Expert and Non-expert Knowledge of Loosely Structured Environments*

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Abstract. Three experiments investigated expert and non-expert knowledge of a familiar but loosely structured spatial environment as revealed through the production of sketch maps. In the first experiment, experts and non-experts in geomatics sketched maps of a well-known park. The analysis of the maps revealed that experts and non-experts used different drawing strategies that reflected different mental representations. In the second experiment, new participants identified good and poor examples from the previous maps. Expert and non-expert evaluators agreed, indicating that experts and non-experts alike agree on what constitutes a "good map". In the third experiment, people familiar and unfamiliar with the park were asked to remove non-essential features from a consolidated map that incorporated all the features drawn by the participants of the first experiment. Those familiar and unfamiliar with the environment retained the same features, notably, the paths in the park. Together, the research shows that experts produce superior maps to non-experts, but that people, irrespective of expertise and familiarity, concur on the features that make a map effective. Even for relatively unstructured environments like a large park, people seek structure in the configuration of paths. These findings have implications for the design of maps.

Keywords: Spatial cognition, maps, navigation, metacognitive knowledge, expertise, design, parks.

1 Introduction

To communicate environments, people commonly rely on descriptions or depictions, language or graphics. These two modes of externalization of spatial knowledge have been analyzed to reveal the content and structure of the mental representations of space. Studies have emphasized both the specificities of depictive and descriptive modes of representation, and also their intimate connections (e.g., Przytula-Machrouh, Ligozat, & Denis, 2004; Rinck & Denis, 2004; Taylor & Tversky, 1992a, 1992b). Tversky and Lee (1998, 1999) went as far as suggesting a common conceptual structure underlying depiction and description of familiar routes. They showed that people's spontaneous sketch maps and verbal directions were described

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by the conceptual structure, a structure Denis (1997) derived from a large corpus of spontaneous route directions. This suggests that both sketch maps and verbal directions are different externalizations of the same underlying mental representation. The core of that structure is a network of paths and nodes.

Corpora of spontaneous route directions have provided a rich source of information about effective directions (e.g., Allen, 2000; Denis, 1997; Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Golding, Graesser, & Hauselt, 1996; Michon & Denis, 2001; Schneider & Taylor, 1999). From these corpora, skeletal directions can be abstracted. To derive skeletal directions, first, all elements from all participants' directions are combined. Then, a group of judges selects those elements that are essential for navigation. Interestingly, judges familiar and unfamiliar with the environment tend to pick the same elements (Denis et al., 1999). The agreement of judges who do and do not know the environment suggests that selecting the crucial pieces of information in route directions is based on metacognitive knowledge that is to some extent independent of a specific environment. Similarly, participants familiar and non-familiar agreed on ratings of the communicative value of the original directions. The skeletal directions and the rated spontaneous directions were validated in studies using directions of varying judged goodness as well as the skeletal directions as navigation aids (Daniel, Tom, Manghi, & Denis, 2003; Denis et al., 1999). These studies confirmed that descriptions are variants of a core structure, a combination of links and nodes reflected in the skeletal directions (see also Fontaine & Denis, 1999; Michon & Denis, 2001). As noted, the core structure is expressed in sketch maps of routes as well as verbal directions (Lynch, 1960; Tversky & Lee, 1998, 1999). It has been applied to the design of computer algorithms that generate effective and popular route maps (Agrawala & Stolte, 2001).

Is this link/node core reflected in survey maps as well as route ones? Will it hold for environments that are not as highly structured as urban environments, environments that are used for recreation and wandering rather than for getting from place to place? Do maps produced by experts in map use and design differ from those produced by non-experts? And, finally, do people familiar and unfamiliar with an environment agree on the features that make for an effective map? In other words, do people have metacognitive knowledge of what is important and what is secondary in maps? We posed these questions in three studies. In the first, experts and non-experts in map production and use were asked to produce maps of a large park well-known to all of them. In the second study, those maps were evaluated by other participants, familiar or unfamiliar with the park. In the third experiment, new participants familiar or unfamiliar with the park selected the information they deemed important from an amalgamation of the information included in the original maps.

This procedure accomplishes two objectives simultaneously: it both reveals the mental representations people have of environments and establishes principles for designing effective maps to communicate those representations, thus creating a context for the development of new representational tools. Because the principles turn out to be the same for familiar and unfamiliar users, they can be broadly applied.

2 Experiment 1: Sketching Maps

The use of sketch maps as indices of spatial knowledge is not free of difficulties. These maps are generally incomplete and distorted, and they tend to mix metrics.

