CO-286

STRATEGIES OF LEGEND AND MAP INTEGRATION

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BACKGROUND AND OBJECTIVES

A legend is a symbol dictionary that explains signs used in a map. It is a critical feature allowing properly read and interpret thematic map. However, the legend also serves several other functions, it helps map a user to understand presented themes, their hierarchy and a way of classification (Schlichtmann 1997, Schlichtmann 2009, Clark et al. 2010). Actually we are facing rapidly increasing extent of available data, therefore the maps presenting several themes are often used. Furthermore, the problems that are solved basing on the maps and spatial information are also getting more complex. Multitheme presentation results in several additional problems in legend layout due to need for an exhibition of a visual logic as well as relations between presented themes. Therefore, the design of the legend should receive high attention to, so that the user may take the full advantage of it.

A detailed guidance on legend design has not been developed yet, and only few general principles were indicated (Dykes et al. 2010). On the other hand, there is a great number of legend design types to choose from. The choice of the design is important for the map effectiveness, since experimental works showed that it influences the accuracy and the response time of answers (np. Cox 1976; DeLucia and Hiller, 1982; Aspaas and Lavin, 1989; Pickle et al. 1995). However, in order to develop rules of the legend design, it is important to understand how information is acquired from a legend and from a map. Hence, not only the result of map usage should be a subject of analysis, but also the entire process of map and legend handling.

Legend information is applied in various ways during map usage process. Hermann and Pickle (1996) presented cognitive subtask model of statistical map reading (fig. 1), that can be generally referred also to other kinds of thematic maps.

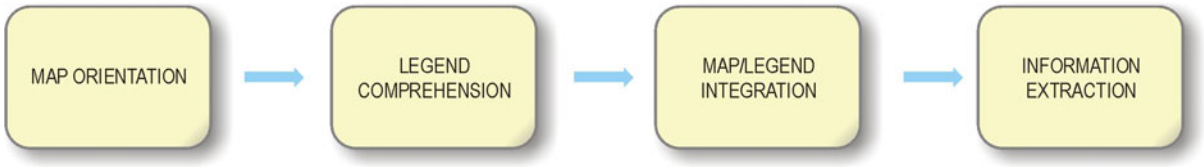

Fig. 1. Map-reading subtask model (after: Hermann and Pickle 1996)

In the model, a legend is included at two stages: “legend comprehension” and “map/legend integration”. Empirical evidence suggests that the subtasks are processed in non-overlapping sequence. Furthermore, each stage involves different psychological processes from those employed by other stages (Hermann, Pickle 1996), hence it is worth to study them separately.

The stage “map and legend integration” is interesting from the semiotic point of view. It covers matching information from the two subsystems: (1) a legend that matches applied cartographic signs with natural language categories and (2) a map that conveys spatial attributes. The integration is conducted in various ways. Pickle et al. (1995) determined two strategies of legend and map integration when analyzing statistical maps that also may be the basis for the analysis of other thematic maps. The first approach is called map-to-legend strategy. When applying such strategy a map user first refers to the map to discriminate signs and their patterns. When the user notices a symbol with unknown meaning, he or she refers to a legend. Alternatively, a map user first refers to the legend, reads the subsequent signs and their meanings. After decoding the signs and remembering the semantic relation, he or she refers to the map and studies its content or searches for the signs of interest. This approach is called legend-to-map strategy. When analyzing thematic maps usage a third strategy may be distinguished: the map user can try to decode the sign by relying on his or her own knowledge or just guessing the meaning of sign. This approach, called here intuitive way, may decrease time required for completing the task, but in the same time may result in higher number of mistakes during map reading.

Many authors emphasize that a legend should be carefully studied before a map reading (e.g. Clarke et al. 2010). Therefore, they recommend the legend-to-map strategy. If applying such approach a map user familiarize himself with the entire sign set of symbols used on the map, its extent and hierarchy (Freitag 1987), as well as other background information conveyed by the legend (Schlichtmann 1997). Applying this strategy, facilitates further map content analysis.

