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Investigating the Readability of School Geographic Map Symbols Using Eye-Tracking Technology

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Annotation. Geography atlas is an educational material that is very important in geography education. For the eye tracking experiment, six mineral maps were selected from different geography atlases for high school students. The aim of this study was to analyze which design of conventional symbols is more understandable for high school students. We hope that the presented methodology and the case study will help mapmakers to create more effective school geographic maps.

Keywords: *school atlas, geography education, thematic maps, eye-tracking, map reading.*

Introduction

The map is a very important source of geographical knowledge, which has a particularly important role in geography education. Today, in geography lessons, it is impossible to provide students with knowledge of the earth, social and economic processes without the use of maps. Educational materials without which geography learning is unimaginable are school geography atlases (Beitlova et al., 2021).

School geographic atlases are special products, the preparation of which requires special professional knowledge, skills, and experience. Not every publishing house produces atlases and maps that are intended for geographic education. The creation of each atlas is a highly labor-intensive and multi-level process, extending from the initial idea to the final printing. This intricate undertaking requires the collaborative efforts of the entire team, including authors, editors, cartographers, and designers (OpenAI, 2023). At the same time, it should not be forgotten that school atlases have strict requirements both in terms of content and design.

In the Republic of Lithuania, it is possible to purchase three school geography atlases, which are intended for high school students. These atlases are published by three different private publishing companies: BRIEDIS, ŠVIESA, and DIDAKTA.

These school geography atlases (Ambrutienė & Krušinskienė, 2005; 2007; GAUBLYS. Geografijos Atlasas 9–12 Klasėms, 2017; ŽEMĖ. Geografijos Atlasas 10 Klasei, 2019) contain maps focusing on the nature and economy of the Republic of Lithuania, the continents, and the world economy. Teachers often have the question of which publisher's atlas to choose, so that students can use it conveniently when learning different topics. Another an important question that is very difficult to answer is which publishers' atlases provide the best and clearest presentation of the content of their maps.

The use of image presentation methods (Bertin, 1967) in school geography atlas maps depends on the nature and size of the object, the space covered by the phenomena, and the directionality and intensity of the processes. The type of map should be chosen depending on the information used in the map (Havelková & Hanus, 2018; Slocum et al., 2008; Tyner, 2010). School maps often use linear signs, localized diagrams, cartograms (Nusrat et al., 2018), as well as the qualitative background method itself. Quantitative indicators of spatial dispersion are provided by the quantitative background method, using monochrome color scales of varying shades (Słomska-Przech & Gołębiowska, 2021), sometimes with hatching. Homogeneous phenomena are mapped by isolines. To enhance the visual impact, the gaps between isolines are colored with harmoniously varying shades of a single color. Areas are represented on the maps in several ways: by contrasting colors or by hatching. These options are used when neighboring ranges do not overlap. The mark method is particularly popular on educational maps. Pictorial and geometric symbols make it possible to distinguish very clearly the phenomena and objects depicted. It cannot be overlooked that many of the cartographic marks on maps depicting the same phenomena or objects are different.

Until now, there has not been enough research to prepare standards or recommendations for the representation of conventional symbols, map creation methods, graphic and informational loads in school geographical maps.

Bautrėnas et al. (2011) assessed the importance of cartographic publications, such as maps, atlases of various topics, wall maps, etc. for secondary schools. The authors of the article seek to confirm the notion that cartographic publications are an integral and continuous part of children's education, which requires the active cooperation of all professionals involved in education. Ročiūtė et al. (2009) conducted a study on the perception of cartographic signs in Lithuanian schools. The questionnaire survey was conducted in nine schools, with a total of 250 respondents from senior classes. Based on the results of the survey, the easiest to understand signs were identified and the lack of sign systems was highlighted. Attempts were made to correct the signs in terms of shape and color, and more informative and accurate ways of cartographic representation were also proposed.

Voženílek et al. (2014) examined the symbolism in different school atlases around the world that are used in European schools. The focus was on students' cognitive aspects of cartographic symbols, in order to answer how students perceive the symbolism in school atlases in different countries. The study used literature search, atlas comparison, online surveys, and statistical processing. The results of the study confirmed that pupils were able to understand map symbols and cartographic techniques in the European school atlases used.

Bugdayci and Bildirici (2016) examined the shortcomings of current atlas maps used in geography and social science education in terms of cartographic design. About 22 atlases were examined for the study. The authors examined the degree of generalization, applied symbols and fonts, colors, and common elements of the map. Several examples and suggestions for improving the cartographic design of the maps in the atlases were also presented.

User research using eye-tracking technology is one way to test the readability and perception of maps (Stachoň et al., 2018) and the validity of geovisualization (Brychtova & Coltekin, 2016; Burian et al., 2018; Popelka et al., 2019). The eye tracking method is considered to be the most appropriate and objective method (Krassanakis & Cybulski, 2021) for conducting user research because there is a close relationship between the user's eye movements and cognition (Duchowski, 2017; Jacob & Karn, 2003; Rayner, 1998). Eye tracking can be used to assess the direction and movement of a student's gaze on the map, the way they read the information or the influence of distracting elements, and other aspects of map perception. The results can be used to develop new maps that take into account user requirements.

