How hard is it to design maps for beginners, intermediates and experts?

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Abstract: An online map reading test was done with 859 subjects to statistically measure the efficiency of information retrieval from three different cartographic images of the same area. The differences between the images (maps) were defined by the graphic variables (size, color, pattern, etc.) for six map data categories: linear features, hydrography, land cover, elevations, point-like objects, geographic names. The subjects solved map reading tasks related to these categories. Cartographic images were designed for each of the three map reader groups: beginners, intermediates and experts. The design method and the grouping were based on the results of previous studies, and the grouping was done with a competency test prior to the map reading task. The results showed the effectiveness of information retrieval from the three different cartographic images. Conclusions about the efficiency were done concerning the age, gender and level of expertise of the subjects.

Keywords: user oriented maps, online maps, map data types, user studies

1. Introduction

Cartographers know for a long time that map users understand the same map with different efficiency (Petchenik 1977; Thorndyke and Stasz 1980). We also know that differently displayed maps can help unskilled users to understand spatial information (Board 1978). To understand the rules and cognitive processes behind these phenomena, user oriented maps were designed, and user studies were conducted (Montello 2002; Allen et al. 2006; Ooms et al. 2014). It was shown that the amount of information comprehended by a user depends on various cognitive competences, such as sign recognition, sense of directions, distance- coordinate- and scale-reading, and recognition of morphology (Muir 1985; Clarke 2003). Using tests targeting these skills in map related experiments, the role of expertise was clearly demonstrated concerning the level of map-data comprehension (Clarke 2003). According to Gerber (1981), the difference between an "experienced" and an "unexperienced" map reader lies in their long term memories: while the first group has previous knowledge about various map symbols, the second one has to "learn" the map during reading it (by consulting the legend). It consumes capacity of the working memory, so the amount of information extracted from the map will be fewer for the beginners than for the experts. This phenomenon is explained by the cognitive load theory (Bunch and Lloyd 2006), and was observed in map user studies many times (Harrower 2007; Ooms et al. 2015). The amount of displayed information, thus, will be a crucial element in the legibility of a map.

2. Thoughts of the map maker and the map reader

Petchenik (1977) was probably right: it is unlikely that the thoughts in the minds of the map maker and the map reader will be exactly the same. However, map reading competency studies regarding the various map data types have already produced many clues to reduce the difference. Basically two or three user categories are distinguished in these studies: novices/experts (Deeb et al. 2012; Ooms et al. 2012) or beginners, intermediates and experts (Gerber 1981; Clarke 2003; Albert et al. 2016). Concerning the six map data types, which are necessarily distinguished in a topographic map database (Thompson 1979; Buckley et al. 2004; Usery et al. 2009), we present some examples of which type of user is sensitive to which map content:

1) Linear features (road network, transportation, and tourist trails). They are usually the structuring elements of a map and they draw immediate attention of map readers (Ooms et al. 2014). The interpretation of linear structures is the most challenging for all map readers; however, the beginners make five times more mistakes than the experts (Albert et al. 2016).
2) Hydrography (creeks, rivers, lakes, springs). Symbols of hydrography do not greatly vary by time (Albert 2014) and help to interpret the surface morphology (Potash et al. 1978). Linear and area features of the hydrography are "easy to understand" features for all map readers.
3) Land cover (forest, meadow, vineyard, etc., built-in area). Interpretation of natural and artificial coverage can be facilitated with familiar patterned symbols (Barkowsky and Freksa 1997).
4) Hypsography (elevations, contours, shading, scarps, peaks). Intermediate and beginner map readers have difficulties in interpreting hypsography (Eley 1992; Wakabayashi 2013). Contour line interpretation requires both navigation and symbol recognition skills (Montello et al. 1994; Murakoshi and Higashi 2015).

5) Point-like objects (symbols, significant man-made or natural objects). It was shown by Albert et al. (2016) that 15% of the expert, 38% of the intermediate and 66% of the beginner map users make mistakes in map symbol interpretation. It was also shown by Easterby and Hakiel (1981) that a symbol is comprehended more easily if it has descriptive details.
6) Geographic names (name attributes of all objects displayed as labels). Map labeling rules (Imhof 1975) are implemented into algorithms where the preference of orientation, shape and texture varies according to expertise (Deeb et al. 2012; Ooms et al. 2012). It was shown that both experts and beginners prefer sans-serif font types, but beginners are more tolerant to diversity.