The goal of this study is to collect information concerning strategies applied during thematic map usage. The objective is to determine if map users apply the recommended legend-to-map strategy. Furthermore, equally important aim is to test, if different legend designs may affect a choice of strategy.

APPROACH AND METHOD

Materials

Designed experiment simulated the execution of problem-solving tasks based on the information derived from a thematic map with differently designed legends. The map face was the same with unchanged symbols design (fig. 2). The map designed for the experiment contains several thematic layers: environmental protection areas, traffic volume along roads, settlements with important objects within them, and condition for territorial management: soil permeability and level of farming profitability.

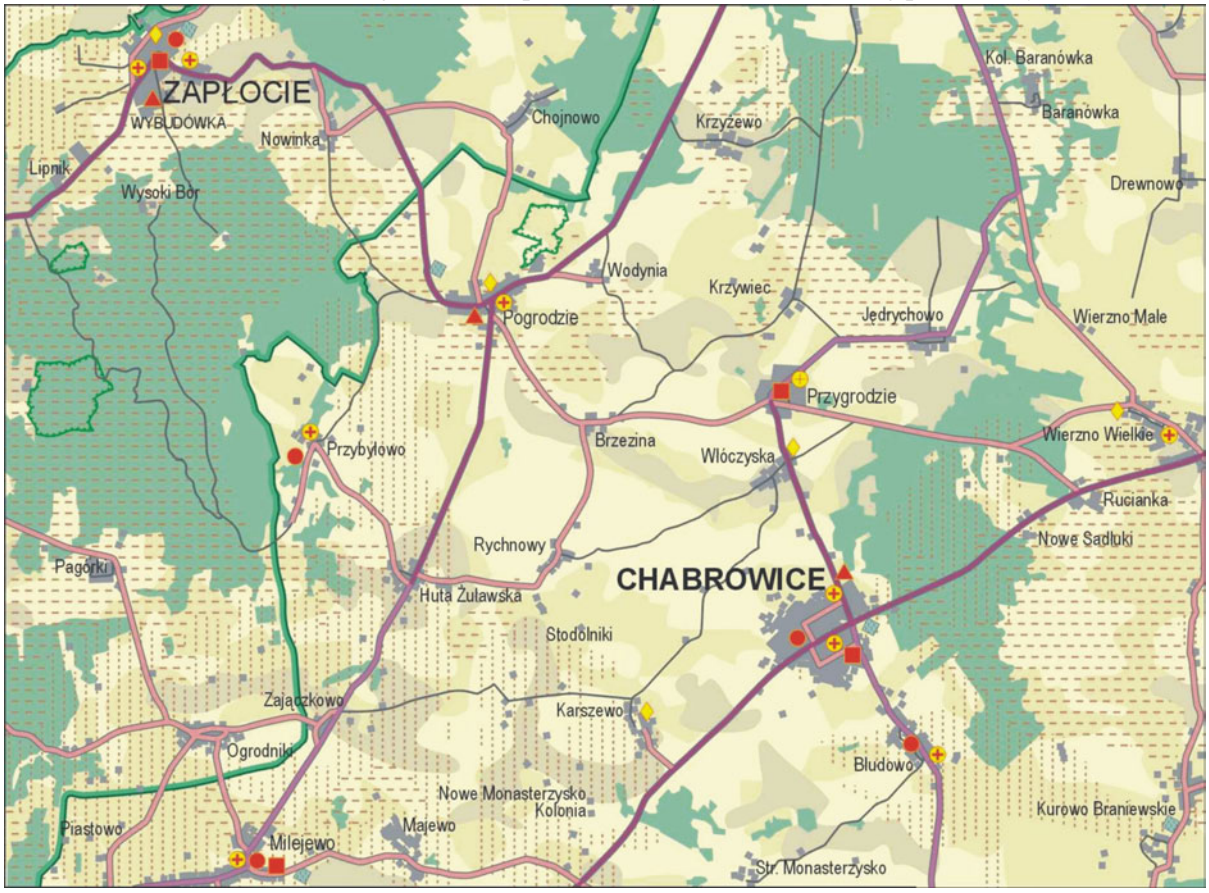

Fig. 2. Map used for the problem solving tasks (scale reduced)

Tested legend designs

Dykes et al. (2010) indicated that the legend layout must reflect meaningful geospatial or attribute structure by arranging symbols in a relational manner. Three legend designs were applied in the experiment (fig. 3). Each of them has its own advantages highlighted by various authors.

