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The Role of User Differences in Customization: A Case Study in Personalization for Infovis-Based Content

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ABSTRACT

Although there is extensive evidence that personalization of interactive systems can improve the user's experience and satisfaction, it is also known that the two main approaches to deliver personalization, namely via *customization* or *system-driven adaptation*, have limitations. In particular, many users do not use customize mechanisms, while adaptation can be perceived as intrusive and opaque. In this paper, we explore an intermediary approach to personalization, namely delivering system-driven support to customization. To this end, we study a customization mechanism allowing to choose the type and amount of information displayed by means of information visualizations in a system for decision making, and examine the impact of user differences on the effectiveness of this mechanism. Our results show that, for the users who did use the customization mechanism, customization effectiveness was impacted by their levels of *visualization literacy* and *locus of control*. These results suggest that the customization mechanism could be improved by system-driven assistance to customize depending on the user's level of visualization literacy and locus of control.

CCS CONCEPTS

• **Human-centered computing → User studies**; *Information visualization.*

KEYWORDS

Personalization, Customization, Information Visualization, User differences

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1 INTRODUCTION

There is mounting evidence that personalization can increase user experience and satisfaction with interactive systems by accommodating the individual needs, abilities and preferences of the users (e.g., [6, 22, 28, 33, 40, 50, 52]). There are two main approaches to support interface personalization: *customization* done by the user and *adaptation* driven by the system. Both approaches have pros and cons. Customization leaves the user in control of the interaction and does not require to acquire information about the users [28, 38, 43, 46, 59]. However, several studies in HCI have shown that some users do not customize, either because they do not want to or they do not know how to do it [5, 22, 37–39, 41, 44]. To counteract this issue, system-driven adaptation (simply adaptation for short) proactively offers personalization options to users, based on the system's assessment of relevant user states, preferences and traits. Although there is increasing evidence on the value of this approach (e.g., [20–23, 33, 34]), it can suffer from serious pitfalls such as intrusiveness and lack of transparency.

To combine the advantages of customization and adaptation while reducing some of their limitations, researchers have been investigating *mixed-initiative* approached whereby the system proposes suggestions for personalization which the user can accept or reject, e.g., [9, 29, 58]. In this paper, we explore another approach for bringing together customization and adaptation, namely devising system-driven support to customization based on *user characteristics* that affect if users can/want to customize. Sundar and Marathe [52] proposes a version of this approach where customization of menus vs. system-driven adaptation are given to users depending on their level of technical expertise, based on evidence they collected on the preferences of the two types of users for customization vs. adaptation. Hooshyar et al. [28] showed that providing prompts to customize interface features to elderly users improved their customization.

In this paper, we contribute to this line of work by investigating the impact of user characteristics on customization in an information visualization (InfoVis)-based interface, to ascertain the potential value of providing personalized support to customization in this context. We focus on customization related to *personalizing the information content* of an interface, namely what information is presented in the interface and/or how it is delivered [33]. Specifically, we study how users customize the amount and type of information displayed by means of visualizations, and we explore if and how user characteristics impact the usage and effectiveness of this mechanism.

To conduct our research, we used a commercial InfoVis-based platform called MetroQuest (*metroquest.com*, MQ from now on). MQ supports the creation of interfaces to engage the public in urban planning decisions typically framed as *preferential choices*, i.e., selecting the most preferred solution out of a set of possible scenarios. The sample MQ interface we studied (called MQ-transit, shown on Fig. 1-2) supports users in making a preferential choice

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related to a real transit planning project, by means of a map and a deviation chart showing complementary information about the project. Based on a previous study [36] that showed the need for personalized InfoVis contents in MQ, we augmented MQ-transit with a customization mechanism that allows users to personalize the interface content by hiding/displaying either one of the two visualizations (map or chart). We conducted a user study with MQ-transit aimed at exploring the potential need for system-driven support to customization, in particular by investigating the following research questions:

- **RQ.1)** Do users customize the information content in MQ-transit using the provided customization mechanism? If yes, how? If not, why?
- **RQ.2)** Is there a relationship among user characteristics, usage of the customization mechanism, and task performance with MQ-transit?

Our findings contribute to gain a better understanding of the role of user characteristics in interface customization. Thus far, the impact of user characteristics on customization has been studied only in the context of personalizing interface features [48, 52, 53] (layout, menus…) or agent behaviors [14, 51], whereas here we focus on customizing information content. Furthermore, we investigate a different set of user characteristics than the ones explored in previous work on the impact of user characteristics on customization effectiveness. In particular, we tested five cognitive abilities and the personality trait of locus of control, which have been shown to impact user performance and satisfaction with information visualizations [11, 13, 26, 54, 54, 57, 62], and thus may affect how users customize visualization-based interfaces as well. In fact, our results do reveal significant impacts of *visualization literacy* (a cognitive ability) and *locus of control* on customization effectiveness, thus indicating that users may benefit from system-driven support to customization in MQ, depending on their levels of visualization literacy and locus of control. Based on our results, we provide suggestions on how this support could be delivered. Altogether, the novelty and main contribution of this work in an investigation of the influence of specific user characteristics on customization in the context of a visualization-based interface for public engagement (MQ).

We also extend previous work by broadening findings on the value of personalization of content displayed by means of information visualizations. In particular, InfoVis-based content personalization has been formally studied in terms of system-driven adaptation [1, 9, 30, 46, 55], but not with customization. Here we provide insights on how effective personalization of InfoVis-based contents could be provided by combining customization and adaptation.

The rest of the paper begins with related work, followed by a description of MQ and of the customization mechanism. Next, we describe the user study, the data analysis and its results. Before concluding, we discuss the implications of our results for personalization, and ways to deliver such personalization in MQ.

