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The Next Generation of Atlas User Interfaces – A User Study with "Digital Natives"

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Abstract Atlases are one of the most complex geovisualization environments as they are very information-rich. Within these environments, a well-designed user interface is essential to explore the variety of atlas maps and media. Involving technology-affine digital natives in the interface design process seems self-evident to provide appealing and intuitively usable atlases in the future. In our study, we presented secondary school students (n=110, age 14-15 years) with five graphical user interface (GUI) mock-ups varying in layout density and tool arrangement. Each alternative design embodies a GUI concept inspired by an existing Web atlas or a popular website. The students have completed five tasks in these atlas interfaces that represent typical use cases for thematic navigation, spatial orientation and information queries. We collected performance and preference metrics for each layout, i.e., the time to solve a task (efficiency), whether students found the correct answers (effectiveness), and their ratings of each layout for "attractiveness". To complete the analysis, we also conducted a mouse click analysis. Results indicate that atlas interfaces with a medium layout density are strongly preferred by the tested participants, and through inferential statistics, by digital natives in general. These medium density layouts also perform significantly better; i.e., they have lower average times, lower number of clicks and a higher percentage of successfully completed tasks. Based on the interpretation of the results of this study, general and practical guidelines for future atlas user interfaces are derived.

[†] This version is the reviewed and accepted version of the manuscript before it was copyedited by the publisher.

Introduction

Digital atlases have been successfully created and edited for over 20 years, but essential information about the usability of atlas interfaces is still largely missing. Similarly to other digital products and technologies, the usability requirements of digital atlases might differ among older and younger users. This distinction based on age and behavioral differences in the use of digital technologies has been classified into “digital natives” and “digital immigrants” (Prensky 2001). More precisely, digital natives are considered as those born on 1980 or later, digital immigrants as those born between 1955-1979, and those born before 1955 are called “silver surfers” (Cody et al. 1999; Prensky 2001). While some critical opinions are voiced against this categorization (Bennett et al. 2008), it is commonly theorized that digital immigrants and silver surfers possess thinking and acting patterns which may differ from each other as well as from the digital natives (e.g., Black 2010; Thompson 2013). This reasoning comes from the fact that digital natives grew up with a ubiquity of digital desktops, mobile devices such as smartphones or tablets, and not least the Internet.

Digital natives are a major target user group for digital atlases among current population. Therefore, we contend that the graphical user interfaces (GUI) of digital atlases need to be optimized specifically for this particular group to enable them to explore and visualize the thematic content of atlases. Based on this reasoning, we take the digital Atlas of Switzerland as an example and explore the *preferences* and *performances* of a sample of digital natives in a classroom environment with five alternative GUI designs. With the digital Atlas of Switzerland, user experiments have already been conducted with silver surfers, and internal feedback was obtained for this age group. However, atlases are often used in schools, as they constitute an important part of geography education (Häberling and Hurni 2013). As entire books are written on the subject (e.g., Palfrey and Gasser 2011), understanding the needs of digital natives in terms of their interface expectations, design requirements and needs may be a worthwhile endeavor both from fundamental science perspective (observing their spatial behavior) and from an applied science perspective (for obtaining design guidelines). From a design perspective, the goal would be to find what works best, and if possible, why – and so that, the principles applied in one GUI design can be possibly transferred to other GUI designs for digital atlases.

In sum, our study was motivated by the reasoning that a) atlases are extremely information-rich, therefore the GUIs need careful consideration, and b) the digital atlas GUIs need to be designed also for the younger generations. This could mean not only avoiding the “old-fashioned” style, but also supporting interaction patterns they are familiar with. To enable the exploration of thematic content for this user group, novel concepts, visualization means and GUIs must be considered. We cannot assume that the youth have a similar expertise level as silver surfers; yet, digital natives may have other strengths. Motivated by this reasoning, we evaluate five alternative visualizations, each tested with five typical ‘atlas tasks’ to answer the questions, “which layout design facilitates the best exploration and why?”, “which layout design is preferred by the participants and why?” and “what can we learn from this experiment in terms of atlas GUI designs?”.