However, the distortions and omissions in sketch maps reflect people's underlying mental representations of environments by numerous other methods (e.g., Tversky, 1981, 1993). They are schematic and incomplete, often including blank spaces and unconnected networks. As a result, scoring for the purpose of assessment is a challenge. However, sketch maps have been shown to be reliable and preserve consistent information over time (e.g., Blades, 1990; Tversky, 1981). Moreover, they closely correspond to other indices of mental representations, such as descriptions, recall, and response times to answer questions about proximity and direction (e.g., Taylor & Tversky, 1992b; Tversky & Lee, 1998). As suggested by Davies and Pederson (2001), analyzing sketch maps can be challenging if the focus is on accuracy, but this does not preclude the value of sketch maps if the focus of the study is to exploring the knowledge elicited and the strategy followed by the people engaged in map drawing.

The construction of sketch maps is related to the organization of information in the mental representation of the described environment. Taylor and Tversky (1992a) analyzed the order in which elements of an environment were included in a map. Drawing order varied, and depended on cognitive features of the environments, over and above any constraints that might be imposed by the task of drawing. Taylor and Tversky found that the order of drawing reflected hierarchical organization of the environments, and that the hierarchy depended on both spatial and functional aspects of the environments. Subgroups were based on spatial proximity, spatial scale, and functional features. Walsh, Krauss, and Regnier (1981) used sketch maps to discover the structures people rely on to describe their neighborhoods. Most participants began their maps with some sort of street grid, and then filled in the pattern with landmarks and a few more streets.

Following these endeavors, the maps collected in the present experiment were first analyzed for their content and structure. We focused on the quality and quantity of information included, in particular landmarks and roads. Errors of location were also examined. As in the previous investigations, we recorded the order in which the different parts of the map were drawn, expecting to find evidence for a hierarchical organization of the maps. Spatial proximity and functional aspects were thought to be potential sources of influence on the structure of the map. Classic research on expertise generally attributes the memory superiority of experts to better organization of information in their knowledge base (e.g., de Groot, 1966). Therefore, the structuring of information in maps of experts should differ from that of non-experts.

2.1 Method

Environment. The environment selected for the study was the major park of Quebec City, the Plains of Abraham. It lies over an extended space, covering about one hundred hectares, rather longer than wide. The park is delimited on the north side by the city and on the south by a steep hill overlooking St. Laurent River. The park presents a wide variety of relief. There are only a few roads in the park. Compared to a city or a campus, this environment is only loosely structured.

Participants. Two groups of people participated in the experiment. The first group was composed of 9 graduate students in geomatics at Laval University (8 men, 1 woman). They were considered as experts in the domain of map processing. The second group was composed of 27 graduate students in other disciplines (13 men, 14 women). They were considered as non-experts as regards map processing. The criterion for including the participants in the study was their knowledge of the park of which they would draw the map. Participants of both groups had been living in Quebec City for more than 15 years and reported to experience the park frequently, at least once a month on the average, both during winter and summer. In this and subsequent studies, the effect of gender was examined; there were no reliable effects, so these analyses are not included.

Materials. White sheets of paper, legal size, were made available to participants to draw the maps.

Procedure. Participants were asked to draw a map of the Plains of Abraham. The map was intended to provide information necessary to navigating the park and finding the major points of interest to those unfamiliar with the park. Sessions were video recorded. At the end of the experiment, participants filled in a questionnaire on how they perceived the task just completed.

2.2 Results

Map Content. For each map, the number of landmarks, road segments, and road intersections were tallied; these appear in Table 1 for expert and non-expert participants. An analysis of variance (ANOVA) was conducted on each group of items. Experts reported more landmarks, $F(1, 34) = 5.70$, $p < 0.05$, road segments, $F(1, 34) = 17.12$, $p < 0.001$, and intersections, $F(1, 34) = 21.32$, $p < 0.001$, than non-experts. Overall, experts reported an average of 52.0 items, while non-experts reported an average of 25.4 items, $F(1, 34) = 15.64$, $p < 0.001$.

Table 1. Average number of items reported (standard deviations are in parentheses)

	Experts	Non-experts
Landmarks	20.4 (9.8)	13.2 (7.2)
Road segments	17.7 (8.8)	7.4 (5.5)
Intersections	13.9 (7.4)	4.8 (4.2)

Errors were categorized as “global” or “local”. To this effect, the area of the park was divided into six sub-areas. For a given sketch map, we considered as a global error every occurrence of an object (a landmark, for instance) which was drawn in a wrong sub-area, and as a local error every occurrence of an object wrongly positioned in its correct sub-area. The average number of errors is shown in Table 2. There were overall very few global errors, but non-experts made more such errors than experts, $F(1, 34) = 4.55$, $p < 0.05$. There was no difference between experts and non-experts in local errors.