Eye movement studies have a major impact on map design. The results of the city plan evaluation study (Burian et al., 2018) showed that the quality of the map symbols and the map legend have a significant impact on the legibility and readability of city plans. Eye tracking was used to identify users' strategies in thematic map analysis tasks (Havelková & Gołębiowska, 2019), as well as the influence of map labels on map perception (Liao et al., 2019). Beitlova et al. (2020) conducted an eye-tracking study that compared students' and their geography teacher's reading of thematic maps. The results of the study showed that students had difficulties due to illegible map symbols. This is the only study that evaluated maps from school atlases.

This paper describes an eye-tracking study. The study used maps of the same topic from different Lithuanian school geography atlases as stimuli. Using these maps, the participants searched for the specified objects.

The purpose of this study was to analyze how quickly, and accurately high school students perceive various signs in different designs of mineral maps. To conduct the research, a working hypothesis was formulated, suggesting that the time spent on a specific task essentially reflects the suitability of a map for the educational process. The results obtained from the study would enable the formulation of guidelines for optimizing the content and design of maps on relevant topics.

Optimizing the content of school atlas maps and map design is becoming an important educational issue. It is not uncommon for school atlas maps to be created by simplifying the content of maps intended for professionals. The spatial perception abilities of pupils, their capacity to distinguish and identify conventional signs, and the nature of their spatial distribution are not always considered (OpenAI, 2023). This is particularly relevant in 5–6 classes. Pupils often struggle with naming geometric shapes of conventional signs, designing more complex visual signs with many elements, non-contrasting colors, and so on.

The main aim of this study was to analyze which design of conventional signs is more comprehensible to pupils in upper secondary school.

Materials and Methods

Participants

24 high school students who study in Lithuanian high schools participated in the experiment. Their age is from 16 to 18 years (16 females and 8 males). Secondary school students were chosen for the research because they already possess experience in map perception through their geography studies. Another essential criterion is the age of the students. Students aged 16 and above can participate in non-traumatic educational experiments, and their involvement does not necessitate parental consent. The students willingly agreed to take part in the experiment. Participants from grades 10–12 were involved in the study. The inclusion of students from various classes in the experiment, according to the researcher's objectives, aims to yield data on the completeness of map perception across different age groups. Furthermore, the research sought to determine whether students of varying genders perceive map content equally quickly and in detail. While studies evaluating the reaction speed of the eyes in different sexes have been conducted (Brychtová et al., 2012), research of this nature is relatively novel and infrequently performed in the school and student environment (Dong et al., 2018). Since these are high school students and this experiment did not require special preparation, this ensured that their knowledge of geography was at a similar level and the results were comparable.

Stimuli and Task

The atlases selected for this study are geography atlases published by three Lithuanian publishing houses and aimed at upper secondary school students. From these atlases, six thematic maps on minerals were selected for the experiment.

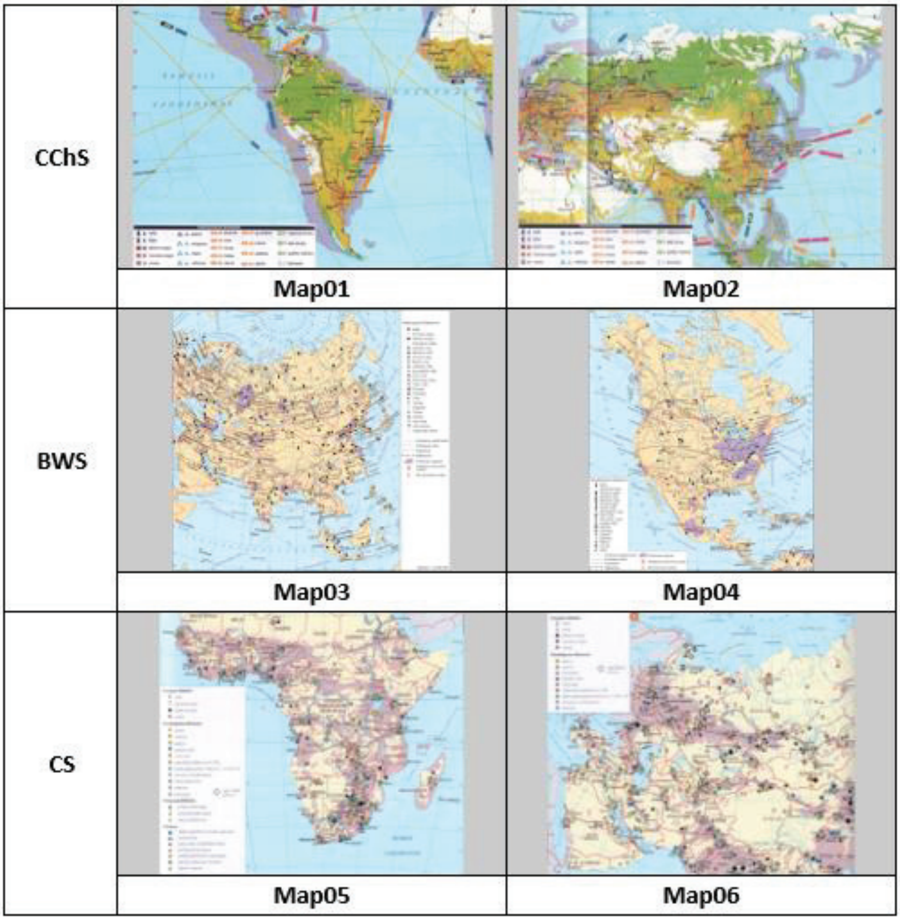
The maps used different design methods and showed different amounts of information. It was decided to divide the maps into three groups, based on the same design style:

- CChS – maps with colored mineral symbols and symbols of chemical elements written on them (Map01, Map02).
- BWS – maps with black and white mineral symbols (Map03, Map04).
- CS – maps with colored mineral symbols (Map05, Map06).

The monitor used in the study had an aspect ratio of 16:9 and a resolution of 1920 × 1080, so some maps have been cropped for better readability. The map legend has been left. Stimuli were presented in random order during the study. All study stimuli are presented in Figure 1. Full resolution previews are available at http://dx.doi.org/10.18279/MIDAS.SF.230153.

Figure 1

Map Stimuli are Used in the Study



Respondents had to find the object in the legend and identify it on the map. A distinct task was formulated for each stimulus. Each participant in the experiment was asked the same set of questions, specifically concentrating on the identification of useful minerals marked on each map. The tasks were presented in Lithuanian. The translations of these tasks are presented in Table 1.

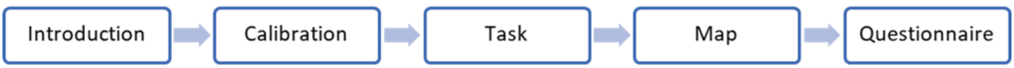
Table 1
List of Tasks for the Experiment (Translated From Lithuanian to English)

Task ID	Description of Task
Task01	Identity tin
Task02	Identity uranium
Task03	Identity platinum
Task04	Identity phosphates
Task05	Identity platinum
Task06	Identity phosphates

Experimental Design and Procedure

An eye tracker called Gazepoint GP3 was used to perform eye movement analysis, which recorded eye movements at a frequency of 60 Hz. This device is lightweight, compact, and does not require a dedicated room or special software for its use. It can be connected to a laptop, creating mobile research "station". This enables researchers to visit participants of the experiment and conduct it swiftly. The device automatically captures eye movements, facilitating the subsequent analysis of the acquired data. The experiment was designed using Gazepoint Analysis software. Due to the nature of the experiment, i.e., eye tracking, only one subject can participate in the study at a time. The scheme of the study is presented in Figure 2.

Figure 2
Scheme of the Study



Each subject is informed that all data are collected anonymously. The experimental procedure was also introduced to the presentation of static map images asking them to find cued objects. The subject is seated in front of the screen at a distance of 60 cm. The eye tracker is calibrated with a 9-point calibration. The study begins by first presenting an image with the task of what the subject must find on the map. Visual tasks (stimuli) were presented on a 17-inch screen monitor with a resolution of 1920×1080 pixels. After reading the question, the participant has to press the space key on the computer keyboard, then a map is shown where the subject has to search for the object. After finding an object on the map, the subject must press the space bar again to move on to the next question. Subjects were not given time limits to read and complete the task. Each experimental task is completed by collecting information about the subject's gender and age. After each experiment, the subject was shown the result of the experiment they performed, how they did by showing a Heat map or Scan Path map.

The survey data were recorded using GazePoint Analysis software, which provides functions for visualizing eye movement data but has minimal data analysis capabilities. Given the substantial amount of data generated by the eye-tracking study, the free, open-source statistical software R was employed for data analysis.

Results

During the study many eye movement parameters were recorded. Several parameters were selected for analysis, namely trial duration, and the number of fixations. Sequence chart visualization was chosen for map and legend analysis. According to these parameters, the signs were judged as having good or bad design.

Trial Duration

The idea of the experiment was based on a working hypothesis: the time spent on a task reflects the optimality of the map image. This means that, all other factors being equal, the speed of obtaining information from the map (object position identification) depends on how well the map is created. This includes the correct and proper mapping of objects (shape of signs, size, colour), the extent to which phenomena are revealed (boundary marks, colours, dashed lines), the presentation of the directionality of processes (vectors, diagrams), and how this relates to the information used.