The first used legend design "list-legend" results from 1-D ordering of legend items. It consists of a one column of signs followed by their meanings. It is often used solution, due to its simplicity. The simple legend layout was a preferred design in experiment conducted by Pickle et al. (1995) when testing statistical maps.

The second applied design is "grouping-legend". In this legend layout signs are again ordered in a row, but they are grouped in thematic categories that are accompanied by appropriate subtitles informing about their content. This is the layout recommended by J. Bertin (1983). He argued that "titling speeds the acquisition of this knowledge and dispels potential ambiguity" (p. 19). Furthermore, it clearly shows the hierarchy of signs and reduces the detail of acquired information by presenting general categories. It improves the cognitive usefulness of the legend, because a map user may learn the whole extent of the sign system by reading only the subtitles. It is not necessary to study sign by sing separately and then create on his or her own the general category. Due to limited capacity of short-term memory (Peterson 1994) such reduction of chunks, especially below the Miller's "magical number" 7±2 (Miller 1956), decreases the

cognitive burden. Furthermore the areal signs where ordered in a matrix legend, which was proved to be more effective than two separate sublegends of each theme (Aspaas, Lavin 1989).

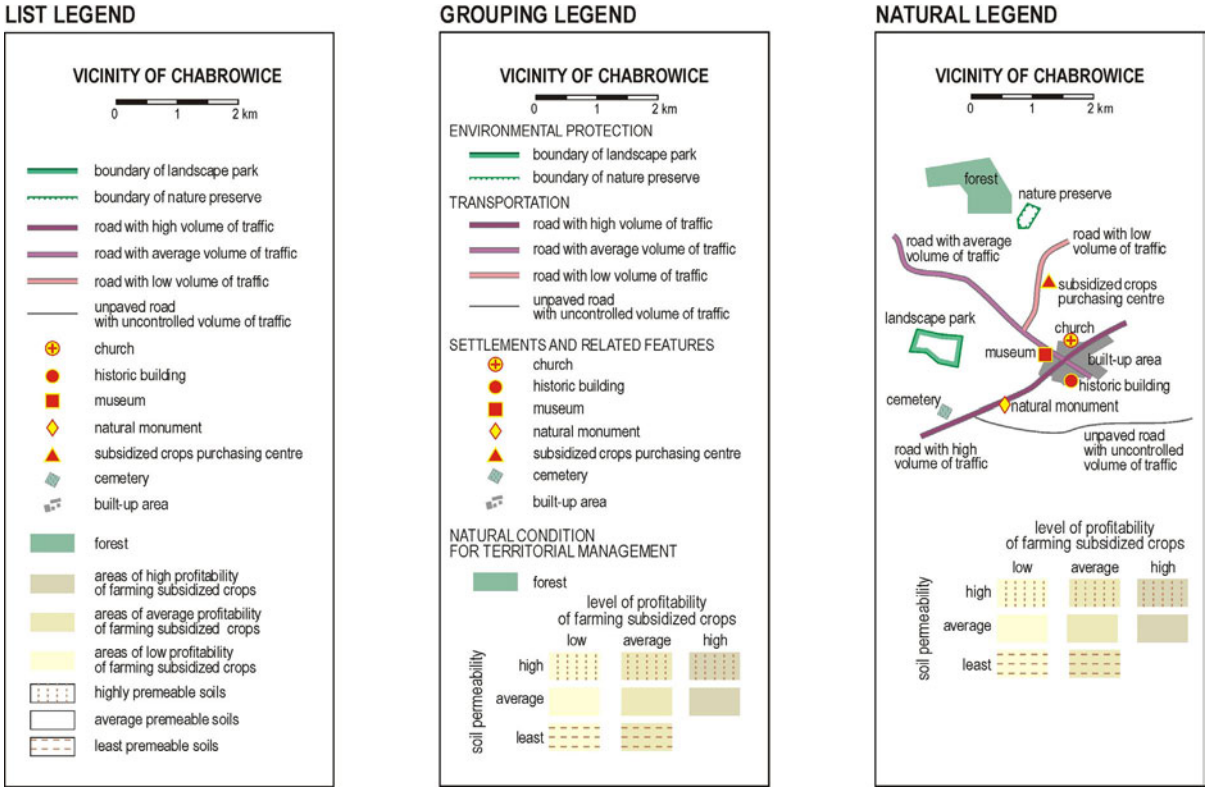

Fig. 3. Legend designed used in the experiment (scale reduced)

"Natural legend" is the last layout applied in the experiment. Since the legend is an auxiliary map, where symbols are depicted in a fictitious geospatial environment, it represents also spatial relations between signs. This way some government topographic services introduce symbols for landforms and water bodies (Schlichtmann 1997), but it is not a commonly used design. Edsall and Deitrick (2009) when studied unconventional design, noted that users focused on untypical solutions what resulted in longer time response, but higher accuracy. In this layout the dimensionality of a legend concurs with dimensionality of a map. MacEachren (1992) explains that legends which reflects the nature of relationships in the data is likely to be more effective. In this way it relies on the schemata – elements of long-term memory used to organize knowledge and frame future understanding. This legend layout was tested in the empirical study and resulted in higher effectiveness than traditional design (DeLucia, Hiller 1982), but the experiment was subject to several objections (Pasławski 1983).