2 RELATED WORK

Customization studies. Customization mechanisms have been extensively studied in HCI. For example, customization of interface menus and toolbars (by adding, removing or modifying items) has been studied for word processors [9], image editors [32] and webpages [15]. Customization of interface layout (by modifying the size, disposition and colour of interface components) has been studied in video players [48], webpages [52, 60] mobile applications [46], and games [14, 53]. In relation to the type of customization we consider in this paper, namely customizing interface content, there has been research on customizing the type and amount of textual information displayed (e.g., description of items in a music player [45], help content in programming environments [27]). Other work has looked at allowing end-users to add or remove "modules" in web portals or apps, e.g., [2, 6, 35]. The modules could contain information in different modalities, including visualizations (e.g., stock charts), however, these studies focused primarily on overall customization activity, without distinguish between visualization-based and other types of content. In contrast, we focus specifically on customization of InfoVis-based content.

The aforementioned work showed that interface customization can improve users' performance and satisfaction with the target interface. However, there is no guarantee that all users will customize [37]. Even with carefully designed and evaluated mechanisms, several studies reported proportions of users who did not customize varying from 10% up to 80% [5, 22, 37–39, 41, 44]. The main reasons for not customizing in these studies include that users were unsure of the benefits of customizing, did not want to waste time, or were satisfied with the default settings.

User characteristics and customization. Existing work has looked at how customization behaviour can be influenced by user expertise, some personality traits and age. User expertise in technology has been linked to the use of menu customization, with expert users customizing more than novice users [52]. The 5-factor personality traits (agreeableness, extroversion, conscientiousness, emotion stability, openness) were found to influence if and how users customized a video player [48]. Extroversion was also found to influence if and how users customized a virtual agents in video games [14] and an interface for problem solving [51]. The tendency of users to be feature-keen (i.e., prefer to have access to many functionalities in the interface) or feature-shy (i.e., prefer having fewer functionalities) has been linked to the perceived usefulness of menu customization [9, 18]. In [28] they looked into the value of providing dedicated help to customize to the elderly, with results showing an improvement in customization usage and experience.

User characteristics and InfoVis. There is extensive evidence on the impact of user characteristics in processing visualizations, supporting the need for personalization in InfoVis. Cognitive abilities were found to affect users' performance and satisfaction during visualization processing in a variety of tasks/visualizations. For examples, perceptual speed and visual WM were found to impact user performance in simple analytic tasks (e.g., finding the maximum value of a distribution) with bar-chart-based visualizations[11, 54]. Spatial memory and visual scanning were found to influence performance in map reading tasks [10]. Locus of control (a personality trait) has been linked to the effectiveness of bubble charts and trees for browsing genomic data [26, 42, 62]. In [36] similar effects of user characteristics were uncovered on how users process the two visualizations in MQ (map and chart). We extend this work by exploring whether some of the user characteristics that have been linked to visualization processing, namely cognitive abilities and locus of control, also influence customization of visualization-based interface content.

Personalization of InfoVis-based content. There is evidence that this type of personalization can be beneficial, but to the best of our knowledge it has only been formally studied in terms of system-driven adaptation, not with end-user customization. For instance, Zhou et al. [61] showed that adapting the amount of information displayed on a map to the user preferences improves the user experience when searching for real estate. Brusilowsky et al. [8] proposed an educational system that visualizes practice problems based on their similarity and adds explanatory icons tailored to the user's knowledge. Ahn & Brusilowsky [3] predicted users' interests based on their history of search terms and adapted the content of a fixed visualization technique to highlight points of interest in the search results.

3 MQ-TRANSIT

As said in the introduction, MQ is extensively commercialized to develop interfaces designed to educate and engage communities in public policy planning and projects. MQ interfaces are often used as walk-up-and-use systems in kiosks at public events, presenting users with a set of urban planning scenarios, and providing visual tools to explore and rank these scenarios based on their preferences, which is a form of preferential choice. All the functionalities discussed for MQ-transit were predefined in the general MQ platform. Only the content specific to the target transit problem was added.

Most MQ interfaces consist of 3 main standardized screens that guide users through the process of learning about the target urban planning scenarios and expressing their preferences over them. Here, we describe these screens using as an example MQ-transit, the sample interface that was developed in collaboration with the MQ company for a previous user study aimed at ascertaining the need for personalization in MQ reported in . MQ-transit addresses a urban planning project of specific interest to the University of British Columbia, namely building a new transportation system to campus. This is a real project currently studied by the City, and it has generated substantial controversy on which of three proposed transit scenarios (light rail, rapid rail, or a combination of both) should be selected. MQ-transit allows users to compare the three scenarios, and rate each of them on a 5-point Likert scale.

Screen 1 provides background information on the university transit project. Screen 2 (shown Figure 1) presents the factors (typically from 6 to 8) that are considered important to evaluate the "goodness" of the various scenarios in a project. For the university transit project, these factors are: *travel time saving, wait time, frequency of stops, accessibility, reduction in auto trips and pollution, noise and vibration, and implementation cost.* Screen 2 allows the user to order by priority a maximum of five factors out of the seven provided, by selecting the factors that they feel are the most important to them. The selected factors are moved to the top list (left of Figure 1) and ranked via their position in that list. The value of the factors in MQ-transit came from real data published by the City, and indicates for each scenario if the transit option is expected to be better or worse than today's status quo (i.e., the current bus system).

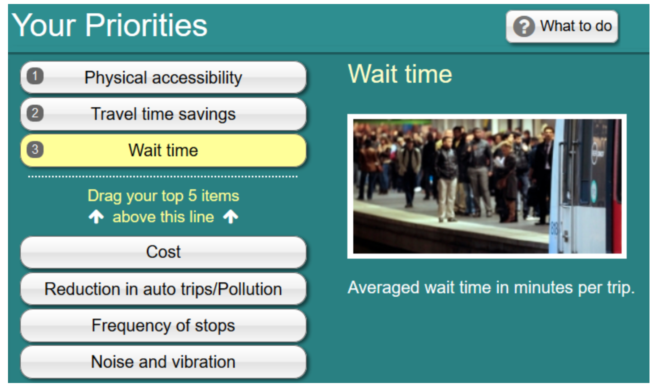

Figure 1: Central components of Screen 2 in MQ-transit.