So, if such remarkable differences exist, how is it possible to design maps which transmit the same meaning from the map maker to the differently skilled map readers? To find answer for this in the present research, we created three different maps of the same area, and with an online test we examined the effectiveness of the three different cartographic images in the case of three user categories: beginners/intermediates/experts. In the map making process, the "Bertinian" graphic variables (Bertin 1967) were used to enhance certain map data types together with the usual generalization methods (McMaster and Shea 1992).

3. What questions can be answered with the experiment?

The research was aimed to answer several questions about the usability and effectiveness of the produced cartographic images. It was expected that the results would help to design automatically generated online maps for those individuals who would reveal their map reading skills (i.e. by filling out a test). These questions were as follows:

- Do the different maps help achieving better results on map related tasks?
- Were the average results better when the participants used their own groups' map?
- Are there any significant differences in the percentage points of correct answers among the map reading groups?
- Are there significant differences in the completion time of different user groups?
- Are there any differences in the completion time of each task among the map reading groups?
- Are there any relations between the age and completion time?
- Are there any differences between the applied map scales of each task?
- Are there any relations between the age/gender and applied map scales?

In order to answer our research questions we gave each participant maps designed for a specific map reading group – half of the participants got maps designed for their own map reading level, and 25%-25% of them got maps prepared for other groups.

4. Categorization of map readers

The first component of the map reading test measured the competency. For this, an online questionnaire was presented for each participant, and measured seven competences:

1. interpretation of topographic elements,
2. interpretation of hypsography,
3. interpretation of map symbols,
4. interpretation of geographic names,
5. orientation and mental rotation skills,
6. application of scale bar,
7. distance and travel time estimation.

The tripartite categorization of the participants followed the same method which was used by Albert et al. (2016). Each of the competences was measured with one multiple-choice question with four answers, and the "do not know" option. The assignments were linked to four simple maps containing only those map-data types which were necessary to solve the questions relating to them. This reduction of content was necessary to lessen the cognitive load of the participants during the test.

Too long online tests are often left unfinished by many participants, so the overall time should not take longer than 15-20 minutes. The duration of the competency test was planned to take 5-10 minutes, so the second part of the test could be similarly long. Sequence of the maps and questions was randomized.

5. Differently designed cartographic images and the test questions

For the second component of the test we created three online maps (level-B for beginners, -I for intermediates, and -E for experts) of the same area which was embedded in a web page that contained the test questions (Szigeti et al. 2017 – a parallel paper in this volume). The varying design and generalization level of the maps are based on the results of various studies (see section 2).

The test area had been chosen to have a large variety of topographic elements (multiple road types, a large city, villages, etc.) and diverse hypsography with both hills and plains. The source of the map data was OpenStreetMap (OSM) and

SRTM 3 arc second elevations. The data was processed with open source desktop and server-side applications (QGIS 2.14).

This part of the test also involved seven questions (Q1-Q7); two of them were interactive, and the other five were multi-choice questions with four answers. Measuring the same competencies as in the first component of the test, the questions were aimed to examine whether the maps were adequate for the targeted map reader group. Additionally, the answering time and the zoom level at the time of the answer were also recorded. The sequences of the questions and the cartographic images were randomized again, but in this case an online map server provided the cartographic images from the same (but differently visualized) database for all participants. The user interface in the browser made it possible to change the zoom level dynamically between 1:1,000 and 1:250,000, which modified the map content quite similarly to the OSM zoom levels (Tab. 1).

The interactive Q1 question tested the orientation skills. Participants clicked along a city route following a written description. The results showed how well the maps helped the participants defining relative (right/left) or cardinal (North/South) directions.

The Q2 question tested the interpretation of linear objects. The task was to choose a route that did not intersect with any main road. Four options were listed, and each of them showed up on the map when the participants clicked on their radio button. Road types varied in color and thickness on all maps. On smaller scale (<1:15,000), the unpaved roads (bridleways and tracks) were generalized using the refinement method (McMaster and Shea 1992). The level-B map had the highest, and the level-E the lowest extent of generalization (Tab. 2).

Table 1. The zoom levels of the online maps. Multiple entries of the same object types in a column indicate a different design and/or generalization.