Debriefing revealed that all experts but one reported having seen a map of the park, but only half the non-experts had (13 had and 14 had not seen a map). Those who had seen a map produced more landmarks, 16.0 (sd = 7.9), than those who had not, 10.5 (sd = 5.5), $F(1, 23) = 4.74$, $p < 0.05$.

Table 2. Average number of errors (standard deviations are in parentheses)

	Experts	Non-experts
Global errors	0.1 (0.3)	0.8 (1.0)
Local errors	2.1 (1.4)	2.0 (1.4)

Questionnaire. In the post-experimental questionnaire, participants rated several aspects of the task on a 1-5 rating scale: confidence in the information contained in the map, confidence in the location of items on the map, ease of map drawing, self-rated knowledge of the park, and self-rated sense of direction. Only the first measure differed between the groups, with experts expressing more confidence in the information they included in their maps than non-experts, 4.1 (sd = 1.0) and 3.5 (sd = 0.9), respectively, $F (1, 34) = 3.85$, $p < 0.05$.

Orientation of Maps. As revealed in Table 3, experts tended to orient their maps north-up, but non-experts did not, Chi2 (1) = 14.48, $p < 0.001$. Non-experts preferred to orient maps with the park entrance at the bottom, as though one could walk into the map, a strategy observed in previous work (e.g., Taylor & Tversky, 1992; Tversky, 1981).

Table 3. Frequency of placement of north at the top or bottom of the sheet by experts and non-experts

	Experts	Non-experts
North at the top	8	5
North at the bottom	1	22

Order of Drawing Roads and Landmarks. We selected the first 20 items (roads and landmarks) drawn by each participant and, among these, those produced by at least half the participants. A value was given to each item, corresponding to the rank order of drawing of this item. The median rank was then calculated for each item. These computations revealed differences between the two groups. Experts drew the structure of the roads earlier than non-experts. Significantly, the first item drawn by experts, but not non-experts, was the Grande Allée, the street which runs along the park and marks the border between the city and the park. This street orients the park in the surrounding environment. Both experts and non-experts drew roads prior to landmarks; roads ranked 6.5 and landmarks 11.5. Thus, maps are structured first by roads or links, and these are used for locating landmarks.

Order of Drawing Landmarks. We selected the 10 major landmarks drawn by all participants in order to determine whether these were hierarchically organized. Following Taylor and Tversky (1992), we conducted cluster analyses on these landmarks. In their research, the clusters were an excellent index of hierarchical organization. Recall order has been used as an index of hierarchical organization at least since Tulving (1962). For each map, we calculated the recall interval for every pairwise combination of landmarks, that is, the number of other landmarks recalled between the two items of the pair. The median recall interval for each pair of landmarks was calculated and represented in a half matrix. We used this matrix to compute the cluster analysis for both groups of participants (ADDTREE; Sattath & Tversky, 1977).

Figure 1 shows the clustering of landmarks for experts. Two groups of items emerged. The first one included the Jogging Loop, the Grey Terrace, the Garden, and the Museum. The second one included the Bandstand, the Loews Hotel, the Martello Tower, and the Citadel. Landmarks from the first group were mostly in the west part of the park and those from the second group were mostly in the east part. The further two landmarks (the Kiosk and the Promenade) were at the eastern limit of the park. This structure thus confirmed the progression from west to east in map drawing and showed that the construction of the experts' maps was mainly based on the principle of spatial proximity.

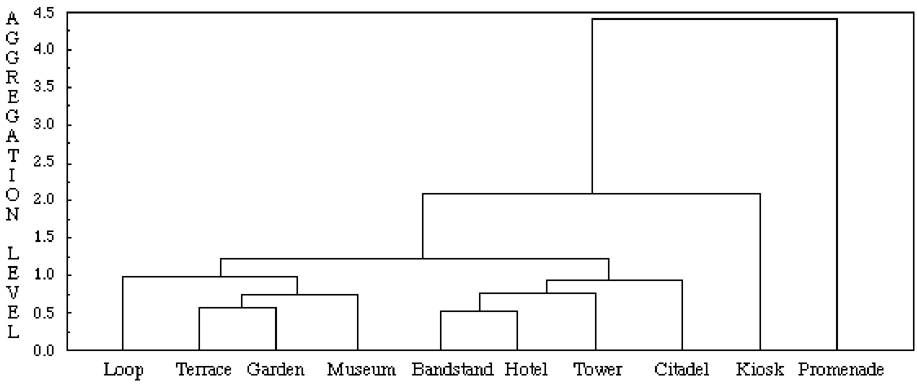

Fig. 1. Cluster diagram for landmarks identified by experts. The ordinal variable is Aggregation Level.