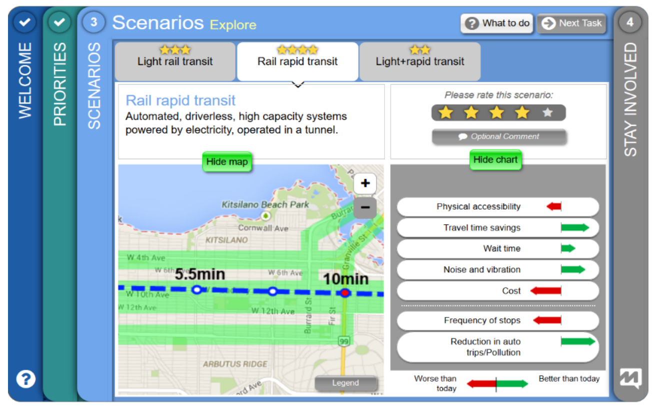

Figure 2: Screen 3 in MQ-transit.

Because some of the factors may conflict with each other depending on the scenario (e.g., higher travel time savings via a subway may imply lower physical accessibility), understanding these trade-offs is a key aspect to evaluate the scenarios. Screen 3 is designed to visualize these trade-offs and support the comparison of the different scenarios. It contains one tab for each available scenario (see Figure 2), and users compare scenarios by switching between these tabs. Each tab displays a brief description of the scenario and a 5-point Likert scale to rate the scenario, and includes two visualizations designed to deliver complementary information related to the various decision factors:

- A *deviation chart* (Figure 2, right), simply "chart" from now on, designed to shows a visual summary of how the value of each factor changes in that scenario compared to the status quo of today: a red arrow means worse than today, a green one means better. The size of the arrows, normalized from 0 to 100, shows the amplitude of the difference. The factors are listed according to users' top 5 factors ranked in Screen 2.
- A *map* (Figure 2, left) which displays spatial, factual information on the transit route and the stops, and is designed to show how each scenario would impact the factors in the context of the urban environment (examples are provided

below). As the entire map cannot be fitted into the interface, users can explore it by panning and zooming. A button at the lower right corner of the map allows opening its legend.

Essentially, the information shown on the chart is abstract in nature, whereas it is contextualized on the map. For example, the chart shows the average travel time saving when travelling to the University of British Columbia, whereas the map shows specific travel time savings at different stops along the route. The chart shows the average expected reduction in daily auto trips in the entire city, whereas the map highlight in green the actual streets where less auto trips are expected. The chart shows the overall levels of noise and vibration expected for each transit option, whereas the map shows the areas that will be exposed to such noise and vibration.

The user can leverage both visualizations to inspect all the information about a scenario, or alternatively focus on the type of information and visualization that interest or appeal them the most. Comparing scenarios requires switching between tabs, because fitting all the available information in one screen would be overwhelming for most users (as the company experienced with previous versions of the system).

4 CUSTOMIZATION FOR MQ-TRANSIT

The combination of a map and a deviation chart, as well as their comparison across displays, are standard features of MQ interfaces, and are the result of several years of user-centered design focused on finding a trade-off between showing rich information on each scenario and enabling comparisons without overwhelming the users. Still, the company acknowledges that, for some users, the MQ interfaces are demanding, especially for one-time usage, and that designing effective and engaging visualizations is challenging due to the large diversity of their users. Thus, the MQ company feels that their users might benefit from dedicated support that facilitates processing and comparison of the information content displayed by means of visualizations. The prior study on MQ-transit reported in [36] aimed at establishing the need for providing such support in a personalized way, based on specific user characteristics. Results showed, among other things, that:

- Users with a high visual WM found the information displayed in the map less useful than in the chart,
- Users with a low spatial memory found the information displayed in the chart less useful than high spatial memory users.

These results support the need for personalization that facilitates processing of the information displayed in the map/chart for users with the aforementioned characteristics. For example, users with a high visual WM or a low spatial memory may benefit from personalization that increases their appreciation for the map and the chart respectively, e.g., giving them a map/chart with less information. Alternatively, these users may prefer to focus only on their most appreciated visualization, and have the other one removed.

Here we explore the latter form of personalization, by adding to MQ-transit a *customization mechanism* that allows users to hide/display either one of the two visualizations. This mechanism aimed at enabling users to hide the visualization that they already perceive as less/not useful, such as, as said above, the map for users with high visual WM or the deviation chart for users with a low spatial memory. Users can perform such customization via two buttons, one labelled "Hide map" and one labelled "Hide chart", located above the corresponding visualizations (see Figure 2). Clicking one of the buttons makes the corresponding visualization disappear, and changes the button's label to "Show map/chart". The remaining visualization becomes bigger. Such enlargement of the remaining visualization was decided in collaboration with the MQ designers, both to avoid leaving unused space, and also because enlarging the visualizations serve the purpose of the customization mechanism, namely to facilitate processing of the preferred visualization. The user can bring back the hidden visualization at any time, by clicking the same button (now labelled "Show map/chart"). A demo of this customization mechanism for MQ is available at *https://ubc2eu01.metroquest.com/*.

5 USER STUDY

We describe in this section the exploratory user study we designed to ascertain the effectiveness of the customization mechanism, and whether this effectiveness if influenced by a set of user characteristics. We first define the user characteristics that were tested in the study, followed by the study procedure and description of dependent measures.

5.1 User Characteristics

The study tested five cognitive abilities, which are well-established measures in cognitive and perceptual psychology:

- *Perceptual speed* (PS): the speed when performing simple perceptual comparisons [16].
- *Visual WM*: the storage and manipulation capacity of shapes and colors of visual objects [19].
- *Spatial memory* (SpM): the storage and manipulation capacity of the spatial arrangement of objects [16].
- *Visual scanning* (VS): the capacity to find information in our surroundings quickly and efficiently [16].
- *Visualization literacy* (vis literacy) a rather new concept in Infovis defined as the ability to extract and manipulate information from data visualizations [7].