<table>
<tr><th>Zoom levels of the individualized maps</th><th colspan="6">Polygons</th><th colspan="7">Lines</th><th colspan="9">Points</th></tr>
<tr><td>Till 1:250,000</td><td rowspan="3">Field</td><td rowspan="3">Vineyard</td><td rowspan="3">Forest</td><td rowspan="5">–</td><td rowspan="11">Built-in</td><td rowspan="2">Hypsographic name</td><td rowspan="3">Tourist route</td><td rowspan="8">Highway</td><td rowspan="8">Primary road</td><td rowspan="8">Secondary road</td><td rowspan="2">–</td><td rowspan="2">–</td><td rowspan="5">–</td><td rowspan="3">–</td><td rowspan="6">–</td><td rowspan="8">–</td><td rowspan="10">–</td><td rowspan="6">City name</td><td>–</td><td rowspan="2">–</td><td rowspan="3">–</td><td rowspan="5">–</td></tr>
<tr><td>1:150,000</td><td rowspan="5">Village name</td></tr>
<tr><td>1:75,000</td><td rowspan="2">Hypsographic name</td><td rowspan="4">Bridleway, track</td><td rowspan="4">Path</td><td rowspan="4">District name</td></tr>
<tr><td>1:70,000</td><td rowspan="3">Field</td><td rowspan="3">Vineyard</td><td rowspan="3">Forest</td><td rowspan="3">Tourist route</td><td rowspan="8">Railway station; Gas station</td><td rowspan="8">Peak name</td></tr>
<tr><td>1:50,000</td><td rowspan="7">–</td></tr>
<tr><td>1:35,000</td><td>Bu.</td><td rowspan="2">Street name</td><td rowspan="6">Railway station name</td></tr>
<tr><td>1:15,000</td><td rowspan="5">Field</td><td rowspan="5">Vineyard</td><td rowspan="5">Forest</td><td rowspan="3">Building</td><td rowspan="5">Tourist route</td><td rowspan="5">Bridleway, track</td><td rowspan="5">Path</td><td rowspan="5">Shop; Doctor; Guesthouse; Cave; Shelter; Tower; Water; Fireplace; Radio tower; Bridge</td><td rowspan="5">–</td><td rowspan="5">–</td><td rowspan="2">District name</td></tr>
<tr><td>1:10,000</td><td rowspan="4">Street name</td></tr>
<tr><td>1:8,000</td><td rowspan="3">Highway</td><td rowspan="3">Primary road</td><td rowspan="3">Secondary road</td><td rowspan="3">Restaurant; Sight, Monument</td><td rowspan="3">District name</td></tr>
<tr><td>1:5,000</td><td rowspan="2">Building</td></tr>
<tr><td>1:4,000 to 1:1,000</td><td>Pub; Cross; Bench; Monument</td></tr>
</table>

Table 2. The extent of generalization on the maps designed for the three groups of participants. The numbers indicate the total numbers of items of the listed feature types on a given scale for the whole test area.

	Beginner (number of displayed objects)				Intermediate (number of displayed objects)				Expert (number of displayed objects)			
Scale level	1: 75,000– 1: 35,000	1: 35,000– 1: 15,000	1: 15,000– 1: 5,000	1:5,000– 1:1,000	1: 75,000– 1: 15,000	1: 15,000– 1: 1,000	1: 35,000– 1: 15,000	1:5,000– 1:1,000	1: 75,000– 1: 15,000	1: 15,000– 1: 1,000	1: 35,000– 1: 15,000	1:5,000– 1:1,000
Fields		372		476		393		476		476		476
Forest		243		277		250		277		277		277
Buildings	-	165	1893	3570	-	165	4439	18945	-	165	14432	18945
Bridleway, track		502		3345		1091		3345		1981		3345
Path		188		1182		351		1182		582		1182

The Q3 question tested the interpretation of land cover by selecting the correct answer out of four possibilities (farmland, suburban, urban, village). The map contained both man-made and natural objects, and buildings only appeared on large scales (>1:35,000). The beginners' map was the most, and the experts' map was the least generalized. On larger scales (>1:75,000), the beginners had detailed, and the intermediates had schematic tree symbols and green background on the forest polygons to facilitate the recognition (Fig. 1).