Trial duration shows how long it took to complete the task. The lowest mean trial duration time was in the CS map group (M = 9.76 s, SD = 4.46) (see Table 2). The BWS group had a slower mean trial duration time (M = 28.25 s, SD = 25.63). The CChS group took, on average, the longest time to complete the map tasks (M = 30.44 s, SD = 14.77).

On average, the fastest task was Map06 (M = 8.80 s, SD = 2.22) (see Figure 3). The Map05 task took slightly longer (M = 10.71 s, SD = 5.81). The time to complete the two tasks was between 20 and 30 s: Map03 (M = 23.48 s, SD = 18.48) and Map01 (M = 28.41 s, SD = 12.57). Similar completion times were observed for the Map02 and Map04 tasks (M = 32.48 s, SD = 16.71, and M = 33.03 s, SD = 30.88). According to the obtained results, the Map04 task required the most time.

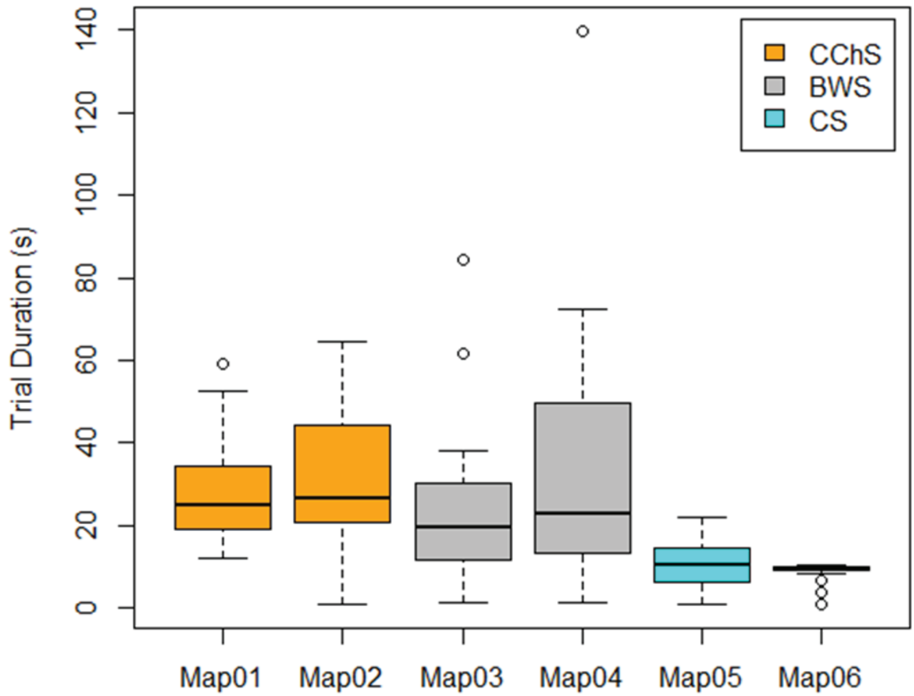
Table 2

Inferential Statistics on Trial Duration

Group	Map	Min	Mean	Max	SD	Mean	SD
CChS	Map01	12.04	28.41	59.36	12.57	30.44	14.77
	Map02	0.90	32.48	64.61	16.71		
BWS	Map03	1.46	23.48	84.36	18.48	28.25	25.63
	Map04	1.17	33.03	139.90	30.88		
CS	Map05	0.87	10.71	21.91	5.81	9.76	4.46
	Map06	0.90	8.80	10.22	2.22		

Figure 3

Boxplot of Trial Duration Values



According to the duration of the test, the marks for the best design are on Map06 and for the worst on Map04.

Fixation Count

The number of object fixations represents the "know-find" relationship between the experimenter and the map. This means that, even knowing where the object is, it is usually not fixed by the eyes the first time. Consequently, the more fixations, the more one moves away from the connection "know – find", and the connections "know – search – find" or "don't know – search – find" begin to dominate.

The number of fixations indicates the number of fixations that have been made during the task. The lowest number of fixations was in the CS map group (M = 25.46, SD = 10.54) (see Table 3). The number of fixations in the BWS group was twice as high (M = 63.42, SD = 52.64). The highest number of fixations was in the CChS group (M = 67.31, SD = 34.52).