Figure 2 shows the clustering of landmarks for non-experts. The clustering is quite different than for the experts. Two groups of items emerged. The first included the Jogging Loop, the Loews Hotel, the Grey Terrace, and the Citadel. The Jogging Loop is at the western end of the park; the Loews Hotel is on a border of the park, equidistant from the western and eastern extremities; the Grey Terrace is in the west part of the park, south of the Jogging Loop; and the Citadel is at the eastern extremity. These items are all located on the borders of the park and their positions provide a rectangle-like frame. Once these items were drawn, the resulting virtual rectangle was filled in with the items located inside the park. Thus, the elaboration of the maps by the non-experts followed a strategy consisting in drawing items on the borders first, then filling in the structure. Spatial proximity was not used as a governing rule in the construction of the maps.

To summarize, while experts seemed to rely on spatial proximity to draw the landmarks, non-experts seemed to rely primarily on the functional properties of the landmarks. Because landmarks were located on the borders, they became functionally significant to enclose the space of the park.

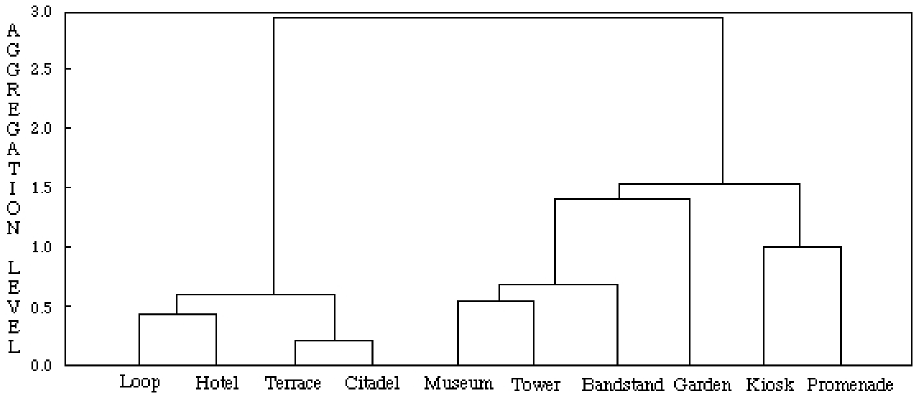

Fig. 2. Cluster diagram for landmarks identified by non-experts. The ordinal variable is Aggregation Level.

2.3 Discussion

Experts' maps of a familiar, loosely structured environment differ from those of non-experts. Experts included more information than non-experts, an effect not due to different exposure as the groups reported equal knowledge and frequency of visiting. More likely, the superior performance of experts is connected to their greater acquired capacity to manipulate spatial information, read and use cartographic materials, which helps them to better organize spatial information. Internal organization of information thus facilitates the retrieval of items to be included in the map. The marked reference to road information is another indication that experts' knowledge is more strongly structured than that of non-experts.

The analysis of errors revealed an interesting finding. Even if we condition recall of location of landmarks on overall recall of landmarks, experts were locating landmarks better. This suggests that for experts, memory for landmark and memory for location were tightly linked, but for non-experts, they were more independent. When non-experts remembered the location, they were as accurate as experts (the number of local errors was the same).

The maps of both experts and non-experts were hierarchically structured, but differently. Experts' maps were primarily structured by roads. The roads constitute a framework with respect to which landmarks are located. Non-experts relied less on roads. They constructed their maps from the borders inside. In addition, the representations of non-experts were less structured than those of the experts.

Expertise had also an effect on the orientation of the maps. The experts followed cartographic convention by placing north at the top of the map. They also demonstrated greater ease in adopting a survey perspective to externalize their spatial knowledge. By contrast, the orientation of the maps suggested that non-experts did not adopt a consistent survey perspective, but rather mixed survey and route perspectives. Taylor and Tversky (1996) reported that people often mix perspectives when they have to produce descriptions of environments. A similar process may be at work in the construction of maps. Inspection of non-expert maps revealed that some landmarks were drawn from a bird's eye view, while others were drawn as if the drawer took a frontal view on them. A route perspective was also evidenced by the orientation of the maps. Non-experts oriented their maps by the way they experience the park when entering and proceeding through it.