The first four characteristics above were measured using well-established tests in perceptual psychology (namely the Kit of Factor-Referenced Cognitive Tests for PS, VS and SpM [16], and the Fukuda & Vogel's test for visual WM [19]). Vis literacy was measured using the test outlined in [7][1].

We selected these five cognitive abilities because the previous study on MQ showed that they all impacted user preference and usage of the two MQ visualizations, and thus they might also influence customization behaviors related to these visualizations. Specifically, as described in the previous section, visual WM and SpM influenced the user's perceived usefulness of the map and the chart. SpM, along with PS, VS, and vis literacy also influenced gaze behaviors related to making comparisons between visualizations across scenarios, i.e., users with lower levels of these characteristics made fewer visual comparisons than their counterparts.

[1]More information about the user characteristics and tests are available at www.cs.ubc.ca/cs-research/lci/research-groups/intelligent-user-interfaces/userchar.html

In addition the five cognitive abilities described above, we also measured two personality traits:

- *Locus of Control* (LoC): the extent to which individuals believe they are able to control events affecting them [47].
- *Extroversion*: the tendency to exhibit high physical and verbal activity, assertiveness, sociability [25].

We used two well-established questionnaires in psychology to measure these traits: the Rotter's questionnaire for LoC [47] and the TIPI questionnaire for extroversion [25].

We selected LoC because of previous studies showing that this trait can impact user performance with a given visualization [26, 62]. Based on the definition of this trait, it is plausible that LoC might also influence the willingness of the users to customize MQ-transit, as being in control of the interface suits the belief of users with an internal locus that they can control their life the way they want. On the other hand, users with an external locus, who believe that their life is controlled by external factors, might simply adapt to the default MQ-transit interface without taking the initiative to customize it. We measured extroversion because this trait has been extensively linked to the extent to which users customize a given interface, as reported in the related work [14, 48, 51].

5.2 Procedure

46 participants (25 female; age 18 to 52) were recruited through advertising at our campus and selected to be members of the community impacted by the transit project. This matches how MQ is used in practice, i.e., via publicly accessible kiosks by users who are likely to care about the task because their lives would be the most impacted by the proposed scenarios. 29 of the participants were students from various departments, and 17 were non-students but lived or worked on or near the campus. All participants were first-time users of the MQ interface. The sample size for the study was determined by a power analysis, using effect sizes from the previous study with MQ-transit reported in [36] (p > .8, a = .05, d =.4).

The experiment involved a 45 mins in-lab session. At the start, each participant underwent calibration with an unobtrusive Tobii T-120 eye tracker, which was used to record the user's gaze during the study task. The task consisted of using MQ-transit to explore each of the three transit scenarios described in the previous section, and rate them using the 5-point Likert scale available in each tab of Screen 3. To mimic the usage of MQ interfaces in a walk-up-and-use setting, participants were given no time constraints nor training in using MQ-transit. Participants spent on average of 4.4 minutes (st.dev=2.3, max=13.8, min=1.7) on the study task. After completing the task, they filled out a post-questionnaire to rate their experience with MQ-transit and the customization mechanism. A series of tests to measure 5 of the 7 user characteristics described in the previous section was administered at the end of the session, to avoid generating fatigue or lowering engagement before the study task. This testing phase lasted for about 30 mins. The tests for the remaining user characteristics (vis literacy and LoC) were administered online, taking about 15 mins to avoid overwhelming participants with too many tests at once[2]. Only these two tests could be performed online because the others were either not computerized or required specific software that was too complicated to set up at home. The last phase of the study was an interview conducted by the experimenter in order to elicit: *(i)* from participants who did not customize, the reasons for not doing so; *(ii)* from the others, reasons for how they rated the customization mechanism in the post-questionnaire.

5.3 Dependent Measures

5.3.1 Measures Related to Customization. To answer our research question RQ.1, we collected sets of measures intended to capture a user's customization behavior as well as the perceived quality of the customization mechanism. First, we measured the *time spent in each of the three possible content configurations* the mechanism can generate: both the map and the chart are visible; only the map; only the chart. This produced three measures (one per configuration) that we leveraged to examine if users actually spent time processing the customized interface with just the map or just the chart, as opposed to processing the default interface showing both visualizations. It should be noticed that we ignored instances when a participant came back to the default interface less than 3 seconds after having customized, i.e., we did not consider such behavior as customizing, as the participant likely miskicked and did not intend to customize.

Second, we measured the perceived *usefulness* and *ease-of-use* of the customization mechanism, which are standard ways to assess the quality of interface features in HCI [4]. Specifically, in the study post-questionnaire, users were asked to rank the following statements on a 5-point Likert scale:

- "I found the possibility of hiding one of the visualizations to be useful." (*usefulness*).
- "It was easy to hide a visualization" (*ease-of-use*).

5.3.2 Measures of Decision Quality. Our research question RQ.2 focuses on the impact of user characteristics and customization usage on task performance. Measuring task performance in preferential choices like the ones supported by MQ interfaces is, however, known to be challenging [31, 49, 56] because there is no easy short-term way to evaluate subjective choices. The performance measures often used in InfoVis (accuracy and completion time) are not suitable because in preferential choice there are no objectively correct or incorrect answers, and taking longer to make a choice is not necessarily wrong if it leads to more informed and confident choices.

Here, we evaluate task performance by using the three complementary measures adopted in [36] to assess the quality of the user's decision process with MQ-transit: *visual comparisons*, *decision confidence*, and *decision coherence*.