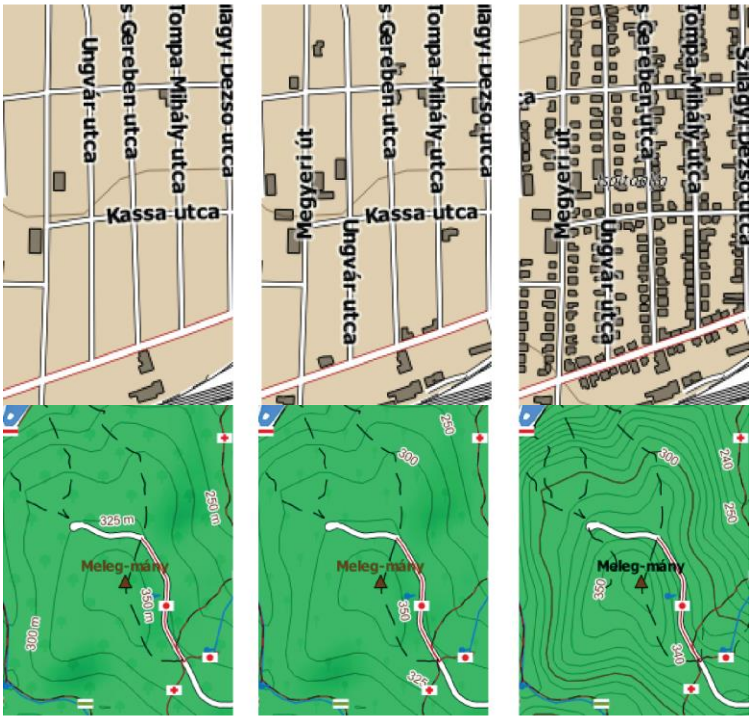

Fig. 1. The difference in the design of land cover in urban and rural areas – top, and hypsography – bottom (target groups from left to right: beginner, intermediate, expert).

The Q4 question tested the interpretation of hypsography interactively. Here the task was to click on the steepest slope of a four sided hill. The judgement of landform steepness, however, is different from the usual contour reading tasks (e.g. Sholl and Egeth, 1982), so the results were taken care accordingly. The contour line intervals on the experts' map were 10 m, while on the level-I and B maps they were 25 m. The latter two also contained hill shading. In order to help the beginners' comprehension, we also added measurement units (m) to the values of the contour lines (Fig. 1).

The Q5 question measured the interpretation of geographic names. Subjects had to tell from four possibilities what village a specific road crosses. The road crossed all, but only one of them was a village. By clicking on them, the map zoomed to their locations. All types of settlement names (towns, villages, districts) had the same fonts, but different sizes and typefaces. The colors of hypsographic names were brown on the beginners' and intermediates' maps to emphasize the semiotic connection with the hypsography.

In the Q6 question the subjects' distance and travel time estimation skills were tested. The task was to select the correct combination of the length and the walk time between two points, which were connected with a tourist route. All three groups were able to use the dynamic scale bar generated by OpenLayers on the web map.

Fig. 2. The difference in the design of point symbols (from left: beginner, intermediate, expert).

The Q7 question tested the adequacy of point symbols. The participants had to tell which of the four listed objects could be found in a certain area on the map. A legend was also provided on the web page for this question. On the experts' and intermediates' map we used simple pictograms commonly used on tourist maps, while the beginners had more detailed and descriptive symbols (Fig. 2).

6. Database – Sampling and weighting

The data was collected between July and September 2016, and the survey was distributed online in Hungarian language. There were a total of 937 participants, but only 859 tests were evaluated. The unfinished ones and the tests with a fill out time less than 5 minutes in the first or second test part were filtered out in order to improve data quality. Those tests where participants did not give their precise educational qualification were also left out. The sample is representative[1] with respect to gender and age categories of the 15–79-year-old Hungarian population. Based on the first test's results, our sample consists of 257 beginner, 305 intermediate and 297 expert map users.

7. Proportion of good answers

The differences between map reading groups by questions show that the proportion of the good answers in the beginner group is significantly lower compared to the same score in the intermediate and expert group (except Q2, the interpretation of topographic objects). Regarding the intermediate map readers' performance in the case of Q1, Q3 and Q7, the proportion of their good answers is similar to that of the experts, while it falls behind in the other tasks (Tab. 3).

Table 3. Proportion of good answers by questions and map reading groups.