Related work

User interface issues linked to geographic visualizations have been studied from various aspects (e.g., layout design, interaction design, integrating multivariate information to map displays, visualizations themselves as interfaces) as the discipline made the transition from static maps towards interactive, on-demand geovisualization services (e.g., Howard and MacEachren 1996; MacEachren et al. 1997; Çöltekin 2002). More than a decade ago, MacEachren and Kraak (2001) have acknowledged user interface design as a research challenge in geovisualization. At the same time, Cartwright et al. (2001) have detailed the issues and challenges *about* the interface design for geographic visualizations based on a set of priorities for interface design that were defined by the members of International Cartographic Association’s Commission on Visualization and Virtual Environments. Cartwright et al. (2001) list a number of challenges that are relevant for designing interfaces in particular for geographic visualizations. They ask “Can geovisualization products offer too much information?” (Cartwright et al. 2001), implicitly making a reference to *information overload* (Ruff 2002), a concept that has strong relevance to information-rich geographic visualization environments, such as digital atlases (Polys et al. 2007).

Atlases are particularly complex geovisualization environments, delivering information on a large collection of themes (MacEachren et al. 2008; O’Dea et al. 2011). As such, providing direct interaction options for all the underlying information at once is out of question, and even organizing the interface categorically in a way that allows access to all the main categories from the main interface can easily cause information overload (Kramers 2008; Bhowmick et al. 2008). In such information-rich environments, various design considerations should be taken into account such as the layout design (e.g., where to place which control, in what size, color, orientation or visual hierarchy based on semantic importance, labeling), organization of the display elements (e.g., what to group together, whether to follow conventions or not when utilizing the “screen estate”), and interaction design (Galitz 2007; Çöltekin et al. 2009).

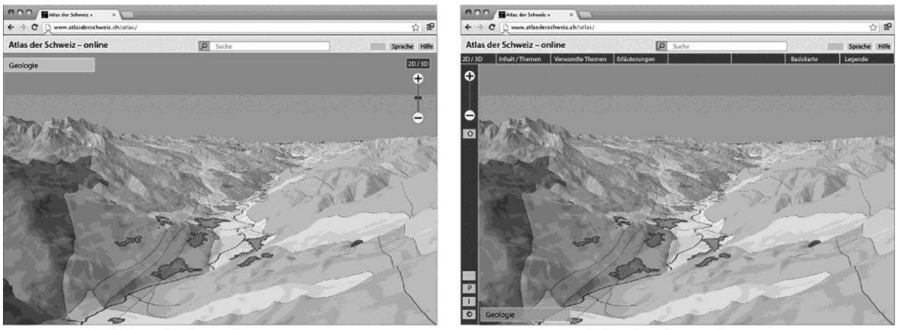
An interaction design principle that is originally proposed for information visualization displays which can be translated to GUI design is the three-level “Shneiderman’s information seeking mantra”: overview – zoom-and-filter – details on demand (Shneiderman 1996). While “Shneiderman’s mantra” is a rather reasonable starting point in organizing the elements of interaction, it appears that evaluating or validating any design often (if not always) requires a user study. Acknowledgement of the needs to place the user in the center of the design process led to the term “user-centered design” (UCD) which is commonly used today (e.g., Fuhrmann and Pike 2005; Holtzblatt 2009). UCD is a formalized approach which ideally involves user feedback in all stages of iterative design: At the early stages a feedback from the user should be obtained, integrated in the next stage of design, and new user tests should be conducted to further improve the design until the ‘right’ solution is reached (e.g., Nivala et al. 2007). However, it should be noted that user-centered approaches appeared in cartography and geovisualization designs even before the digital and interactive maps have become common (Bartz 1970; Eastman 1977 via Olson 1979). More recently, we see prototypical examples in which users can personalize the display or the GUI as they wish (Balciunas 2013) or utilize Web 2.0 approaches such as map recommendations, user comments, tag clouds and RSS feeds for online atlases (Özerdem et al. 2013).

The closest work to our project in the literature appears to be by Kramers (2008), as this study features an evaluation of an atlas interface. Kramers (2008) highlights the importance of understanding the users, individual and group differences among users, their ‘map use’ behavior, the task and the context of use. Presenting how user-centered design improved the user performance over time with the Atlas of Canada, Kramers (2008) focuses on the evolution of a particular design. Contrary to this, in our project we evaluate five alternatives with a specific age group. In this project, we draw concepts from earlier literature as well as from modern interface examples that may be well-known by digital natives. Using five alternative GUI designs in which we allow limited interaction, we experiment with layout density (linked to information overload concept), visually grouping the elements based on their function (or semantic closeness) on the interface and some standard interaction paradigms (linked to information seeking mantra).