Visual comparisons: Comparing the content of the visualizations across tabs is important in MQ interfaces to understand the tradeoffs between the scenarios and establish one's preferences over them. We measured to what extent participants made such comparisons by leveraging eye-tracking data. Specifically, we counted the

[2] Most participants took the online tests at least one day before the study as they were instructed by email, expect for 2 who did not do it online and had to took them in the lab after the study.

occurrences of the following pattern: *(i)* user fixates[3] at least once on the map or the chart ; *(ii)* user switches to a different scenario; *(iii)* user fixates again on the same visualization. This pattern is labelled as "*visual comparison*" from now on. It is meant to capture successive fixations on a given visualization during tabbing, as a proxy for comparing the visualization across scenarios. We considered having at least two successive fixations (one before and one after tabbing) on the map or the chart to be a suitable lower bound for capturing user attention to the visualization, for instance when the user try to compare information about a specific factor across scenarios.

Decision confidence: Confidence is often used in decision making to evaluate how well decision-support tools aid users in making informed choices (e.g., [30, 51]). Following this work, we assessed confidence by asking participants to rate on a 5-point Likert scale the statement: "I am confident in the ratings I gave."

Decision coherence: This measure captures to what extent the ranking of the top 5 study factors generated in Screen 2 (cf. Figure 1), is consistent with how the user rated each scenario in Screen 3 (cf. Fig. 2). Specifically, for each user:

1. We derived from the ranking of the top 5 factors the user's most likely rating, or expected rating (*ER*), for each of the three scenarios. This was done using a weighted sum model:

$$ER_i = a \sum_{j=1}^{5} w_j s_{ij} \quad (1)$$

Where s_{ij} is the value of factor *j* in the scenario *i* (i.e., the size of the corresponding arrow in the deviation chart); w_j is a weight based on how the user ranked it, ranging from 1 (best factor) to 0.2 (fifth factor); *a* is a constant that makes the range for ER_i values to be the same as the range of the users' rating (1 to 5).

2. For each scenario *i*, we computed the absolute difference between its expected rating and the actual rating the user gave it in Screen 3. The average of these differences over all scenarios reflects the distance between the ratings the participant actually gave to the three scenarios and the expected ratings given her ranking of the top 5 factors. Thus, higher differences indicate less coherence, with differences ranging from 0 ("most coherent" rating that fully coincides with the expectation) to 3.1 (the "least coherent" set of ratings possible in our dataset).

6 RESULTS

6.1 Results for RQ.1

Recall that this question asks: "*Do users customize the information content in MQ-transit? If yes, how? If no, why?*" The goal of RQ.1 is to gain a better understanding of how participants customized MQ, before analyzing the relationship among customization behaviors and user characteristics in RQ.2 (which is our main goal in this paper, as stated in the introduction). The study data reveals that 15 participants out of 46 (about 33%) customized MQ-transit at least once. Figure 3 shows the mean and standard deviation of the time spent by these 15 participants in each of three possible content configurations (plain blue bars), as well as the proportion of the time they spent on Screen 3 in each configuration (dotted red bars).

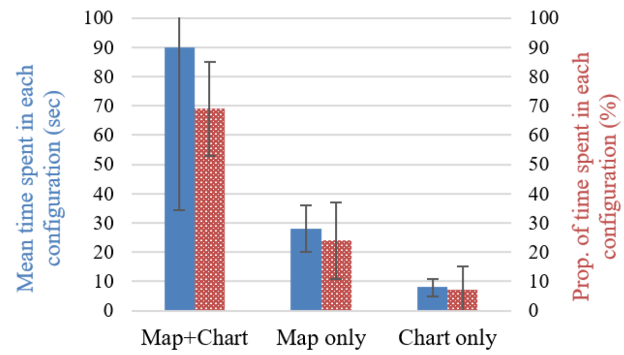

Figure 3: Time spent in each visualization configuration.

Figure 4 shows the distribution of the proportion of time spent with just the map and just the chart for the 15 users who customized. Figure 5 provides insights on how many participants used each customization button at least once to hide a visualization, and to bring back both visualizations together.

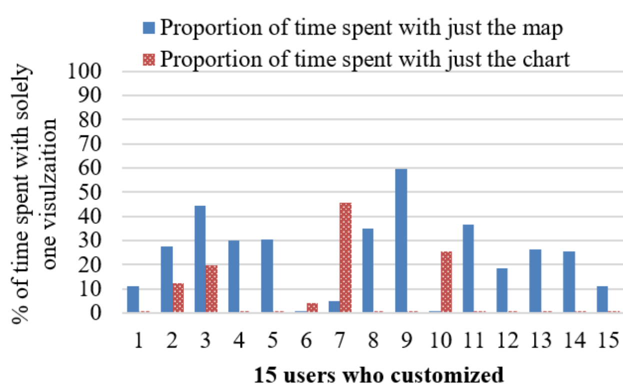

Figure 4: Prop. of time spent in each visualization configuration by the 15 users who customized.

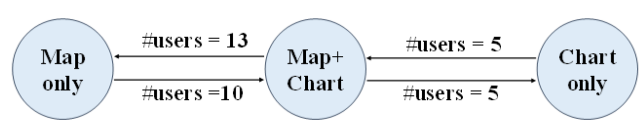

Figure 5: Number of users who transitioned at least once between visualization configurations.

Overall, these 15 participants spent the majority of their time with the two visualizations together, even if they customized, as shown Fig. 3 and 4. Consistent with this result, Fig. 5 shows that most of the participants who hid a visualization eventually went back to two visualizations. Specifically, all 5 participants who hid

[3]A fixation is defined as gaze maintained at one point on the screen for at least 60ms, as captured by our Tobii eye tracker.

Table 1: Subjective ratings for the customization mechanism.

Measure	Mode	Mean	St.dev	Min	Max
Ease-of-use	4	4.1	0.6	3	5
Usefulness	3	3.1	1.4	1	4

the map brought it back, and 10 out of 13 participants who hid the chart also brought it back. Although these results indicate that participants preferred working with the two visualizations together, Fig. 3 also shows that they spent about a third of their time on average with just one visualization. Furthermore Fig. 4 reveals that all participants who customized, except the sixth, spent quite some time with one visualization (at least 10% of their time). These results are noteworthy especially because customization is typically devised for repeated usages of an interface, but here several participants already customized the interface content after a few minutes of interaction.