	Map reading category		
	Beginner	Intermediate	Expert
(Q1) Orientation skills	2.9%$_a$	7.6%$_b$	9.8%$_b$
(Q2) Interpretation of topographic objects	45.7%$_a$	53.2%$_a$	72.2%$_b$
(Q3) Coverage	70.4%$_a$	79.8%$_b$	87.4%$_b$
(Q4) Interpretation of hypsography	67.4%$_a$	90.4%$_b$	98.4%$_c$
(Q5) Interpretation of geographic names	43.7%$_a$	63.9%$_b$	83.9%$_c$
(Q6) Distance and travel-time estimation	54.0%$_a$	74.0%$_b$	85.2%$_c$
(Q7) Interpretation of map symbols	34.3%$_a$	62.9%$_b$	70.0%$_b$

Note: Values in the same row not sharing the same subscript are significantly different at $p< 0.05$ in the two-sided test of equality for column means (t-tests). The dark blue cells are significantly higher than the light blue ones in absolute value. Tests assume equal variances.

It was expected that the respondents' average percentage points would depend on the maps they got. In the case of the intermediates, this tendency well appeared on the average percentage point results. However, the map designed for the begin-

[1]A sample is said to be representative with respect to a variable if its relative distribution in the sample is equal to its relative distribution in the population.

ners worked oppositely to our preliminary expectations – it did not close the gap between the map reading groups. For the better understanding, it is worth examining the second test's questions step by step with special attention to the beginners' and intermediates' performance (see Tab. 4).

In the case of Q1 (orientation skills), the beginners' average score was significantly higher when they used level-I maps compared to the one created for them. The result suggests that in this kind of task the too low density of the built-in area could affect negatively the respondents' results.

Regarding Q2 and Q3, there is no significant difference in the proportion of good answers, but remarkable differences can be found again in the interpretation of hypsography (Q4): those beginners who used level-E maps performed better than those who worked on level-B or I. This result could be explained with the denser contour intervals and the lack of hill shading on the experts' map.

Answers to questions Q5, Q6 and Q7 showed no significant difference, but there are observable tendencies towards one or another groups' map, which may be accounted for many parameters (such as the contour intervals, land cover, the unpaved roads' generalization, the coloring of the peak names and labels, etc.).

Table 4. Proportion of good answers by questions, map reading groups and maps used for the second test.

	Beginner map readers			Intermediate map readers			Expert map readers		
	Type of maps used in the second test			Type of maps used in the second test			Type of maps used in the second test		
	Beginner	Intermediate	Expert	Beginner	Intermediate	Expert	Beginner	Intermediate	Expert
(Q1) Orientation skills	0.7%$_a$	8.5%$_b$	2.4%$_{a,b}$	5.6%$_a$	9.1%$_a$	7.4%$_a$	11.5%$_a$	8.0%$_a$	10.0%$_a$
(Q2) Interpretation of topographic objects	56.0%$_a$	45.9%$_a$	60.5%$_a$	55.2%$_a$	73.4%$_a$	56.3%$_a$	75.9%$_a$	86.6%$_a$	70.6%$_a$
(Q3) Coverage	74.7%$_a$	69.7%$_a$	79.6%$_a$	67.4%$_a$	79.3%$_{a,b}$	90.3%$_b$	86.4%$_a$	93.4%$_a$	84.7%$_a$
(Q4) Interpretation of hypsography	65.1%$_a$	64.8%$_a$	81.4%$_b$	86.1%$_a$	88.3%$_{a,b}$	97.2%$_b$	98.9%$_a$	97.9%$_a$	98.9%$_a$
(Q5) Interpretation of geographic names	43.0%$_a$	50.3%$_a$	51.2%$_a$	53.9%$_a$	75.8%$_b$	51.4%$_a$	76.7%$_a$	97.9%$_b$	80.2%$_a$
(Q6) Distance and travel-time estimation	60.7%$_a$	55.3%$_a$	51.5%$_a$	76.2%$_a$	76.5%$_a$	67.6%$_a$	91.6%$_a$	84.6%$_a$	82.1%$_a$
(Q7) Interpretation of map symbols	35.0%$_a$	39.0%$_a$	37.8%$_a$	55.3%$_a$	64.5%$_a$	72.2%$_a$	73.7%$_a$	68.2%$_a$	69.2%$_a$
Average points [max. 7]	3.27 $_a$	3.36 $_a$	3.54 $_a$	3.89 $_a$	4.58 $_b$	4.31 $_{a,b}$	5.04 $_a$	5.26 $_a$	5.00 $_a$

Note: for explanation of subscripts and colors, see Tab. 3.

Intermediate map readers who worked on level-B or E maps generally performed worse than those who used their own level's map. The only significant exceptions were the Q3 (coverage) and Q4 (hypsography). In these cases the proportion of good answers was 9-11% higher when the respondents used level-E maps, suggesting that the result was affected positively by the higher level of details on the experts' map.