Experiment

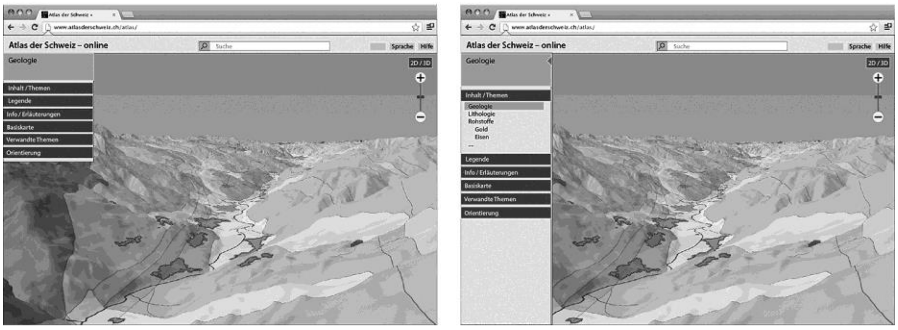
Materials

We created five “mock-up” atlas GUI layout designs varying in layout density and tool arrangement (Fig. 1). As Figure 1 shows, the layouts include GUI concepts that are used in web atlases and popular websites such as Google Maps or YouTube. To control the interactivity, only specific elements were clickable in the layouts at a time. Layouts were kept in grey-scale to avoid any bias that may come from color interactions.



Layout 1: Minimalistic style

Layout 2: Statistical Atlas style



Layout 3: Tablet style

Layout 4: Google Maps style

Layout 5: YouTube style

Fig. 1 Five clickable atlas interfaces as stimuli *(independent variables)* of the study

Participants and Procedure

Students at secondary school level (n=110, age 14-15 years, 61 female, 49 male) were asked to complete predefined tasks using the prepared layouts in the user study. The study was designed as a classroom experiment on desktop computers within a standard 45-minute lesson. Students had to fill out a digital questionnaire delivered by a survey software (SelectSurvey.NET[2]) running in a web browser.

The experimental procedure was divided into four parts in which participants: (A) delivered background information about themselves, (B) voted on useful atlas tools and functions, (C) solved tasks in the five GUI layouts and judged their attractiveness and usability, and (D) assessed the "look and feel" of some specific atlas functions. Since the study focused primarily on solving tasks using different layouts, part (C) will be presented and discussed in more detail in the following sections of this paper.

The study started with a short introduction including general information about atlases and instructions on the survey procedure. After this, each student launched the digital survey individually and provided socio-metric and background information (age, gender, formation level, frequency of computer/tablet usage, use of computer games, and use of Internet maps) in part A of the online form. Part B dealt with the usefulness of 17 atlas functions. Using a Likert scale ranging from 1 (not useful) to 7 (very useful), students were asked to judge functions such as zooming, panning, printing, and querying. These feature questions were mainly asked to familiarize the participants with typical atlas functions.

Part C – assessing different GUI layouts – was the core part of this study. *Before* solving tasks, students were asked to rate (without any additional information) the visual attractiveness of our five layouts on a 7-step Likert scale. Following that, students conducted five tasks in all five mock-up interfaces (i.e., the experiment was designed as a within-subject study in which we obtained repeated measures). The tasks represented typical use cases for thematic navigation, spatial orientation and information queries in atlases:

1) Switch the map topic from "geology" to "raw materials",
2) Resolve the meaning of map colors (gray shades) by means of the legend,
3) Query the name of the settlement and the underlying geological structure in the center of the map,
4) Access any additional media (e.g. images, text) of the map, and
5) Find out where the displayed map region is located within Switzerland.

The GUI layouts appeared in random order to avoid learning effects (however, the task order was not manipulated). As indicators for the students' performance, the *number of mouse clicks* (how many clicks does it take to solve a task?) as well as the *mouse-click position* (do they click in the right places?) and the *required time to solve the tasks* (how long does it take for them to solve the tasks?) were recorded on each design. A *maximum limit* of 10 clicks and 20 seconds per task and layout type was implemented and participants were informed about these limits. After succeeding in or failing in a task, an immediate response was given by

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[2] http://selectsurvey.net/

means of an alert. Hypertext Markup Language (HTML) image maps and jQuery[3] were used to provide layout interactivity on the client-side. A node.js[4] application stored the test data in a SQLite[5] database on the server-side.