3 Experiment 2: Evaluating the Quality of Maps

The maps produced by experts are superior to those produced by non-experts. Do their evaluations of maps produced by others correspond to their own maps, or is there general agreement despite expertise on the qualities of a "good map"? Following the procedures of Denis et al. (1999) for the analysis of verbal route directions, experts and non-experts were asked to assess the quality of the maps on several rating scales. Because this task was time-consuming, we randomly selected a subset of 25 maps from the 36 collected in Experiment 1. Cartographers use explicit criteria for the generation of maps and if these criteria are applied, the quality of the resulting map is assured. The question here was whether non-experts would adopt the same or different criteria.

Based on the literature in graphic semiology and cartography (e.g., Bertin, 1967), we selected two classes of criteria that seemed to be important to experts: those related to the physical qualities of the maps, and those related to their functional qualities. For the physical qualities, three aspects pertain to structures (i.e., roads and landmarks): identifying the structures, preserving their proportions, and preserving their relative positions. Another three aspects pertain to the map itself: amount of information included, homogeneity of scale, and aesthetic qualities of the map. For functional qualities, three aspects pertain to the processing of the map: ease of reading, ease of locating structures, and ease of recognizing structures. Another three aspects are related to using a map: ease of locating oneself, ease of selecting a goal, and ease of constructing a route.

If people have metacognitive knowledge of what constitutes a good map, judgments of experts and non-experts, those familiar with the environment and those not, should be similar. If, on the other hand, such shared knowledge does not exist, we would expect experts, who rely on a set of cartographic rules, to give more importance to these criteria than non-experts. Additionally, experts might be harsher in their evaluations. Moreover, not knowing the described environment could make the judges more demanding, so that they might give lower evaluations than judges familiar with the park. On the other hand, those unfamiliar with the environment might be more forgiving of the inclusion of landmarks and of the accuracy of their locations simply because their knowledge is incomplete.

3.1 Method

Participants. Twelve people participated in this experiment. Four of them were experts according to the criterion used in Experiment 1, and eight were non-experts. In each group, half were familiar with the park (visiting it at least once a week), and the other half had never visited it or had done so just once. Within these categories, there was an equal number of men and women.

Materials. A subset of 25 of the maps collected in Experiment 1 were used, 9 from experts and 16 from non-experts, presented on separate sheets of paper.

Procedure. Participants evaluated the overall quality of the maps and then used 7-point scales to judge them on 12 criteria.

3.2 Results

Overall Scores. An ANOVA did not reveal any significant differences between judgments of experts and non-experts, nor between participants who were familiar or unfamiliar with the environment. Furthermore, the correlation matrix among the scores given by the 12 judges revealed that all 66 correlation values were positive, with 55 significant at a probability level of 0.05 or less. Intra-class coefficients amounted to 51.3% for the whole set of judges; 52.6% and 48.9% for experts and non-experts, respectively; and 45.2% and 53.7% for familiar and unfamiliar judges, respectively. These data suggest a common conception of what is a good map, and of implicit criteria shared by the experts and the non-experts.

Scores on Individual Criteria. ANOVAs were conducted on scores given to the maps for each of the 12 criteria considered in turn. Expertise and familiarity did not affect the scores on any of these criteria. We also wanted to estimate the relative weight of the criteria in the global evaluation expressed by the overall score. This was done by using an analysis of stepwise regression on the overall score. The analysis proposed a model with 8 of the 12 criteria, with $R^2 = 0.8455$. The results showed that 81% of the variance of the overall scores was explained by three criteria (in decreasing order): ease of locating oneself; amount of information included; and ease of recognizing structures. These three criteria were also found in the models calculated for experts and non-experts separately, and for familiar and unfamiliar participants, separately. The model obtained for the experts also included the aesthetic qualities of the map.

"Good" Versus "Poor" Maps. Three maps received average overall scores of 5.00 or more; two of these were produced by experts, and one by a non-expert. The three maps had similar profiles over the 12 individual criteria. The three maps rated poorest (below 2.00) were drawn by non-experts. When examining their scores across the 12 criteria, there was in fact less homogeneity in their profiles than for the best maps.

