CARTOGRAPHIC DESIGN FOR MOBILE DEVICES: A CASE STUDY USING THE UW-MADISON INTERACTIVE CAMPUS MAP

by

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Chapter 1. Introduction

1.1 Introduction: Mobile Maps

It is estimated that by 2016, 80% of the United States population will be using a mobile phone and 50% will be using a tablet (Alexander 2013). As of 2012, five billion people in the world owned a mobile phone and over one billion of them owned a smartphone (Alexander 2012). It is estimated that 72% of these 1 billion people use their smartphone to access mobile maps (Alexander 2013). Despite the omnipresence of mobile maps, few empirically-derived and time-tested guidelines have been developed regarding map design on mobile devices. Existing design conventions for mobile mapping are a result of trial and error or, are unmodified from non-mobile implementations on the web. This means that maps designed for viewing on a non-mobile or laptop machine are now viewed on screens a fraction of the size. It is not only screen size that constrains map design, but also the screen resolution, color depth, screen refresh rate, and viewing conditions, as well as aspects not associated with the display, such as bandwidth, battery life, and the processing power of the device. In order to investigate these design and hardware constraints, the University of Wisconsin–Madison interactive campus map will be used as a case study.

The University of Wisconsin-Madison (UW) interactive campus map (http://map.wisc.edu) is a collaboration between the UW Cartography Lab and UW Communications that began in late 2005 (Roth et al. 2009). After a year of development and testing, the first version of the map (Figure 1.1) went live in late 2006 with two main audiences in mind. The first audience included potential and new students to UW who needed to familiarize themselves with the campus layout, major buildings, and other general campus information. The second audience included current students and faculty familiar with UW who required more detailed information about a specific location or building. The first version of the map was written in Flash ActionScript 2.0 and utilized technologies such as Adobe Illustrator CS2 and Adobe Photoshop CS2 for preparing data layers, Zoomify integrated into ActionScript 2.0 for aiding in map navigation, and Ruby on Rails for manipulating and sending requests to the backend database.

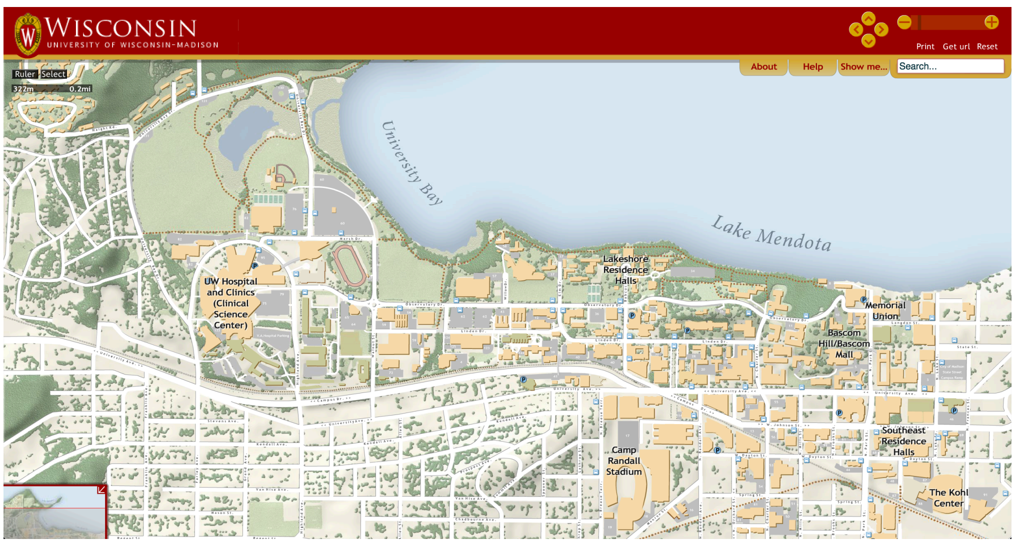

Figure 1.1—Original UW interactive campus map

The technology stack in the first version of the UW interactive campus map worked well for the desktop user typical of the mid-2000s. However, a shift occurred in personal computing during the late 2000s towards consumption of information on mobile devices. While mobile devices are outfitted today with modern browsers that connect to the Internet through telecommunication networks or wireless receivers, few of these devices support browser plug-ins, such as Flash Player (Roth et al. 2013). Given this shift towards the mobile user, a redesign effort was initiated in 2012 to make the map available on mobile devices. The second version of the map launched in late December of 2012, and was developed in JavaScript using open web mapping technologies, such as Leaflet.js, OpenStreetMap data, and PostGIS.