After having dealt with the tasks, the students were asked to rate the five GUI layouts in terms of attractiveness and usability for a second time. In addition, they had to choose their favorite layout. By asking them to rate the attractiveness of the design before and after executing the tasks, we were able to determine the influence of the task solving process on the GUI attractiveness rating.

The final part (Part D) was optional and not part of the core study, three topics on specific atlas functions were inspected: a) the placement and behavior of an information panel, b) the labeling of tool buttons, and c) the use and behavior of tool panels. These topics were aimed at revealing the preferences of digital natives on the accessibility of atlas tools and thematic information. The study closed with a text field for qualitative remarks and suggestions on how to improve the atlas concept (and the survey). The entire study was conducted in German.

Results

We carried out a statistical analysis based on collected data, i.e., the responses to questions, mouse click positions and recorded task completion times. Performance (effectiveness and efficiency) and attractiveness measures are derived from these data and their mean scores were compared between the five GUI layouts. Individual differences were identified by pairwise significance tests at a 95% confidence level (i.e., p-value < 0.05). To explore the clicking activity per task and layout, maps of the first and other clicks as well as density surface maps were created with the Heatmap plugin[6] of Quantum GIS. We calculated success rates per task using SQL statements in the database, and used these as reference values for comparison.

Most tasks were completed successfully using Layout 4 (Table 1); that is, in 93% of cases neither the time limit of 20 seconds nor the limit of 10 clicks was reached. Layout 4 was also most efficient in terms of required time (Table 1). On average, tasks could be solved twice as fast with Layout 4 as with Layout 2. Since some tasks involved more consecutive actions than others, the number of clicks was normalized for a meaningful comparison by the number of screen changes. For example, students had to click at least twice to solve the first task in Layout 1, whereas in Layout 5 one click would have been sufficient; so we divided the number of clicks by 2 (i.e., the number of screen changes) for Layout 1. The normal-

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[3] http://jquery.com/

[4] http://nodejs.org/

[5] http://www.sqlite.org/

[6] http://www.qgis.org/de/docs/user_manual/plugins/plugins_heatmap.html

ized number of clicks is considered as a measure for efficiency, as it indicates the participants' effort (Tamir et al. 2008) to solve a task. A value of 1 would be optimal. However participants needed for instance 2.5 times more clicks per task on average in Layout 1 and 5 before they managed to find the right GUI element (Table 1).

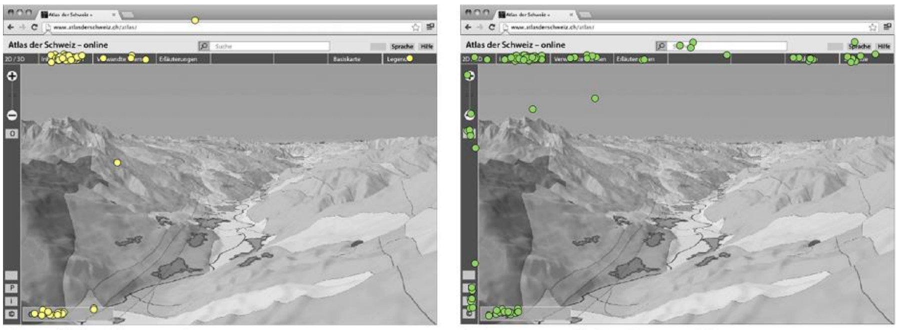
Table 1 Performance metrics (effectiveness and efficiency) for tested layouts

Stimuli	Successfully completed tasks	Time spent on a task on average (95% confidence interval)	Normalized number of mouse clicks needed for a task on average (95% confidence interval)
Layout 1	66%	8.93s (± 0.68s)	2.51 (± 0.20)
Layout 2	72%	9.21s (± 0.68s)	3.31 (± 0.24)
Layout 3	90%	5.37s (± 0.51s)	1.85 (± 0.18)
Layout 4	93%	4.52s (± 0.41s)	1.87 (± 0.21)
Layout 5	78%	7.87s (± 0.47s)	2.53 (± 0.22)