Drawing Expertise. The maps produced by experts received higher overall scores than those produced by non-experts, 4.0 and 3.2, respectively, $F(1, 284) = 19.01$, $p < 0.001$. Experts' maps were rated higher on many of the criteria for a good map: preserving proportions among structures; preserving relative positions of structures; amount of information included; homogeneity of scale; ease of locating structures; ease of locating oneself; and ease of constructing a route (in all cases, $p < 0.001$). The criteria receiving the highest scores in experts' maps were related to the spatial properties of the maps. Thus, what differentiates expert from non-expert maps is spatial adequacy and veracity. These, of course, are the first requisites of a map, and point to the difficulties encountered by non-experts in accurately representing spatial relations among structures.

3.3 Discussion

This study, in which experts and non-experts rated maps produced by experts and non-experts, provides clear evidence for shared conceptions of what constitutes a good map. The ratings of map quality were strongly correlated across participants irrespective of expertise and familiarity, echoing previous work on route directions (Denis et al., 1999). Shared knowledge and criteria create a context conducive to easier communication, whether that communication is by maps or language.

Three criteria for a good map were especially strong in the regression analysis. A good map must, first of all, help users position themselves in an environment; next, it must contain an adequate amount of information; and finally, the structures drawn on the map should be recognizable.

4 Experiment 3: Constructing a Skeletal Map

The aim of Experiment 3 was to construct a “skeletal map” of the environment considered, by following a procedure paralleling a similar procedure used in building “skeletal directions” (Denis et al., 1999; Fontaine, 2000). As a first step, we built a “mega-map” containing all information provided by all the participants in Experiment 1. Participants in the present experiment selected the items that they thought should be present in a map intended to provide necessary and sufficient information to users. As before, both people familiar and people unfamiliar with the environment participated, allowing assessment of effects of familiarity. By comparing the responses from people familiar or unfamiliar with the described environment, we expected to uncover whether common implicit knowledge is available for people, independent of their knowledge of the environment. If the responses of familiar and unfamiliar participants are similar, then it is likely that this is because they share knowledge of the criteria of good maps.

4.1 Method

Participants. Thirty-two participants were recruited, half of them familiar and the other half unfamiliar with the park, according to the criteria used for the previous two experiments. In both groups, there was an equal number of men and women.

Materials. A mega-map of the environment was generated on a computer from a geo-referenced database. A total of 114 informational items, drawn from the responses of participants of Experiment 1, were positioned on the mega-map at their exact locations. For the roads and the major landmarks, existing locational data were used, but for many other landmarks, we had to measure their exact spatial coordinates with a GPS receiver. The map was then constructed using MapInfo™ software (see Figure 3).

Procedure. Participants were tested in groups. The experiment took place in a classroom. Participants faced two screens. On one screen, the mega-map was shown for the whole duration of the experiment. On the second screen, four successive enlargements of the mega-map were projected, each enlargement representing an area of the park. On each enlargement, information items were shown, then suppressed, then shown again. Instead of selecting or rejecting each item by all-or-none choice, the participants were invited to use a 5-point rating scale to estimate the extent to which they thought this item should be kept in the skeletal map. The map was said to allow a person who does not know the park to move efficiently without getting lost and to find every element that he or she could be interested in. With this purpose in mind, the participants were invited to give the value 1 to information items that should definitely be eliminated, 2 to items that should probably be eliminated, 3 to items that could be kept or discarded indifferently, 4 to items that should probably be kept, and 5 to items that should definitely be kept. This was done for all 114 information items in turn.

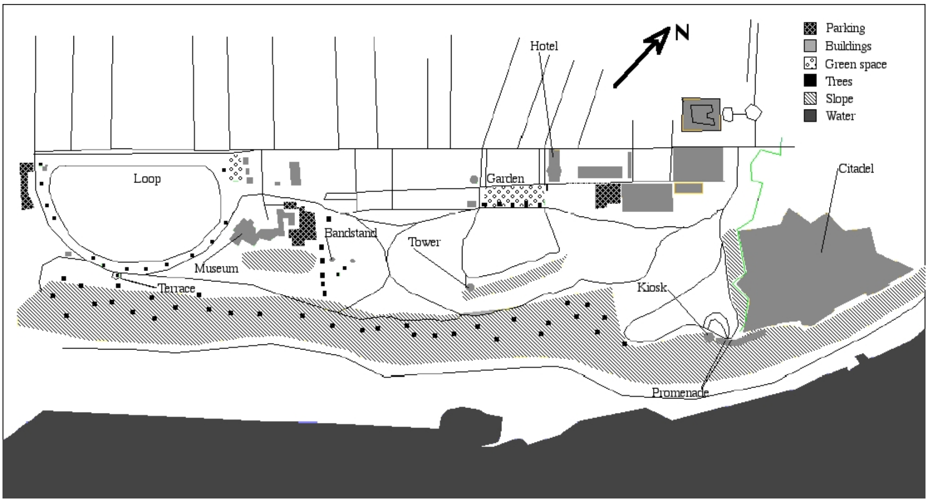

Fig. 3. Mega-map for the Plains of Abraham Park

4.2 Results

We classified the 114 information items of the mega-map into ten classes, which are listed below (with the number of items included):