8. Completion time

The time interval between clicking on the "next" buttons on two subsequent web pages to proceed in the test was recorded and analyzed in every participant's case (both who answered correctly and incorrectly). Since the test was accessible from any internet-capable devices, the filling time could be affected by the speed of the connection. The observed tendencies remained generally the same, when only the correct answers were accounted. During the analysis the focus was mainly on intragroup differences (Tab. 5). Based on the completion times, the Q1 proved to be the hardest of all. It was followed by the Q2 and the Q7.

Beginners, who got maps designed for their own level, have spent more time with the test on average (15 min.) compared to those who used the intermediates' (12.14 min.) and experts' (12.33 min.) maps. A clear tendency shows that the beginners' map was not adequate for beginners. This is revealed mainly in four types of tasks: 1) orientation skills, 2) interpretation of hypsography, 3) distance and travel-time estimation, 4) interpretation of map symbols. The positive exception was the Q5 task, where the beginners were quicker when they worked on their level's maps.

Table 5. Average filling time in minutes by questions, map reading groups and maps used in the test.

	Beginner map readers			Intermediate map readers			Expert map readers		
	Type of maps used in the second test			Type of maps used in the second test			Type of maps used in the second test		
	Beginner	Intermediate	Expert	Beginner	Intermediate	Expert	Beginner	Intermediate	Expert
(Q1) Orientation skills	5.53_a	3.90_b	$4.85_{a,b}$	5.08_a	5.84_a	8.05_b	5.10_a	5.11_a	6.12_a
(Q2) Interpretation of topographic objects	2.39_a	2.56_a	1.96_a	4.21_a	2.50_b	$2.62_{a,b}$	2.47_a	2.40_a	2.16_a
(Q3) Coverage	1.28_a	1.38_a	0.82_a	0.88_a	0.90_a	1.07_a	0.76_a	0.94_a	0.98_a
(Q4) Interpretation of hypsography	1.28_a	0.67_b	$0.79_{a,b}$	0.81_a	$0.70_{a,b}$	0.56_b	0.80_a	0.81_a	0.60_a
(Q5) Interpretation of geographic names	1.32_a	1.49_a	1.69_a	1.38_a	1.43_a	1.05_a	1.32_a	1.08_a	1.39_a
(Q6) Distance and travel-time estimation	1.20_a	0.86_b	$0.95_{a,b}$	1.07_a	1.53_a	1.15_a	1.16_a	1.21_a	3.24_a
(Q7) Interpretation of map symbols	2.00_a	1.27_b	1.27_b	1.79_a	1.78_a	2.04_a	1.37_a	1.44_a	1.42_a
Total [minutes]:	15.00_a	12.14_b	12.33_b	15.22_a	14.67_a	16.53_a	12.98_a	12.99_a	15.90_a

Note: for explanation of subscripts and colors, see Tab. 3.

The intermediate map readers were quickest with the maps designed for their level (14.67 min.), which is followed by the case when they got beginner (15.22 min.) and expert maps (16.53 min.). For them, only the Q4 task was problematic on their own map, which was solved significantly quicker by those who got expert maps.

The experts, although they could have answered the questions correctly on any maps, completed the test the slowest when they worked with level-E map (15.9

min.); the use of other maps resulted in a 3-minute shorter filling time on average. This tendency showed up in the cases of more than half of the questions, except Q2 (interpretation of topographic objects), and Q4 (interpretation of hypsography).

A slight correlation (0.1) was observed between the participants' age and their filling time, which means that solving the tasks took slightly longer with the increase of the age.

9. Map Scale

To find out the preferred scale levels of different map reading tasks, the website logged the maps' zoom level relative to the default value, after the participants left the web page. The default zoom level of each task is denoted by 0 by the OpenLayers plugin, while the level of zooming in is represented with positive integers, and zooming out with negative integers. Each zoom level halves or doubles the map scale.

The general tendencies show that participants at the Q1 task mainly used larger scales, and experts used more zoom than beginners and intermediates. Smaller scales were used more frequently at the Q2, Q3 and Q7 questions, and the experts used smaller scales than the beginners (Tab. 6). In these cases, the scale level has a low inverse correlation (–0.3) with the correct answers, implying that with smaller scales more correct answers were given.

Table 6. Average zoom level by questions and map reading groups calculated from the integers recorded with the OpenLayers plugin. Positive numbers indicate zooming in, while negatives show zooming out tendencies.