Study participants

60 graduate students of Territorial Management at University of Warsaw volunteered to participate in the study. They were selected as participants because of their good skills of thematic map reading and being accustomed to the usage of a map as a tool for problem solving. Furthermore, the user group do not perform given tasks as a routine, and is as homogenous as possible in their skills and knowledge: they all pass the same entrance exam to the Masters' studies. To obey bias caused by the sex of participants, the same number of males and females was allocated in each group. Age of participants ranged from 21 to 28 years, with 23 years as average.

Procedure

The participants were divided into three groups, 20 subjects each. Every group was presented the same face map but different legend layout. Each person had to solve three problems using information from the map. Subjects were asked to determine the best locations of objects with different locational requirements: (1) a dumping site, (2) a luxury hotel and (3) a plantation of subsidized crops. Therefore, localizing each of those objects required using different information from the map.

Method

In the experiment the think-aloud method was applied. The method was chosen since it provides direct, in-depth information on cognitive processes (Elzakker 2004). The subjects were asked to voice their thoughts during the tasks executions, the whole process of verbalization was recorded. Moreover, the action was

captured from the screen, as the users were asked to pick with cursor the area of the map they were looking at. Recording from the screen was the complementary information in case of any doubts arise during coding of protocols.

RESULTS

Think-aloud protocols were prepared based on the collected recordings. The protocols show what kind of map-legend interaction strategy was applied. Based on the coded protocols the triangular graphs were developed (fig. 4). This type of graph is applied in many other disciplines (economy, statistics) for presentation of features' structure consisting on three characteristics, as well as for the presentation of typology (e.g. *Nationalatlas Bundesrepublik Deutchland* 7 Bd., p. 18, 2006). The point's location close to one of corners shows the dominance of one of the characteristic.