- Roads within the park (13)
- Roads at the outside border of the park (28)
- Buildings within the park (large surface objects) (30)
- Buildings at the outside border of the park (10)
- Objects and monuments within the park (small surface objects) (15)
- Objects and monuments at the outside border of the park (3)
- Properties of the terrain (9)
- Specific indications (restrooms, points of view, services) (4)
- Indication of north (1)
- St. Laurent River (1)

For each information item, we computed the average rated value. Those items receiving a value equal to or above 4.0 were considered to be kept as items of the skeletal map (a total of 55 items were in such a situation). Not surprisingly, the single items of the last two classes were selected as skeletal items, namely, the reference to north, and the reference to St. Laurent River. Although the river was not part of the park itself, this remote landmark had a special status as a reference in the description of the park (see Figure 4).

The first four classes listed above contained items that were selected to be included in the skeletal map, but none of the items in the next four classes (objects and monuments of secondary importance, properties of the terrain, and specific indications) were rated to be included in the skeletal map.

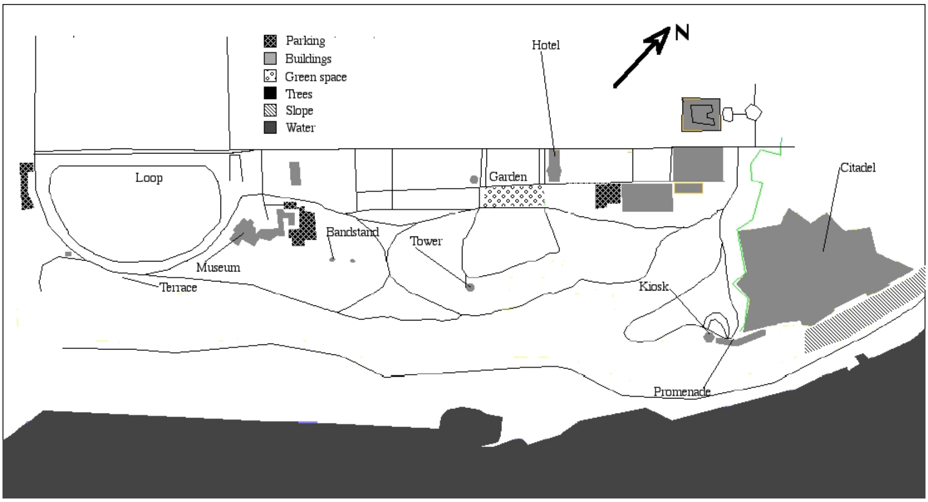

Fig. 4. Skeletal map for the Plains of Abraham Park

Table 4 shows the number of items of the first four classes kept in the skeletal map by the two groups of participants. Not surprisingly, more items within the park were maintained in the skeletal map than outside items, and roads were preserved more than buildings. The most interesting feature here was that the familiarity of the participants with the environment did not affect their perception of the importance of items. In other words, those items of primary importance for a guidance or navigation purpose were perceived as such even by those participants who had no knowledge of the environment. Based on the number of items kept by familiar and unfamiliar participants, the Chi2 value was not significant.

Following the procedure developed with route directions (Denis, 1997), we computed a measure of richness for the maps, that is, the proportion of skeletal items present in individual maps collected in Experiment 1. Here, we focused on the best three and the poorest three maps, according to the participants of Experiment 2. The first three maps had an average richness index of 69.1%, whereas the last three had an index of 16.4%. Thus, the richer a map is in items belonging to the skeletal map, the better it is judged in terms of quality.

Table 4. Number of items in the mega-map and in the skeletal map for participants familiar and unfamiliar with the environment

	Roads within the park	Roads at the outside border of the park	Buildings within the park	Buildings at the outside border of the park
Mega-map	13	28	30	10
Skeletal map (Familiar part.)	12	14	17	5
Skeletal map (Unfamiliar part.)	12	17	16	6

4.3 Discussion

The analyses reported above did not show any effect of familiarity on the judgment of the necessity of including items in the skeletal map. This lack of difference is highly compatible with the hypothesis of a common knowledge base. Being familiar or not with an environment does not appear to be crucial for determining the necessity of information on a map. Selecting essential elements in a map is based on knowledge that is independent of the specific environment.