When participants customized to view the content of only one visualization, they did so predominantly to select the map. Namely, as shown Figure 5, 13 participants customized MQ-transit by hiding the chart. They spent about 28 seconds on average (st.dev = 10) in this "map-only" configuration (see Figure 3), i.e., 24% of the time they spent on Screen 3. By contrast, only 5 participants customized by hiding the map, spending about 7 seconds (st.dev = 1) on average in this configuration (6% of their time, see Figure 3).

As stated in the *Dependent Measures* section, the participants who customized were asked to rate on a 5-point Likert scale the ease-of-use and usefulness of the customization mechanism. Table 1 provides descriptive statistics of their ratings.

Almost all users who customized found the customization mechanism easy to use. Three participants (20%) found it to be useful (rated above 3), 3 participants (20%) found it not useful (rated below 3) and 9 (60%) remained neutral (rated 3). Based on the post-interviews, the main reason for finding the customization to be useful is that it helps focusing on the preferred content. As for the reasons for finding the customization moderately or not useful, 7 participants (58%) preferred having all the available information visible, and 5 participants (42%) found easy to process the two visualizations together. These reasons are in line with the finding that even users who did customize spent most of their time looking at the two visualizations together.

As for the 31 participants who never customized, 18 (58%) reported that they did not want to remove a visualization because they preferred to have all the available information visible. 8 participants (25%) reported a lack of understanding of the customization mechanism itself. Specifically, six of them said that that they did not realize they could hide a visualization, whereas two were aware of the mechanism but were concerned that they would not be able to bring the hidden visualization back. Although these participants amount to only 15% of the whole study population, their remarks indicate that it would be worth making the customization mechanism more noticeable/clear, were it to be deployed in MQ. Of the remaining 5 participants, 2 said that they did not customize because they did not like any of the visualizations anyway, and 3 reported being too focused on understanding the task.

Table 2: Summary statistics of the decision quality measures.

Measure	Mean	St.dev	Min	Max
Decision confidence	3.8	0.7	1	5
Decision coherence	0.7	0.24	0.09	0.94
Visual comparisons	4.3	3.2	0	19

Table 3: Summary statistics of user characteristics.

Measure	Mean	St.dev	Min	Max
Perceptual speed	45	8	24	66
Visual WM	2.3	0.9	0.3	4
Spatial memory	11	5.2	1.8	22
Visual scanning	26	8.2	7	38
Vis literacy	0.4	0.5	-0.85	1
Locus of control	12	3.7	6	20
Extraversion	3.8	1.4	1.5	7

6.2 Results for RQ.2

This question asks: "*Is there a relationship among user characteristics, usage of the hide/display mechanism, and task performance with MQ-transit?*" As discussed in the *Dependent Measures* section, we evaluated task performance in terms of decision quality, expressed by the three measures listed in Table 2 along with their summary statistics.

We first examined if customization alone impacted decision quality, by running a MANOVA with *used_customization* (2 levels: yes or no) as the factor, and the three measures of decision quality as the dependent variables[4]. The MANOVA uncovered no significant main effect of *used_customization* ($F(1,43) = 0.39$, $p = .68$, $r = .19$)[5].

Next, to answer RQ2, we checked for effects of customization and user characteristics on decision quality. We ran 7 MANCOVA analyses, one for each of the 7 user characteristics collected in the user study (listed along with their summary statistics in Table 3). Each MANCOVA has one of the user characteristic as co-variate, the three measures of decision quality as the dependent variables, and *used_customization* as the factor. We ran separate MANCOVAs for each user characteristic to avoid overfitting our models by including all co-variates at once. This approach was appropriate because there was no strong correlation among the user characteristics[6], thus we considered each MANCOVA as an independent analysis on the impact of customization and the target user characteristic on decision quality.

[4]There were moderate correlations among our dependent variables (Pearson's r ranging from .42 to .55), which is suitable for a MANOVA [17].

[5]We report statistical significance at the .05 level, and effect sizes as large for r > 0.5, medium for r > 0.3, and small otherwise.

[6]Pearson's $r < 0.2$ for all pairs of user characteristics, except for visual scanning and spatial memory where $r = 0.5$, which indicates only one moderate correlation and is still suitable for analysis [17].

We found interaction effects of used customization with vis literacy on visual comparisons (F(1,41)=3.6, *p*=.02, *r*=.21) and with locus of control on confidence (F(1,41)=3.4, *p*=.03, *r*=.16), described next.

6.2.1 Interaction effect of used customization and vis literacy on visual comparisons. This effect (shown in Fig. 6) and post-hoc Holm-corrected univariate ANOVAs reveal that, among the users who customized (left side of Fig. 6), those with high vis literacy (8) performed more visual comparisons than users with low vis literacy (7). As we discussed in the MetroQuest section, comparing the content of the visualizations by tabbing across screens is crucial to make informed choices, but can be difficult. Thus this effect suggests that a high vis literacy is necessary in order to successfully leverage the hide/display mechanism to facilitate scenario comparisons via tabbing. For low vis literacy users, customization seems to act as a distractor or impediment when it comes to making visual comparisons. There is also a statistically significant difference in the number of visual comparisons for users with high vis literacy (dashed red line in Fig. 6) who customized (8) and those who didn't (14), with the latter making fewer comparisons. This indicates that high vis literacy users should use the hide/display customization, because it can help them compare scenarios more extensively.

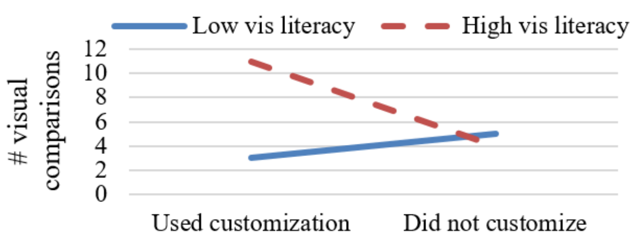

Figure 6: Interaction effect of vis literacy with customization on visual comparisons.