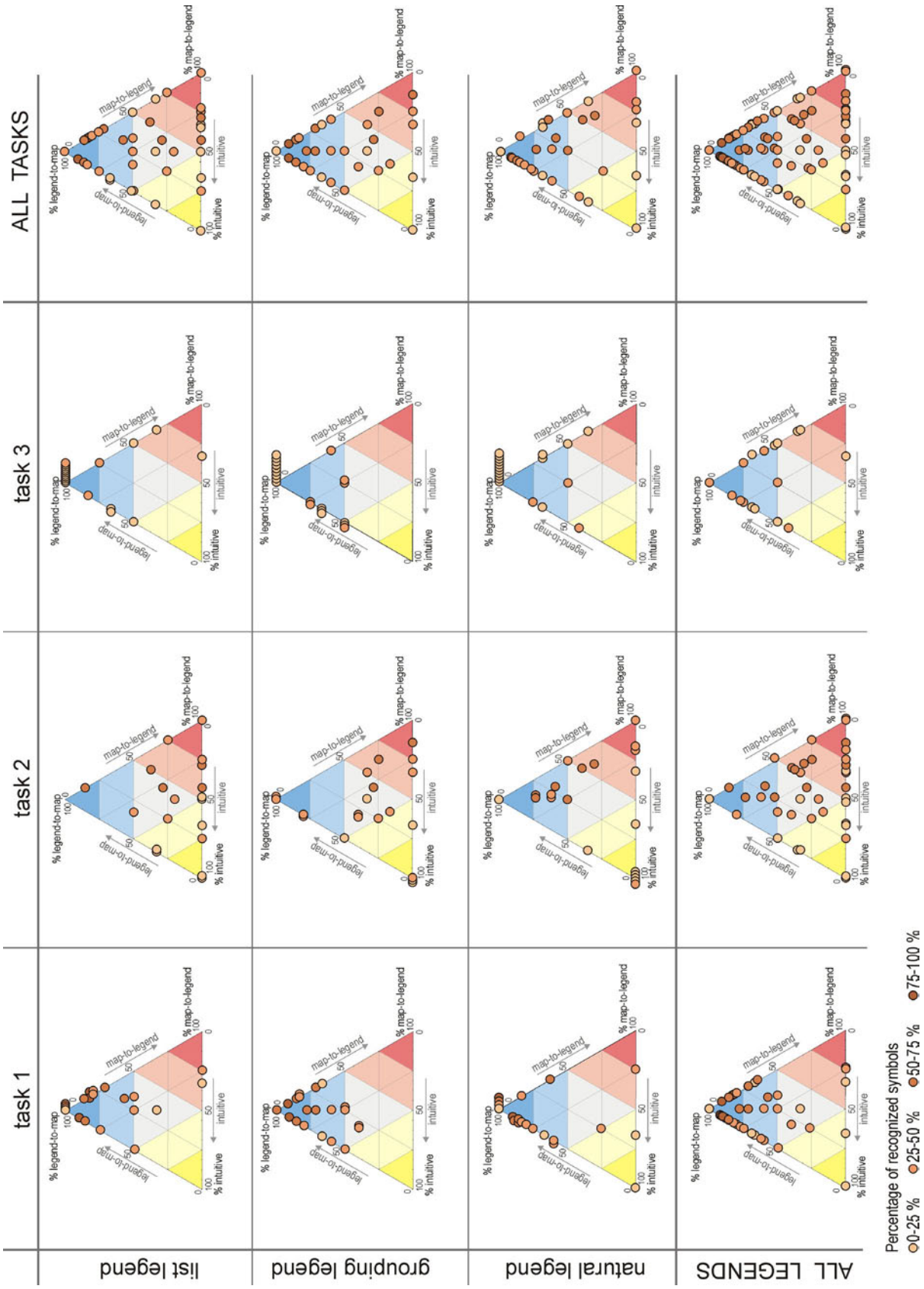

Fig. 4. Strategies of map and legend integration applied by users

The graphs on fig. 4 show percentage of recognized symbols using each strategy. For sake of clarity the background color was applied: the more saturated color in the background, the more dominant is one of the strategies of map and legend integration. One symbol on each graph represents one participant. The fill color of symbols indicates the percentage of recognized symbols by a user in a given task. The symbols

within graphs referring to particular task and legend were slightly moved in case of being covered by other symbols characterizing the same values, e.g. in a result symbols in top corners of graphs referring to the third task are located in a row. Symbols' location within graphs that represents the results from all tasks (last column) and all legends (the last row) was not modified when covering, because there were too many of such cases.