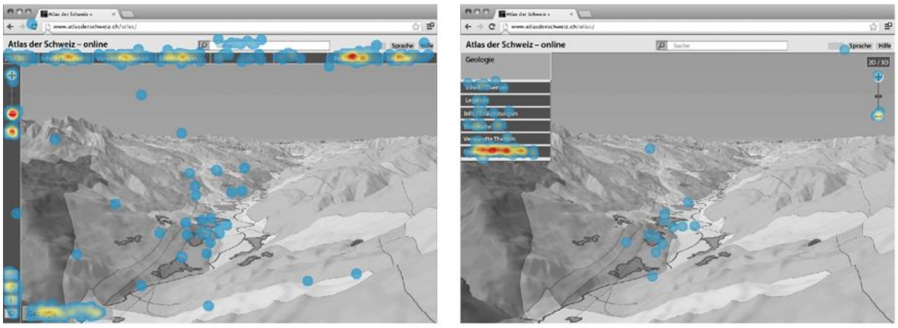
A statistically significant difference in the average time spent on the tasks was found between Layouts 3/4 and Layouts 1/2/5, because their confidence intervals at a 95% level do not overlap. A pairwise analysis of variances resulted in significantly different average times between Layout 3 and 4 (p-value = 0.01) as well as Layout 1 and 5 (p-value = 0.03), however not between Layout 1 and 2 (p-value = 0.37). Regarding the normalized number of clicks needed to solve a task on average, 95% confidence intervals do not overlap for Layouts 3/4, Layouts 1/5 and Layout 2. A pairwise analysis of variances did not reveal a significant difference concerning the normalized number of clicks between Layout 3 and 4 (p-value = 0.88) as well as Layout 1 and 5 (p-value = 0.91).

A qualitative visual analysis of click maps suggested that the students were strongly focused on the given tasks, as they were mainly clicking on the task-relevant GUI items. Only a small number of clicks appeared on browser elements like the URL bar, the refresh or the close button. To depict the students' first intuition to solve the task, we separated their first clicks from subsequent clicks (Fig. 2, top). By this, we could identify whether students followed our intention or whether they thought of alternative ways to solve a task. In most cases, first clicks occurred at just a few functions. If the first click did not lead to the right result, following clicks were more scattered. In the latter case, students lost time when functions were not grouped.

Further exploration of click maps and surface density maps revealed different interaction patterns for each layout. In the following section, the most remarkable findings are summarized for each task.



First clicks (Layout 2) Subsequent clicks (Layout 2)



Scattered clicks (Layout 2) Clustered clicks (Layout 3)

Fig. 2
Top: Separation of first clicks (left) from further clicks (right). Participants were asked to change the map theme in Layout 2.
Bottom: Different small mouse-click hotspots (marked with blue-yellow-red colors, red being the most dense) in Layout 2 (left) and one large hotspot in Layout 3 (right) become apparent on a surface density map. Students were asked to get an overview of the given map extent.

Aggregated for all layouts, 90% of answers were correct for the *first task*. To be able to solve this task, participants had to change the map theme between geology and raw materials in a list. The list was already open in Layout 4 and 5 or appeared when clicking on a button labeled 'Content/Theme' in Layout 2 and 3. In Layout 1, the list opened when clicking on the map title. Interestingly, 29% of students, who were faced with Layout 2 for the first time (so being unbiased by the other layouts), expected the map title to be interactive (Fig. 2, top). Approximately one fifth (21%) of the students clicked at least once into the search box in one of the layouts for this task, however this functionality was not implemented.

For the *second task,* the participants had to discover the meaning of thematic colors (gray shades) on the map and this was possible only by clicking on a button labeled 'Legend' or in the legend itself. This task was completed successfully in 81% of cases overall. Approximately half of the students (52%) clicked at least once on the theme menu or on the map title to find the legend.

To finish the *third task*, the students were asked to click on the center of the map in all layouts to query feature information. In the end, 75% of answers were correct for this task and about 61% of these correct answers were given in less than two seconds. Comparing the latter value with those of other tasks (Task 1: 6%; Task 2: 13%; Task 4: 14%; Task 5: 36%), it seems that the third task was very easy for some participants, whereas others found it quite difficult. From the tested GUIs, Layout 1 with its minimalistic style showed the best success rate for this task (86%). Success rates of the other layouts ranged between 70% and 75%.