	Map reading category		
	Beginner	Intermediate	Expert
(Q1) Orientation skills	0.047_a	0.029_a	0.336_b
(Q2) Interpretation of topographic objects	-1.236_a	-1.487_b	-1.727_c
(Q3) Coverage	-0.007_a	-0.049_a	-0.066_a
(Q4) Interpretation of hypsography	-0.006_a	0.008_a	0.111_a
(Q5) Interpretation of geographic names	-0.041_a	0.015_a	-0.064_a
(Q6) Distance and travel-time estimation	0.009_a	0.084_a	0.110_a
(Q7) Interpretation of map symbols	-0.310_a	-0.425_b	-0.554_b

Note: for explanation of subscripts and colors, see Tab. 3.

No strong relationship was found between the participants' age and the applied map scales, and the participants' gender only caused slight differences regarding the application of map scales: women respondents used zooming less frequently than men.

10. Summary

A previous study carried out by Albert et al (2016) noted that group-specific mistakes are hard to be found in the beginner map readers' case due to the diversity of people within the group. Since they have different strengths and weaknesses in cognitive skills, their mistakes are varying. The present paper's results show that while it was achieved to design good maps for the intermediate map readers – in a way that their average performances approach the experts' results –, in the beginners' case it is a more complicated task. Measuring the beginners' performance in different tasks, it is clear that their results are highly affected by the density of the land cover symbols and contour lines. Concerning these map data types, they usually performed better with maps that were designed for intermediates or experts. This suggests that the object density of the built-in area was unusually low in the beginner maps' case (over-generalized), and the use of smaller contour intervals (and the avoidance of the hill shading) was welcomed by the beginners, and it affected the results positively. Although the tendency is clear that in all tasks the proportion of good answers was higher if they used intermediate and expert maps, the answering time shows that they still performed more quickly on their own level in the case of the geographic names.

From the aspect of filling time, a clear tendency shows up, which emphasizes the conclusions derived from the good answers. Those beginners answered the questions the slowest, and those intermediates the fastest who got maps designed for their own map reading level. Expert map readers solved the tasks more quickly if they used beginner or intermediate maps. A weak relationship between the respondents' age and the completion time was also observed.

Regarding the zoom levels used by the participants, there are differences between the map reading groups: the experts and the beginners used a little bit smaller, the intermediates a little bit larger map scale. Only small differences can be experienced by gender.

The study presented here can help future experiments and map applications in two ways: partly as a methodological paper and partly by providing data for dynamic online maps. The latter belongs to the wider discipline of adaptive map creation (Sarjakoski and Sarjakoski, 2008), which emerged with the technology of online maps. Adaptive map design based on the results of our research is discussed from the aspects of utilizing purely open source data and tools (Szigeti et al. 2017). The primary aim of our research was to statistically measure the usability of the designed maps, and the settings of the experiment made it possible to achieve this aim. Although the effective map design was only partly achieved, the numerical results, categorized by the basic map data types are informative. Online map applications – aiming to produce different maps for different people – will have to define explicitly the level of generalization, and the optimal map keys for the individual users. The findings presented here may serve as a stepping stone for this process.

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12. References

Albert, G. (2014, 2014.09.04). *What Does an Archive Map Tell the Contemporary Map Readers?* Paper presented at the 9th International Workshop on Digital Approaches to Cartographic Heritage, Budapest.

Albert, G., Ilyés, V., Kis, D., Szigeti, Cs., Várkonyi, D. (2016). Testing the map reading skills of university students. In T. Bandrova & M. Konecny (Eds.), *6th International Conference on Cartography and GIS* (pp. 188-199.). Albena, Bulgaria: Bulgarian Cartographic Association.

Allen, G. L., Cowan, C. R. M., Power, H. (2006). Acquiring information from simple weather maps: Influences of domain-specific knowledge and general visual–spatial abilities. *Learning and Individual Differences, 16*(4), 337-349.

Barkowsky, T., & Freksa, C. (1997). *Cognitive requirements on making and interpreting maps.* Paper presented at the International Conference COSIT, Pennsylvania, USA.

Bertin, J. (1967). Sémiologie graphique: les diagrammes–les réseaux–les cartes. *Mouton, Paris*.

Board, C. (1978). Map reading tasks appropriate in experimental studies in cartographic communication. *Cartographica: The International Journal for Geographic Information and Geovisualization,* 15(1), 1-12.