The information that is preserved on the skeletal map essentially consists of roads and landmarks. The selected landmarks only consist of large-size buildings. This confirms visual saliency as a primary criterion of landmark selection (cf. Nothegger, Winter, & Raubal, 2004; Tom & Denis, 2003, 2004).

5 Conclusions

The three experiments reported here were conducted to investigate the mental representations of loosely structured environments by experts and non-experts, by those familiar and those unfamiliar with the environment. Implicit in this interest is the hope that mental representations of such environments will provide clues to the design of effective visualizations of environments. This double enterprise extends the efforts of Denis and his collaborators (Denis, 1997; Denis et al., 1999) and Tversky and her collaborators (Tversky, Agrawala, Heiser, Lee, Hanrahan, Stolte, & Daniel, in press; Tversky & Lee, 1998, 1999) from route directions and route maps of structured environments to area maps of loosely structured environments, in particular, a large urban park. This endeavor raises several questions. Is there a core structure underlying mental representations and visualizations of environments? The previous findings, discussed in depth in the introduction, indicate that there is core knowledge for route maps; here we have provided such evidence for the case of survey maps. Is there any metacognitive knowledge of what is important in a map and of what may be considered to be a good map?

To summarize, our results showed that experts' maps are different and better than those of non-experts. Experts begin by orienting the environment in the larger surroundings, continue to the basic framework of the environment, the structure of the roads, and then attach the landmarks to the framework. This structure and the order of drawing contradict some old notions of spatial cognition that claim that people construct mental representations of space first from landmarks and then paths, followed by survey representations (e.g., Siegel & White, 1975).

People who are not expert and not familiar with the environments prefer the maps that experts construct, a recurrent finding (see Tversky et al., in press) and the reflection of a lag between comprehension and production. We can appreciate and evaluate movies and books and meals that we cannot create. This is encouraging for design, as it says that design principles can be extracted from expert productions that will be successful for experts and non-experts alike. The techniques developed by Denis (1997; Denis et al., 1999) of extracting collective knowledge (mega-descriptions and skeletal descriptions) and judgments thereon are useful for finding design principles. The present research provides guidelines for constructing survey maps that are analogous to the guidelines for route directions produced by Denis (1997) and confirmed by Tversky and Lee (1998, 1999), namely, they provide the structure of the links and locate the landmarks with respect to these.

Design principles for constructing effective route maps growing out of the research of Denis (1997) and Tversky and Lee (1998, 1999) were implemented in an algorithm that generates thousands of route maps a day on demand (http://www.mappoint.com; cf. Agrawala & Stolte, 2001). These maps have been enthusiastically received by users (cf. Tversky et al., in press). The design principles for route maps include depicting the paths and turning points (links and nodes) clearly; exact distance and direction as well as links not on the path can be ignored. The present research suggests that these principles can be extended to designing survey maps. In the case of survey maps, the link and node structure will place additional constraints on distance and direction, increasing their accuracy.

The experiments reported here allowed us to situate the knowledge of experts with respect to the knowledge of non-expert map users, and hence to advance understanding of how spatial information is organized and presented as a function of expertise. There has been a longstanding interest in whether efforts should be made to structure map representations more “naively”, closer to the way that non-expert users experience the environments. Our research suggests that experts’ maps serve the needs sought by experts and non-experts alike, and hence justify the role that experts play in the process.

Furthermore, we have gained insight into how spatial information in loosely structured environments is organized and represented. By focusing on map knowledge of the space, our experiments confirmed what appears to be a shared knowledge core about the organization of spatial information for different tasks, different levels of expertise, and different levels of familiarity. It may be the case, likewise, that loosely structured environments which favor less goal-oriented navigation are more readily represented using survey knowledge, although our experiments did not lead to unequivocal results. It would be useful to test this further in other experiments.

The role of roads as organizing elements, even when these are not regularly structured, is an important result for representing loosely structured environments. One may speculate that hiking trails as well as roads are useful reference structures in large wilderness parks and that efforts should be made to include these in map representations. Topography was not extensively used in the representations of the Plains of Abraham Park. In larger unstructured environments, it may play a more important role, but representing topography in ways understandable to non-expert map users is still a challenge.

Overall, the experimental program shows that basic and applied research can be done at the same time, especially using generated external representations. The map sketches, when carefully analyzed, reveal the mental representations of their producers and, when evaluated by others for goodness and essential information, provide principles for designing effective visualizations for all.

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