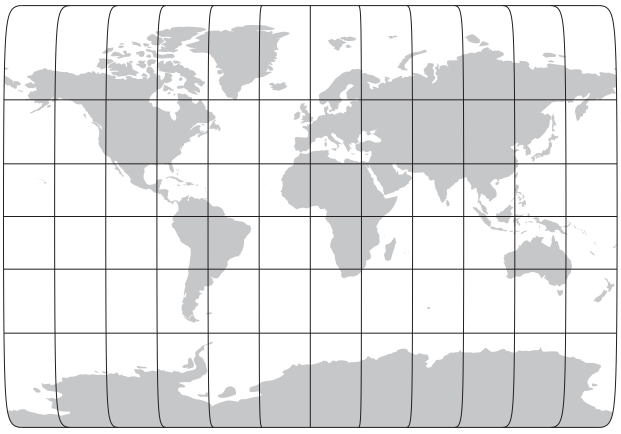

Figure 5. Miller with rounded pole line corners.

Appendix 2. Characteristics of participants in the user study

Table A1. Number of participants per categories of their characteristics.

Participants characteristic and categories	Map-readers	Professionals
Most often used type of maps		
Paper map, paper atlas or similar	71	21
Physical globe, or virtual globe like Google Earth	73	20
Web or smart-phone maps like Google Maps, Bing maps, or similar	211	52
Virtual globe map usage		
Never	24	2
About once or twice a month	175	31
About once or twice a week	86	22
More than twice a week, but not every day	56	16
Daily	14	22
Web maps usage		
Never	2	0
About once or twice a month	118	6
About once or twice a week	106	12
More than twice a week, but not every day	89	28
Daily	40	47
Gender		
Female	146	27
Male	209	66
Age group (years)		
18–25	80	14
26–35	189	47
36–45	46	10
46–55	24	8
56–65	14	10
66 or older	2	4
Highest level of education completed		
Did not complete high school	3	0
High school	63	2
Bachelor's degree or equivalent	180	19
Master's degree or higher	106	72
Other	3	0

(*continued*)

Table A1. (*Continued*).

Participants characteristic and categories	Map-readers	Professionals
Courses or workshops in map reading or map making		
Never taken any course or workshop	243	6
Taken a limited number of courses and/or workshops	101	9
Taken several courses and/or workshops	11	78
Experience in map making		
Never created a map (online or paper)	215	2
Created a limited number of maps (online or paper)	118	12
Created several maps (online or paper)	22	79
Total	355	93

Table A2. Number of participants per country of residency.

Country of residency	Map-readers	Professionals
Argentina	1	
Australia	1	1
Austria	2	3
Belgium	1	
Belize	1	
Bosnia and Herzegovina	1	
Brazil		1
Canada	2	3
Croatia	1	2
Ecuador	1	
Egypt	1	
France	6	6
FYR of Macedonia	1	
Ghana	1	
Germany	6	8
Greece		1
Hong Kong		1
India	107	
Italy	2	
Malaysia	1	
The Netherlands	2	2
New Zealand	1	1
Philippines	2	1
Poland	3	2
Romania	4	
Russian Federation	1	
Serbia		1
Slovenia	22	7
Switzerland	5	12
Taiwan	1	
Thailand		1
Turkey		2
The United Kingdom	2	3
The United States	175	35
Venezuela	1	
Total	355	93

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