The first graph presents results from the first task (determining the best location for a dumping site) of subjects using list-legend. The percentage of legend-to-map strategy application increases toward the top corner. Therefore, the higher a symbol is located within the triangle, the more often subject applied this strategy: all but three subjects applied this strategy for at least half recognized signs. There were four subject who applied this strategy for all of the recognized symbols. The percentage of map-to-legend strategy increases towards left bottom corner of the triangle, the right side axis scales the percentage and within a triangle it is located according to oblique lines leaning towards right side and left side axis indicates zero value for the map-to-legend strategy. The graph shows that only 2 subjects applied the strategy for more than 50% of recognized signs, whereas 14 subjects used this strategy for 25% or less read symbols, and 8 subjects did not applied the strategy at all. The last strategy – intuitive – is scaled on the bottom axis and the percentage of its application increases toward left axis and is located according lines leaning toward left side with zero value at the right side of the triangle. On the analysed graph it can be seen, that only one subject used the intuitive way to determine the meaning of 50% of recognized sign, and 17 subjects used the strategy for recognition of 75% and less read sign. Furthermore, half of subjects did not used the intuitive strategy.

To sum up, users of list-legend in the first task preferred legend-to-map strategy. About 1/3 of users did not make this strategy the dominant one (used it for less than 50% of recognized signs) and it resulted in reading only limited extent of signs – they recognized less than half of symbols.

Analyzing in this way rest of the graphs can lead to noticing some differences in using strategies of map and legend integration that are described in next sections: across used legend designs and across tasks.

Effect of legend design

Users of the different legend designs applied three strategies of legend-map integration in different frequency. The differences are the most visible in the first task, when users had to acquire the whole information from the map. Whereas in next questions the learning effect played gradually more important role.

In general, in the first task (determining the best location for a dumping site) the legend-to-map strategy dominated among users of every legend layout (69% of recognized signs in average). The two other strategies were applied in different proportions by users of different legend layouts. The users of the list-legend the more often relied on the map-to-legend (used for 19% of recognized signs) than intuitive strategy (used for 12% of recognized symbols). The subjects using other layouts, grouping and natural legends, applied more frequently intuitive strategy than map-to-legend. Grouping-legend resulted in rather balanced distribution of applying the two strategies: 13% of read symbols was recognized through applying intuitive strategy and 17% ─ through map-to-legend approach. The users of natural legend often applied legend-to-map strategy (69% of recognized symbols) together with intuitive approach (22%). They hardly ever applied map-to-legend strategy, used it for recognition of only 9% of read symbols.

In the second task (choosing the best location for luxury hotel) the dominant strategy was intuitive for all users. Users of list-legend most frequently applied map-to-legend strategy, for over 38% of recognized symbols, and least frequently referred to legend-to-map strategy (18% read symbols was recognized using this approach) comparing to users of other layouts. Subjects using grouping-legend often applied the three strategies in similar proportions. Whereas the natural legend's users gave more extreme results: the points are located within areas with colored background, that symbolizes dominance of one of the strategies.

The third task was the most influenced by the learning effect, and showed very little differences between users of the three legend layouts.

The aggregated results from all three tasks, presented in the last column, reveal additional differences among the layouts. Users of the list-legend tends to prefer map-to-legend strategy. Furthermore, participants using this legend design applied legend-to-map strategy the least often: there is a number of symbols located on the triangle's bottom axis, which represents zero value for this strategy. The grouping legend resulted in similar distribution to list-legend users, but with more frequent usage of the legend-to-map strategy. Whereas the natural legend is the only layout that resulted in solution with dominance of one of strategies – there are no symbols within the grey area.

Effect of tasks

Frequency of applied strategies for each task is presented in the last row. The applied strategy differs across the questions. The learning effect is important, as well as the different requirements of each solved task.

When reading a map with unknown content, users often started with studying the legend – 85% of subjects applied this strategy for more than half recognized sings, but only half of subjects used this approach for more than 75% of recognized signs. Therefore, it turns out that legend was not so carefully studied as cartographers would wish. Other strategies were dominant in the similar frequency. What is important, subjects who featured a dominant legend-to-map strategy recognized more signs (almost half of included in the legend) than participant who preferred other strategies (about 25% for each strategy). There was strong, positive correlation between number of recognized symbols and application of legend-to-map strategy ($r=0,53$; $p<0,01$).