76% of participants managed to access the required additional map information for the *fourth task.* Most difficulties arose in Layout 5 where only 35% of students noticed the information text that was implicitly given in a content panel. In other layouts, map media could be accessed by clicking on an information/explanation menu button which seems to have made the task easier.

The *fifth task* resulted in an overall success rate of 77%. Participants were asked to get an overview of the displayed map extent. In Layouts 1, 3, 4 and 5, this could be achieved by clicking on a menu button with the caption 'Orientation'. In Layout 2, however, this functionality was represented by a button labeled with 'O'. Only one participant found the correct answer with the first click. 30% of clicks were finally correct in Layout 2 while other clicks were quite disseminated (see Fig. 2, bottom). Roughly one quarter (24%) of students wanted to zoom out for an overview in Layout 2 alternatively.

Besides these five tasks that were related to performance, digital natives' preferences concerning the overall GUI attractiveness and usability were evaluated before and after task solving (Fig. 3). Ratings given on a Likert scale (1-7) indicated distinct differences between the five layout styles.

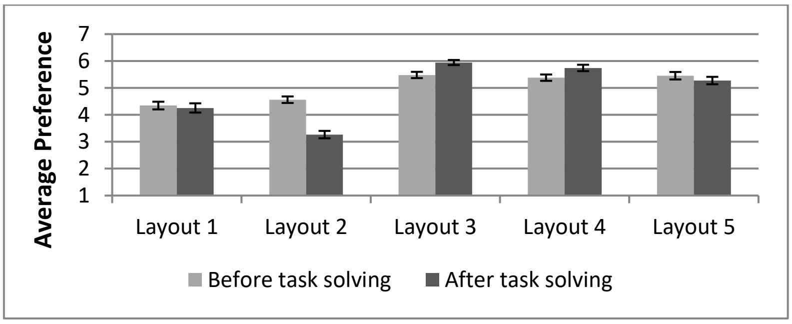


Fig. 3 Rating on attractiveness (preference) of the five GUI layouts

Two groups of layouts could be discerned: Layout 3, 4 and 5 were preferred more than Layout 1 and 2 at a 95% confidence level, both before and after task completion. While Layouts 3 and 4 were rated initially on the same level as Layout 5, they improve after having dealt with the tasks. Layout 2 is judged worse after task solving. However, the statistical t-test does not indicate significance for Layout 1 ($p = 0.694$) and Layout 5 ($p = 0.364$). Even in the question about the students' *favorite layout,* the votes for Layout 3 (30.3%) and Layout 4 (32.1%) turned out to be the highest, while the others ranked far behind (Layout 1: 11.9%; Layout 2: 7.3%; Layout 5: 18.4%).

In summary, Layouts 3 and 4 did not only outperform the other GUI layouts in terms of efficiency and effectiveness, but also in terms of visual attractiveness (preference or satisfaction regarding the visual design).

Discussion

Although the five tested atlas GUI designs included exactly the same functionality and they were presented in grey-scale, it seems that students rated some of the layouts as more attractive than others. While this is not always the case in user studies (Hegarty et al. 2009), the subjects' intuition seems to be perfectly aligned with their performances in this case; those layouts which were rated as most attractive were also those where task performance was best. This impression was reinforced by the fact that students retained their favorite layouts – *Layout 3 and Layout 4* – before solving the tasks and also after solving the tasks. These layouts were characterized by a compact GUI design where functions were grouped and easily recognizable through labels. Since these two layouts (3 and 4) had a quite similar appearance (Fig. 1), the possibility of an indirect learning effect for these two layouts cannot be excluded despite the stimuli randomization. This possible bias can be addressed in a future study when the two layouts are evaluated in an inter-subject test. However, at this point, one should note that while the two interfaces were similar, they are not identical, and especially given that the students stated their preferences before solving tasks, we can assume that the applied design concept indeed may have a favorable configuration compared to the others. Another possible reason for the popularity and success of Layout 4 may be a familiarity bias as it was modeled after Google Maps (which is likely well-tested, as well as used by the participants before).

Contrarily, *Layout 2* showed a poor performance and effectiveness. Besides a more scattered arrangement of functions, ambiguities appeared in this layout between the map title, theme menu and legend. Digital natives seem to have assumed the map title was an interactive area and expected the theme menu or legend to open when clicked. To evade this ambiguity, the map title should either be clearly discernible as such or implement the functionality of the legend or theme menu. Another drawback of Layout 2 was that students did not grasp the meaning of icons as fast as with the labeled functions of other layouts. Tooltips and better-designed icons could have helped the participants identify these functions.