Table 3
Inferential Statistics on Fixation Count

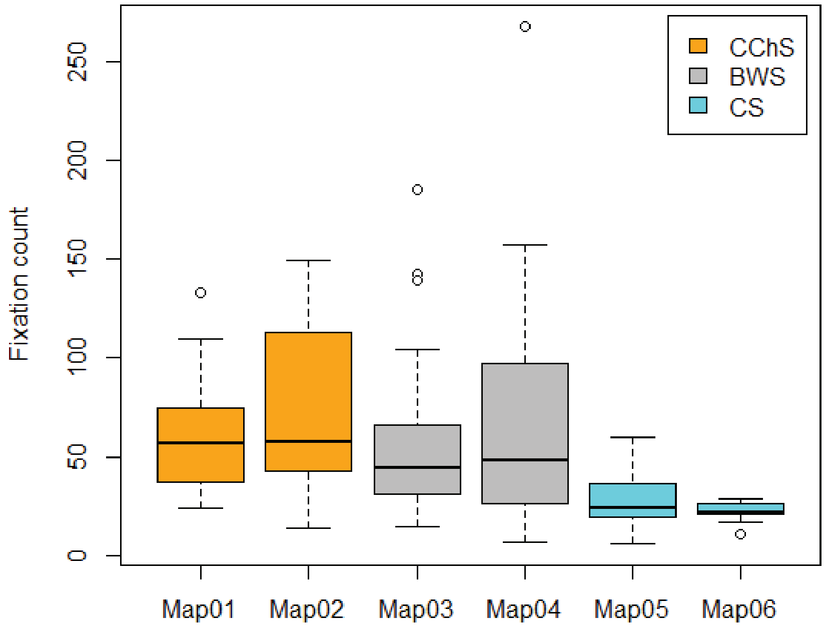
Group	Map	Min	Mean	Max	SD	Mean	SD
CChS	Map01	24	58.88	133	26.66	67.31	34.52
	Map02	14	75.75	149	39.70		
BWS	Map03	15	58.17	185	43.37	63.42	52.64
	Map04	7	68.67	268	61.02		
CS	Map05	6	28.29	60	13.96	25.46	10.54
	Map06	11	22.63	29	3.94		

On average, the lowest number of fixations was recorded in the Map06 task (M = 22.63, SD = 3.94) (see Figure 4). Slightly more fixations were recorded in Map07 (M = 28.29, SD = 13.96). Two tasks had almost the same number of fixations: Map03 (M = 58.17, SD = 43.37) and Map01 (M = 58.88, SD = 26.66). A relatively high number of fixations was recorded in the Map04 task (M = 68.67, SD = 61.02). The highest number of fixations was recorded in the Map02 task (M = 75.75, SD = 39.70).

Based on the count of fixations, we conclude that the best design is Map06, and the worst is Map02.

Figure 4

Boxplot of Fixation Count



The Relationship Between Map and Legend

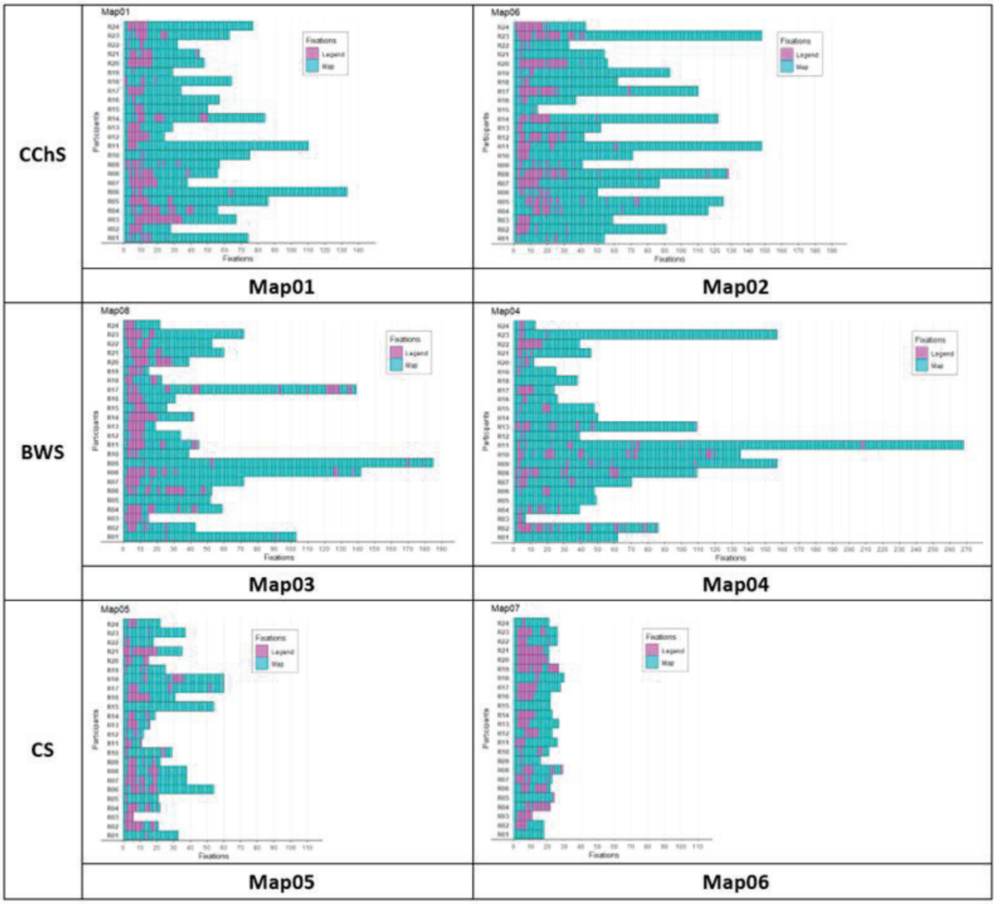
Map legend – a key used to identify the symbols on the map: signs, lines, colors. At the beginning of the study of the map, it is necessary to analyze its legend and understand what graphic symbols are used to present its content. While analyzing the map, the participant of the experiment constantly pays attention (returns) to the legend, checking the meaning of the symbols. This means that the subject consistently pays attention to the map and its legend.