The second task resulted in even frequency of each strategy: the points are rather equally distributed within the graph. More than 35% of subjects applied the intuitive strategy for most recognized signs, so they recall the meaning of symbols learned during previous task. Furthermore, there was narrower extend of recognized signs (23%) comparing to subjects preferring other strategies (35% to 42%). It was the result of the fact that users have already learnt the thematic extent of the map and they refer to the characteristics that were expected to be necessary to solve the given problem.

The last tasks was solved in very similar way by all users, the signs are located in several location within the triangle, many of them are covered by another. In this tasks users generally referred only to the symbols that were crucial for solving this task. What is interesting, most users (85%) applied only two strategies – most signs are located on the one of the axis of the triangle. Only one user combined map-to-legend with intuitive strategy, most subjects combined legend-to-map strategy with one of the rest two approaches. The legend-to-map strategy turned out to be again dominant due to variations in type of characteristics that were required for the task – users had to refer to the areal symbols which present ordinal information.

CONCLUSION AND FUTURE PLANS

The largest differences between approaches to integrate legend and map were visible during solving the first task. It was not affected by the learning process, hence the effect of the different legend layouts was the most visible.

Results show that hardly any user studied the entire legend in the very beginning of the task solving process. In fact, in most cases, subjects acquired only part of the information concerning the applied system of symbols, proving to be "cognitive misers": they did not perceive the entire available information. Furthermore, there was the strong, positive correlation between the extent of recognized symbols and the frequency of legend-to-map strategy appliance. Therefore, focusing a user's attention on the legend content is very important, especially at the beginning of the map use. Such attention differed when using various legend layouts.

Subjects that were given a list-legend applied the map-to-legend strategy the most often among all users. They tend to resign from studying the entire legend in "symbol after symbol" way, and the most often decided to refer to the legend when they noticed an unknown sign on the map. Also in the second task the users applied map-to-legend strategy more often than other users. Çöltekin et al. (2009) when comparing the interface design reported one participant saying that "people don't like reading too much" (p. 15). This research supports this statement showing that such long column of signs seemed to be discouraging for users. Therefore, list-legend design should not be applied in case of numerous symbol set that has to be explained.

Users that were given the grouping-legend were willingly using the legend, since it is a familiar and visibly structured layout. In result, users recognized the largest extent of the symbol system. Also referring to the legend in map-to-legend approach was not difficult to them, and they easily applied this strategy. Furthermore in the last task, users that were given the grouping-legend applied the most often intuitive way of recognition symbols' meaning. It suggests that they remembered the greatest extent of symbol system. The analysis showed the positive results of grouping-legend appliance.

Natural legend usage resulted in least often use of map-to-legend strategy during solving the first task. This effect is probably caused by the fact that it was difficult for users to refer to legend content instantaneously after observing an unknown symbol on the map. In order to learn the meaning of symbols they the most often studied the legend or discouraged with unfamiliar legend design – guessed its meaning. In the next tasks, when they got familiar with the legend design, they more often applied map-to-legend strategy than in the first task. The users reported that initially they were a bit confused with the unfamiliar

layout, but after noticing how symbols are ordered, the natural legend usage was not a problem. Therefore, when choosing the untypical legend design the attention should be put on indicating the rules of applied design.

Learning and recalling operations were gradually more important in the subsequent tasks. This effect decreased the importance of different legend layouts and make the strategies uniform for all subjects in the last task.

In order to supplement the knowledge concerning the role of legend in map use process, the results will be compared with other information acquired from the think-aloud sessions: sequence of reading of the legend content and strategies of problem solving. Due to applying mixed methods approach (Creswell 2003), the usability metrics will be integrated: the accuracy and response time of answers as well as the users' opinion on the legend used. This will enable analysis of various aspects of legend use at various cognitive subtasks (Herrmann, Pickle 1996) and will make the conclusions more comprehensive.

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