Layout 1 was more efficient than Layout 2; however, tasks were solved less successfully. An explanation for this might be that participants had to click twice at four tasks in Layout 1, so probably some participants proceeded to the next question after the first screen changed although the task has not yet been completed. Interestingly, a large map panel – as given in Layout 1 – did not increase the attractiveness at first sight.

Layout 5 obtained average results altogether. Although all functions could be accessed immediately with only one click in all five tasks, Layout 5 did not outperform the others. While efficiency and effectiveness in atlases do not have to be necessarily the most crucial criteria (often, goals are open-ended for learning and exploration), they implicitly influence user satisfaction. In combination with an appealing design like in Layout 5, it is more likely that the users enjoy using an atlas and revisit the application from time to time.

A persistent affinity to favorite layouts could be noticed although students were not very experienced with digital maps and atlases. Results of all layouts would probably improve when alternative solutions were allowed, e.g., entering the map theme in the search box for the first task or zooming out to get an overview for the fifth task. In general, it can be stated that the implicit hypothesis of the study is true: There are significant differences between the five layout types concerning visual preference and simple task-solving performance.

Conclusion and Outlook

The user interface is *the* gateway to explore maps and media contained in a digital atlas. Therefore, much attention should be paid to the optimal interplay of functionality, graphical design and user behavior. User studies are a crucial means to reveal the intuitive usability of an application, especially with test subjects such as digital natives. The results of this study demonstrate that students strongly prefer atlas GUIs with a medium layout density, conforming to well known “inverted U-curve” in performance studies (e.g., Eppler and Mengis 2004); too little information (minimalistic layouts) and people cannot find what they are looking for, too much information (highly dense layouts) and there is too much to process, thus it gets difficult. These medium density layouts not only have significantly lower average task completion times, number of clicks and a higher percentage of completed tasks, but they also received the best scores of attractiveness concerning the general GUI impression at a first glimpse. This rating preference has been further accentuated after solving the given tasks.

Some general and practical advice for atlas user interfaces could be derived from the study:

- Seemingly, desktop (in terms of screen size) atlas GUIs should have a medium tool density in terms of covered screen area (map space vs. interface space), and proportion of visible tools.
- Based on this experiment, it appears to be better to avoid screens with only a few visible atlas GUI elements; the search-and-find process decreases performance.
- Important and often used GUI elements should be immediately accessible; the hierarchical structure of the GUI elements thus has to be determined by a use-oriented priority list.
- Functional grouping within the layout is highly recommended: Tools should be clustered and not distributed.
- GUI elements should be user tested for ambiguity (which needs to be minimized); the use and effect of a tool should be easily recognizable.

These findings might appear as common sense propositions, however, with this study we confirm the principles of user-oriented GUI design (Nielsen 1999) specifically for atlas GUIs. Together with additional information on GUI design and user profiling, other atlas authors might benefit from the methodology of this study to improve their digital atlas interfaces. Most importantly, this study demonstrates again how much a design team can benefit from running a user study, despite the tedious work involved in conducting one.

Follow-up studies related to our project should consider more complex tasks (e.g., interrelating map features spatially and/or temporally), other atlas user groups (e.g., silver surfers), or interfaces including more functionality (e.g., analysis tools). To give more realistic feedback to the participants when performing an action, not only atlas mock-ups but rather prototypically implemented GUIs have to be tested. An iterative testing process within the design cycle should give further validity to our findings as well as to others pursuing similar endeavors.

As mobile devices become a common means for visualization and information retrieval in everyday life, business and education, atlases should also consider tablets as communication devices. The design of an atlas GUI for tablet devices has to conform specific mobile usability concepts (which highly differ from a stationary ‘regular’ sized display), including gesture-driven commands (Nielsen and Budiu 2012).

To summarize, the investigation of atlas GUI designs is fruitful for both atlas authors and atlas users. In every stage of the development process, it may reveal positive effects and deficits on the graphical and technical level of an atlas application. Involving digital natives with their intuitive sense for technology into usability studies from the beginning seems to be an expedient way to provide carefully designed atlas interfaces in the future.

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