The distribution of attention between the map and the legend was visualized using sequence charts. These charts were used to find out how often and for how long an object was searched for in the legend and on the map. Therefore, the legend of each map was indicated as an area of interest (AOI). The sequence chart shows the sequence of viewing by respondents. From the sequence chart, it is possible to see where the respondents' attention was focused first and later.

The sequence charts show the recorded eye movement data at the identified AOIs. Sequence charts were created using RStudio. The data are represented by colored bars according to the AOI. The fixations are shown in cyan in the map field and magenta in the legend. For each map, a sequence chart was created with data from all respondents. All sequence charts are shown in Figure 5. Sequence charts for all tasks are available at http://dx.doi.org/10.18279/MIDAS.SF.230153.

Figure 5

Sequence Charts for All Six Maps



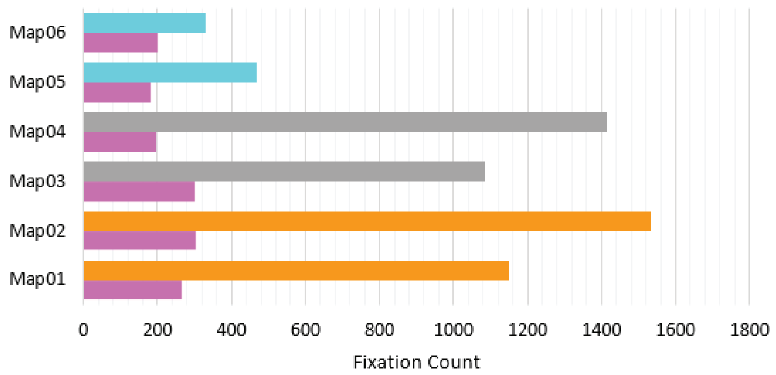
As can be seen from the sequence charts, on some maps, respondents found the symbol in the legend, looked for it on the map, and then looked at the legend again, or even multiple times. However, the opposite search pattern can also be observed. They first looked at the map and then looked for the symbol in the legend. After finding the symbol in the legend, they continued to look for it on the map.

The number of map fixations contained in each AOI (legend and map) was calculated and is shown in Figure 6.

The most fixations were observed in the Map02 legend and the most fixations were also recorded in the Map02 map. A similar number of fixations were recorded in the legend Map03. The lowest number of fixations in the legend was recorded in Map05. Although Map06 had the least number of fixations in the map.

Figure 6

Number of Fixations in Legend and Map

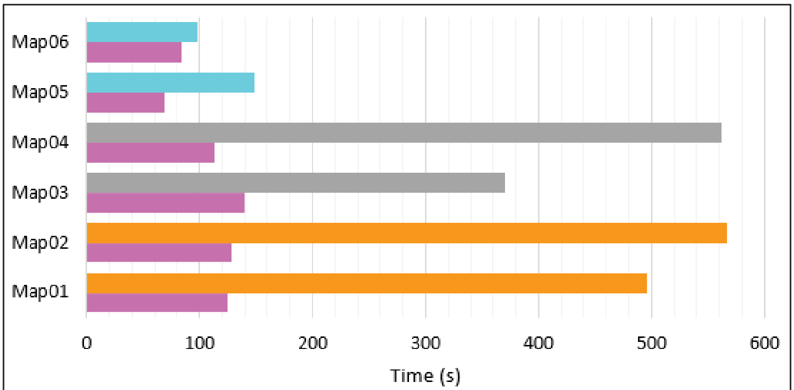


	CChS		BWS		CS	
	Map01	Map02	Map03	Map04	Map05	Map06
Map	1151	1531	1083	1415	470	329
Legend	265	305	300	197	180	202

The time spent in the AOI was also calculated. As can be seen from Figure 7, the viewing times on the map and in the legend Map06 are very similar. However, the least amount of time in the legend was observed in Map05 and the longest in Map03. The least time spent on the map is on Map06 and the most time is on Map03.