Figure 7 reveals that high vis literacy users dedicated more of their time to process the customized interface compared to low vis literacy users, and this difference is significant according to a *t*-test ($p < 0.01$, $r = 0.39$). High vis literacy users also performed significantly more visual comparisons than low vis literacy users when only one visualization was displayed ($p = 0.01$, $r = 0.23$, left part of Figure 8). In fact, these high vis literacy users used the customized interface to perform a majority of their visual comparisons (Fig. 8). Altogether, these findings indicate than high vis literacy users did process the customized interface more extensively than low vis literacy users, and took advantage of it to perform more visual comparisons. This strengthens our finding above, that the customization mechanism is useful to high vis literacy users for scenario comparisons. We also found an interesting trend, that high vis literacy users performed almost twice more visual comparisons with one visualization than with two (7.5 versus 4, respectively, see Figure 8), although this difference is not significant ($p = 0.09$, $r = 0.21$).

6.2.2 Interaction effect of used customization and locus of control on confidence. Recall that high values of locus of control indicate people with an internal locus who believe they are in control of their life. Low values of locus of control indicate people with an external locus who believe that events in their life are caused by external factors. The interaction effect of locus of control on confidence (shown in Fig. 9), along with post-hoc Holm-corrected univariate ANOVAs, reveal that among the users with an internal locus of control (dashed red line in Fig. 9), those who customized (9) gave higher confidence ratings than those who didn't (13). The effect is the opposite for external locus users (solid blue line in Fig. 9). These results appears consistent with the definition of locus of control. Namely, the ability to customize boosts the internal locus of control users' confidence because it suits their belief that they can control the events that happen in their life. In contrast, external locus of control users who customized did not gain confidence because they do not really believe that they have power to change anything.

We further examine usage of the customized interface among internal and external locus of control users by reporting on Figure 10 the proportion of the time they worked with the customized interface. A *t*-test reveals no statistically significant difference in the proportion of time spent with one visualization among internal and external locus of control users ($p = 0.11$, $r = 0.19$). This finding suggests that that the possibility of customizing MQ-transit is enough for internal locus of control users to gain confidence (and vice-versa for an external locus), regardless of the time spent processing the customized interface. Alternatively, it is possible that we simply lack of power to find a significant effect, since Fig.

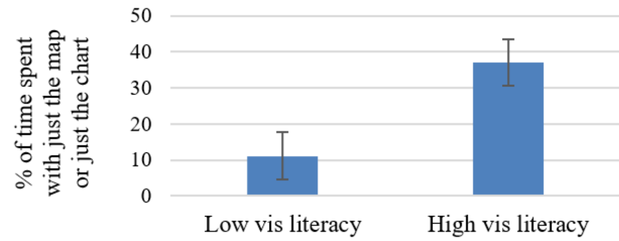

Figure 7: Proportion of time spent processing the customized interface with either just the map or just the chart, for low and high vis literacy users.

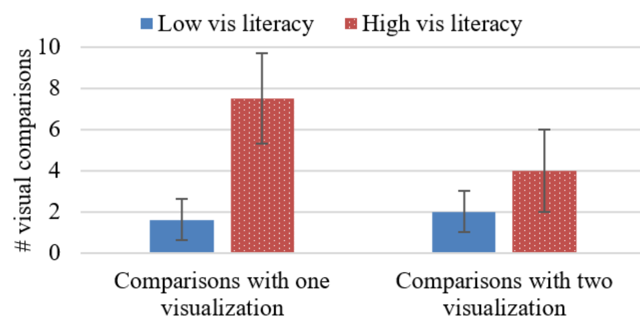

Figure 8: Number of visual comparisons performed with the customized interface (one visualization) versus the non-customized interface (two visualizations), depending on the levels of vis literacy.

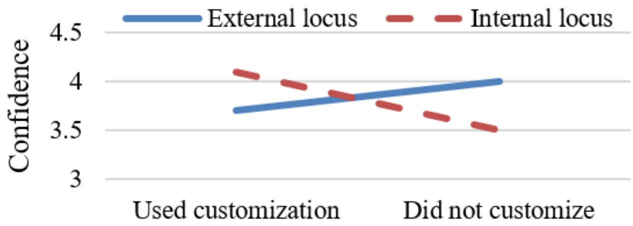

Figure 9: Interaction effect of locus of control with customization on confidence.

10 does show quite a large difference in time spent with one visualization between internal and external locus of control users (29% versus 17%).

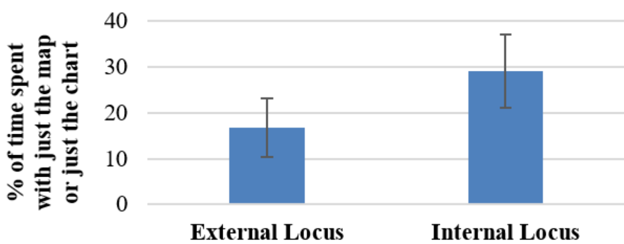

Figure 10: Proportion of time spent processing the customized interface with either just the map or just the chart, for users with an external and internal locus of control.

7 IMPLICATIONS FOR PERSONALIZATION

The effects of *vis literacy* and *locus of control* discussed in the previous section suggest that it could be worthwhile adapting the customization mechanisms to these to user characteristics, in particular via system-driven support to customize when appropriate. The first two rows of Table 4 summarize our ideas for such adaptation. Users with high vis literacy or internal locus of control benefited from the hide/display customization, suggesting that this option should remain available to these users. This result also suggests investigating ways to encourage users with a high vis literacy or an internal locus of control to customize when they do not do it spontaneously. Specifically, there were 17 (55%) of such users out of the 31 who did not customize: 5 with a high literacy, 4 with an internal locus and 8 with both. Four of these 17 users did not use the mechanism because they did not notice it, thus for these users it might be sufficient to make the customization mechanism more noticeable, for instance by adding to the MQ interface specific instructions on how to use it. The remaining 12 high literacy/internal control users, on the other hand, knew about the customization mechanism and chose not to use it. Thus, they may need more proactive encouragement, such as prompts delivered by the system to promote the use the hide/display buttons during interaction.