Buckley, A., Hurni, L., Kriz, K., Patterson, T., Olsenholler, J. (2004). Cartography and visualization in mountain geomorphology. In M. P. Bishop & J. F. Shroder (Eds.), *Geographic Information Science and Mountain Geomorphology. Springer, Praxis, Chichester, UK* (pp. 253-287).

Bunch, R. L., & Lloyd, R. E. (2006). The Cognitive Load of Geographic Information. *The Professional Geographer,* 58(2), 209–220.

Clarke, D. (2003). *Are you functionally map literate.* Cartographic renaissance. Proceedings 21st International Cartographic Conference (ICC 2003), Durban, South Africa.

Deeb, R., Ooms, K., De Maeyer, P. (2012). Typography in the eyes of Bertin, gender and expertise variation. *The Cartographic Journal,* 49(2), 176-185.

Easterby, R. S., & Hakiel, S. R. (1981). Field testing of consumer safety signs: the comprehension of pictorially presented messages. *Applied ergonomics,* 12(9), 143–152.

Eley, M. G. (1992). Component Processing Skills In The Interpretation Of Topographic Maps. *Cartographica,* 29(1), 35–51.

Gerber, R. V. (1981). Competence and Performance in Cartographic Language. *The Cartographic Journal,* 18(2), 104-111.

Harrower, M. (2007). The Cognitive Limits of Animated Maps. *Cartographica,* 42(4), 349–357.

Imhof, E. (1975). Positioning names on maps. *The American Cartographer,* 2(2), 128-144.

McMaster, R. B., & Shea, K. S. (1992). *Generalization in digital cartography*. Washington: Association of American Cartographers.

Montello, D. R. (2002). Cognitive Map-Design Research in the Twentieth Century: Theoretical and Empirical Approaches. *Cartography and Geographic Information Science,* 29(3), 283-304.

Montello, D. R., Sullivan, C. N., Pick, H. L. (1994). Recall memory for topographic maps and natural terrain: effects of experience and task performance. *Cartographica,* 31(3), 18–36.

Muir, S. P. (1985). Understanding and Improving Students' Map Reading Skills. *The Elementary School Journal,* 86(2), 206-216.
Murakoshi, S., & Higashi, H. (2015). Cognitive characteristics of navigational map use by mountaineers. *International Journal of Cartography* 1(2), 210-231
Ooms, K., De Maeyer, P., Fack, V. (2014). Study of the attentive behavior of novice and expert map users using eye tracking. *Cartography and Geographic Information Science,* 41(1), 37-54.
Ooms, K., De Maeyer, P., Fack, V., Van Assche, E., Witlox, F. (2012). Investigating the Effectiveness of an Efficient Label Placement Method Using Eye Movement Data. *The Cartographic Journal,* 49(3), 234-246.
Petchenik, B. B. (1977). Cognition in Cartography. *Cartographica,* 14(1), 117–128.
Potash, L. M., Farrel, J. P., Jeffrey, T. E. (1978). An approach to assesment of relief formats for hardcopy topographic maps. *The Cartographic Journal,* 15(1), 28-35.
Sarjakoski, L. T., Sarjakoski, T. (2008). User interfaces and adaptive maps. In *Encyclopedia of GIS* (pp. 1205-1212): Springer.
Sholl, M. J., & Egeth, H. E. (1982). Cognitive correlates of map-reading ability. *Intelligence, 6*, 215–230.
Szigeti, C., Albert, G., Ilyés, V., Kis, D., Várkonyi, D. (2017). On the Way to Create Individulized Cartographic Images for Online Maps Using Free and Open Source Tools. In M. P. Peterson (Ed.), *Advances in Cartography and GIScience - Selections from the International Cartographic Conference 2017*. New York: Springer.
Thompson, M. M. (1979). *Maps for America : cartographic products of the U.S. Geological Survey and others*. Reston, Va. Washington: USGS.
Thorndyke, P. W., & Stasz, C. (1980). Individual-Differences in Procedures for Knowledge Acquisition from Maps. *Cognitive Psychology,* 12(1), 137-175.
Usery, E. L., Finn, M. P., Starbuck, M. (2009). Data layer integration for the National map of the United States. *Cartographic Perspectives*(62), 28-41.
Wakabayashi, Y. (2013). Role of geographic knowledge and spatial abilities in map reading process: impilcations for geospatial thinking. *Geographical reports of Tokyo Metropolitan University, 48*, 37-48.