1.2 Functionality of the UW Interactive Campus Map

Upon entering the original, Flash-based UW interactive campus map, the full extent of the campus was presented to the user, providing an initial overview of the map and the available map features. From this overview, the user was given three ways to access additional information on the map. First, a search field was included allowing users to search for building names, departments, areas of interest, and bus stops (Roth et al. 2009). Second, the user could directly manipulate the map in order to browse the complete campus and to retrieve specific information about a mapped feature of interest (Harrower & Sheesley 2005). Third, a list of popular sites on campus was provided as a dropdown menu, including overlay layers on parking locations, visitor centers, and art venues. The map also included a variety of other notable interface features, such as a distance measurement tool, a road map/satellite image hybrid view, and a URL function that enabled users to create a unique URL of the current map view that could be saved for future interaction or shared with others (Roth et al. 2009).

Several aspects of the interface functionality were revised in the updated version of the UW interactive campus map to account for mobile viewing. Upon entering the map, the user is shown only a portion of the campus, rather than the entire campus, with the map center dependent upon the display device used to view the map. On a smaller-screen device, the user is centered by default at the 'Bascom Hall' area of campus (Figure 1.2), while on a larger-screen device the user is centered by default at the 'Van Hise Hall' area of campus (Figure 1.3). That difference in centering is due to the assumed portrait aspect ratio of the display on smartphones and the typical landscape aspect ratio of the display on monitors. On either size screen, the user then is prompted to allow the browser to use his or her location (Figure 1.4). If the user allows the website to use his or her location by selecting 'OK', the website will place a blue dot on their approximate location. If 'Don't allow' is selected, the user's current location is not displayed.