The results in the previous section also suggest that the hide/display customization hindered users with an external locus of control in terms of decision confidence. Therefore, it might be worthwhile

Table 4: Forms of personalization suggested by our results.

Personalization	For:
Prompts to use the hide/display buttons	Internal locus of control / high vis literacy users
Deemphasize or disable the hide/display buttons	External locus of control users
Get a simpler deviation chart	Low spatial memory users
Prompt to perform visual comparisons	Low spatial memory, visual scanning, vis literacy or perceptual speed users

to investigate ways to discourage the use of the hide/display buttons for these users, e.g., by de-emphasizing the buttons or even disabling them.

The users who are not willing to customize might also benefit from other forms of personalization suggested by the results in the previous study with MQ [36] and listed in the last two rows of Table 4. Specifically, low spatial memory users, who found the chart less useful than their counterparts, may benefit from personalization that increases the chart perceived usefulness. One approach could be, for instance, to simplify the chart by showing only the factors that were top priorities of the user, to better suit these users reduced capacity to retain visual information. Users with low levels of spatial memory, perceptual speed, vis literacy and visual scanning, who compared less the visualizations across scenarios, may benefit from personalized support that facilitates such comparisons. For instance, they could receive prompts to perform comparisons when they occur too infrequently.

To deliver the forms of personalization listed in Table 4 at the system's initiative, there is a need to collect or infer the user's levels of relevant user characteristics. These characteristics could be captured before a user starts working with MQ-transit, by administering tests as we did in this study. A version of MQ-transit could be given to the user with suitable forms of personalization selected based on test results. This approach, however, is not suitable when it is not realistic to expect users to take tests (e.g., in walk-up-and-use settings). As an alternative, user characteristics could be predicted in real-time by the system, leveraging implicit information on the user's interaction behavior. Initial evidence that such real-time prediction is possible by leveraging eye-tracking data has been provided for perceptual speed, spatial memory, vis literacy and visual WM during interaction with MQ-transit [12], as well as for perceptual speed and visual WM while processing bar and radar charts [24]. These works have also shown that prediction is possible early on during visualization processing, typically after observing 10% to 50% of a user's data. Based on such prediction, early in the task the system could proactively recommend the suitable forms of personalization to the users who need them. How to provide such system-driven recommendations in an effective and unobtrusive manner is an open question, but a promising approach is mixed-initiative adaptation, where the users make the final decision on whether to personalize based on system recommendations [9, 29, 58].

8 CONCLUSION

Our research contributes to understanding the need for bringing together the two main approaches for interface personalization, namely customization and system-driven adaptation. In particular we explore one such approach: devising system-driven support to customization based on user characteristics that affect if users can/want to customize. We presented a user study to examine the relationship among user characteristics, task performance, and usage of a customization mechanism integrated into MQ, a visualization-based system designed to engage the public in environmental decision making. With this mechanism, users can select the type of information displayed in the interface by removing/displaying at will one of two visualizations used in MQ to support the decision making process. As in other studies on customization, we found that a majority of our participants did not customize, not because of usability issues but mainly because they wanted to have all existing information immediately available. On the other hand, 33% of the participants still customized even after a few minutes of exposure to MQ, and some of them benefited from customization depending on their levels of visualization literacy and locus of control.

Our findings extend previous work on interface personalization by showing the impact on customization effectiveness of two user characteristics not included in existing work on interface customization, namely visualization literacy and locus of control. These findings suggest ways to encourage customization for users who could benefit from it but do not customize spontaneously, namely users with a high visualization literacy or an internal locus of control, for instance via system-driven assistance to customize. On the other hand, users with a low visualization literacy or an internal locus of control could benefit from other forms of personalization, such as getting simpler visualizations. These results also show that customizing is useful to some users (those with a high vis literacy and an internal locus of control), suggesting that, even if only a minority of the users customized, there is for some of them a need for customizing that can be in part satisfied by the current mechanism. Altogether, these findings suggest that it is worthwhile investigating ways to augment customization mechanisms with system-driven support, both to help specific users customize, and to enable other forms of personalization, depending on specific user characteristics. The above findings also contribute to gain a better understanding on the need for personalization of visualization-based interface content, which is important because visualizations are becoming more and more widespread, not only in professional settings, but also for personal usage [30].

One limitation of our approach is that we discretized users into two groups in the analysis, based on whether they customized MQ at least once or not, which does not allow to distinguish between different customization behaviors, such as customizing permanently versus exploring the customization mechanism before coming back to the default interface at some point. As a matter of fact, most users did come back to the default interface with two visualizations at some point. One possible explanation for this is the fact that several "subtasks" were required to complete the overall task in MQ, such as exploring each scenario, integrating the map and its legend, comparing each of the map and the chart across scenarios, providing and revising the rating... Thus users might have needed to customize for some of these subtasks, while the default interface was suitable for others. For example, hiding the chart could be very useful to focus on comparing the map across scenarios. Thus future work could explore in more details customization usage, to elicit when the users need to customize the most, and how this relates to specific user characteristics. In particular, we plan to further explore the effects we found for vis literacy and locus of control, by taking into account the proportion of time sent processing the customized interface, as well as the subtasks/goals of the users when customizing, even temporarily.

As future work, we also want to investigate specific ways to provide the forms of personalization suggested by our results. We are especially interested in dynamically supporting customization via dedicated support delivered by the system based on the real-time prediction of the user characteristics from eye tracking data (as done in [12]). To make such prediction, we plan to investigate the feasibility of collecting gaze data in a public setting, for instance by using a non-intrusive eye-tracking bar integrated into a kiosk.

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