Figure 7

Respondents' Viewing Time Spent on AOI (Map and Legend)



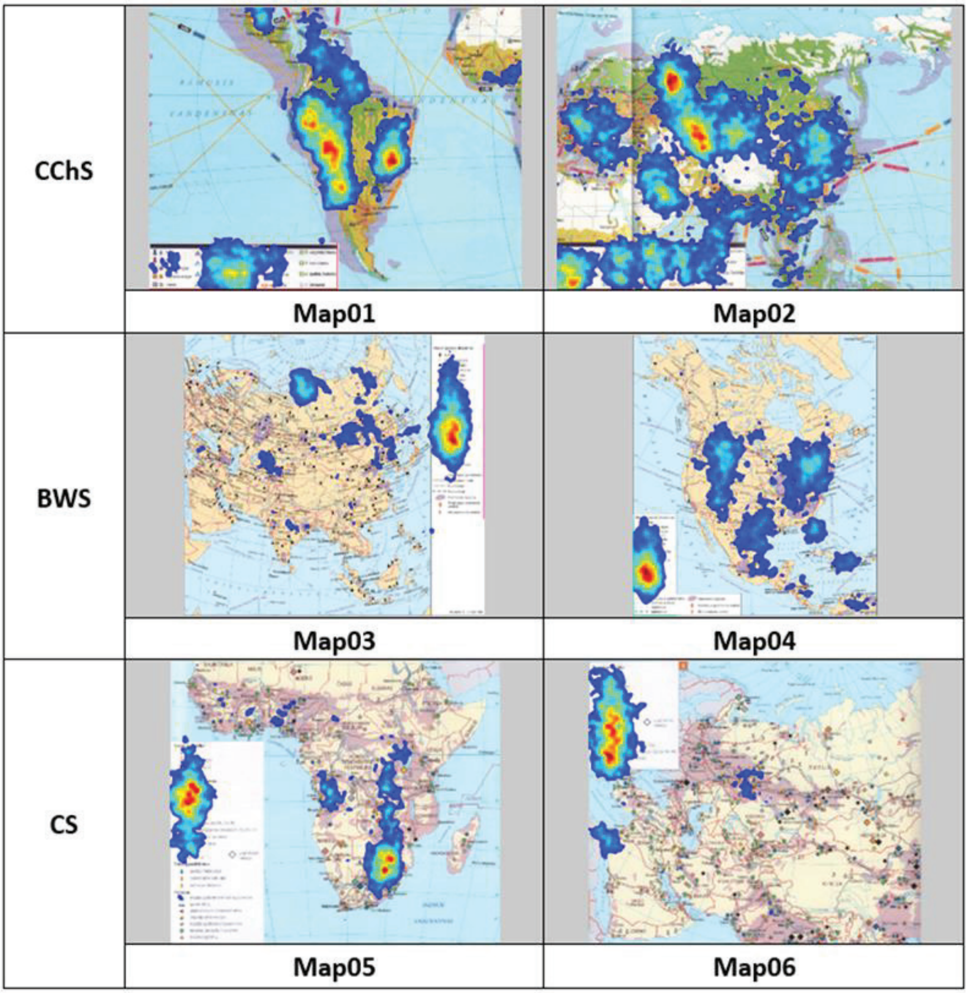
	CChS		BWS		CS	
	Map01	Map02	Map03	Map04	Map05	Map06
Map	495.63	566.98	370.46	562.03	148.14	98.44
Legend	125.11	128.77	140.01	113.74	69.25	83.80

The gaze fixations of the respondents were visualized. One commonly used way of visualizing eye movement data is Heat maps.

Heat maps can be used to quickly review survey data. These maps show the distribution of visual attention across stimuli. Gaze heat maps are quantitative representations of the fixations of all respondents, as they are based on statistical data. Heatmaps of all maps are shown in Figure 8. In the heat maps, red areas are hot and blue areas are colder (Pernice & Nielsen, 2009). The red color shows areas with many gaze points. The yellow and green areas show areas with fewer gaze points, while the blue areas show the areas with the least number of gaze points recorded by the respondents. Heat maps for all tasks are available at http://dx.doi.org/10.18279/MIDAS.SF.230153.

Figure 8

Heat Maps Showing the Aggregated Gaze Movements of Participants Across Stimuli



When seen from the heatmaps, most of the gaze points distributed throughout the stimulus are Map02. In the Map06 stimulus, the gaze points are mainly concentrated in the legend, while in the map they are only distributed in two regions.

Discussion

This paper describes an empirical study that assesses students' perception of the conventional signs used in the maps of different school atlases.

For this research experiment, the authors selected six thematic maps depicting mineral contract signs of different designs. The maps were used as stimuli. They were cropped to 16:9 aspect ratio to preserve the legibility of the marks on a computer monitor. There were no time limits for students to read and complete the task. The participants were 24 high school students studying in Lithuanian gymnasiums. The average age of the subjects is about 17 years.

The parameters of test duration and number of fixations were used to analyze the eye movement data. Sequence charts and heat maps were chosen for visualization. The aim was to assess which design of symbols was easier for the respondents to read and understand.

Map symbology has a significant impact on the legibility of maps (Stachoň et al., 2013). It is therefore particularly important to choose map symbols that are clear and easy to remember (Stachoň et al., 2020). According to the results obtained for the Trial duration and the Fixation count, the easiest symbols to understand are those of the maps assigned to the CS group. In maps Map06 and Map05 of this group, the lowest results were found in the AOI, both in the legend observation and in the map. This could be due to the fact that the mineral symbols on the maps in this group are presented in a simple geometric shape, quite bright, and in different colors. The quantitative information on the maps is presented in two pastel colors, showing the cultural and natural landscape. The legend is clearly structured and organized.

According to the research results, the most difficult maps to read and understand are the CChS groups. Map02 had the highest number of fixations. The legend AOI was monitored for a long time and the map AOI took the longest time to find the answer. Although the results for Map01 were better, the time required to observe the legend was similar. We believe that the problem with these maps was an inappropriate choice of visualization. In the CChS group maps, the mineral symbols are very blurred and the chemical element letter symbols are written in white. Therefore, these labels are very difficult to read. The quantitative information on the map is presented in rather bright colors, which makes the symbols themselves very difficult to see on the map. These maps contain information relating to world industry. This large amount of information makes the map difficult to read and understand.

The results obtained for the BWS group are not very good either, as Map04 was the maximum test duration. This was due to one participant's long object search. From the sequence diagrams, we can see that the participants kept coming back to look at the legend and continued to look for answers on the maps. The problem with the maps in this group was the choice of black and white symbols. Also, the outlines of the symbols are too thin, and they blur on the map. Although the maps show information related to industry and energy in colored symbols, which are more legible and eye-catching. The maps highlight industrial regions in pastel colors and line symbols in thin lines. The legend is presented in an orderly and structured way.

The research was conducted in several Vilnius schools. The number of participants in the study was small, so the assumptions for extrapolation of wider generalizations are insufficient. On the other hand, the "suitability" or "unsuitability" of mineral maps of school atlases became apparent, related to the visualization of the content of the maps: signs, colors, size of signs, and the structure of the map legends.

Conclusions

This article presents the results of a study using eye-tracking technology to investigate the perception of mineral symbols on school geographic maps.

The results show that the CS maps are the easiest to understand for students in the upper grades. These maps are color-coded with clearly distinguishable symbols and a small amount of information.

Based on the results of the study, we also conclude that the visualization of the maps of the BWS group can be improved by replacing the black-and-white symbols with colored symbols. As the design style and information content of these maps are similar.

We conclude that the CChS maps are not suitable for school atlases. The large amount of information and the poor choice of cartographic visualization make the maps difficult to read and have a significant impact on the perception of the map.

These findings are important and may inform future research. School atlases are one of the tools most often used in Lithuanian schools. It is therefore very important to carry out more user studies that focus more on map reading and perception. Such studies can be useful for map publishers and improve the cartographic perception of students. The authors plan to continue research related to the use of symbols and cartographic methods used in school atlases, using eye tracking technology.

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Mokyklinių geografinių žemėlapių simbolių skaitomumo tyrimas naudojant akių stebėjimo technologiją

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Santrauka

Geografijos atlasas yra labai svarbi geografijos ugdymo mokomoji medžiaga. Lietuvos mokyklose naudojami trijų leidyklų išleisti geografijos atlasai. Mokytojams neretai kyla klausimų, kurios leidyklos atlasus pasirinkti, kad moksleiviams būtų patogu jais naudotis mokantis skirtingas temas. Akių stebėjimo eksperimentui buvo atrinki šeši naudingųjų iškasenų žemėlapiai iš skirtingų geografijos atlasų, kurie yra skirti vyresniųjų klasių mokiniams. Žemėlapiuose pateikti naudingųjų iškasenų ženklai yra skirtingo dizaino, be to, žemėlapiuose pateiktos informacijos kiekis yra nevienodas. Pagal vienodo dizaino stilių žemėlapiai buvo suskirstyti į tris grupes. Šio tyrimo tikslas buvo išanalizuoti, kurio dizaino naudingųjų iškasenų sutartiniai ženklai yra labiau suprantami vyresniųjų klasių mokiniams. Tyrime dalyvavo 24 vyresniųjų klasių mokiniai. Jų buvo paprašyta atlikti nurodytų objektų paiešką žemėlapiuose. Atlikta gautų akių judesių duomenų statistinė analizė parodė reikšmingus žemėlapių skirtumus. Problemiškiausi buvo žemėlapiai su spalvotais ženklais, kuriuose įrašyti naudingųjų iškasenų raidiniai simboliai. Geriausiai suprantami buvo spalvoti simboliai. Tikimės, kad pateikta metodika ir atvejo analizė padės žemėlapių kūrėjams sukurti efektyvesnius mokyklinius geografinius žemėlapius.

Esminiai žodžiai: *mokyklinis atlasas, geografijos mokymas, teminiai žemėlapiai, akių sekimas, žemėlapių skaitymas.*

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