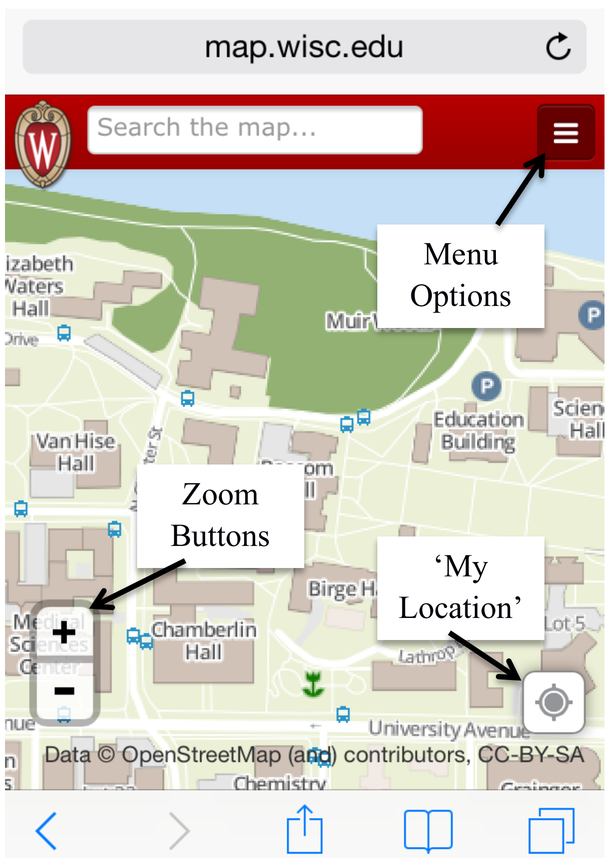

Figure 1.2—Updated UW interactive campus map, viewed on a smaller-screen

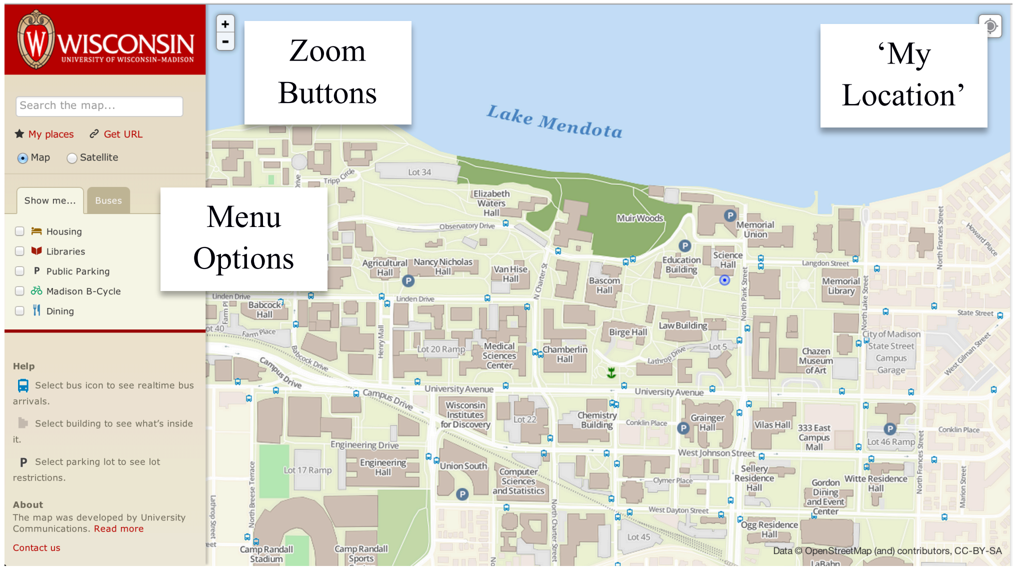

Figure 1.3—Updated UW interactive campus map, viewed on a larger-screen

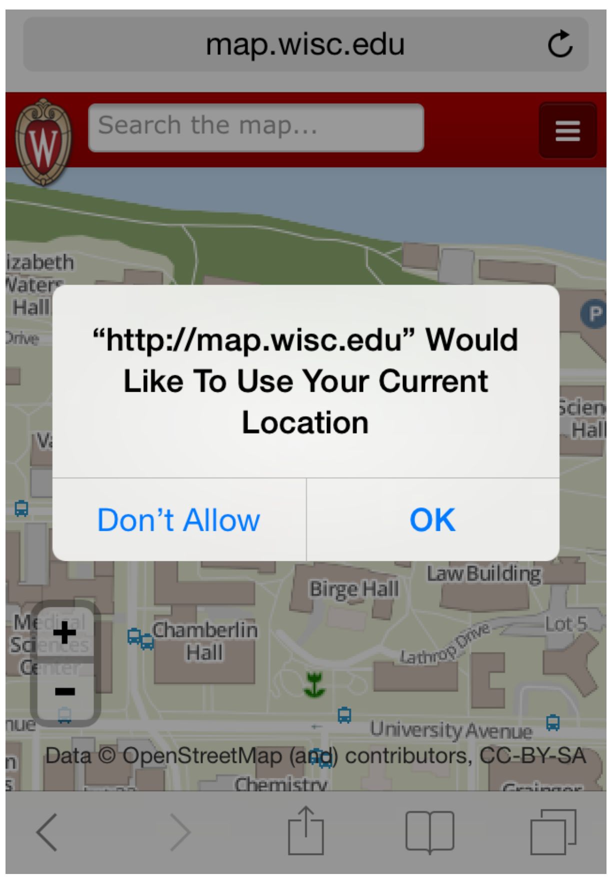

Figure 1.4—Prompt asking the user to allow location tracking

The supported interactive functionality remains consistent regardless of viewing on a smaller-screen or larger-screen device, but the layout of interface panels and widgets is responsive across screen size. The ‘My Location’ button, which pans the user to his or her location and zooms the map to a larger cartographic scale, is located in the bottom-right corner when the map is viewed on a smaller-screen (Figure 1.2) and the upper-right corner of the map when viewed on a larger-screen (Figure 1.3). A pair of zoom buttons (‘+’ and ‘-’) are provided to change the scale of the map; they are located in the upper-right corner of the map when viewed on a smaller-screen (Figure 1.2) and the upper-left corner of the map when viewed on a larger-screen (Figure 1.3). Importantly, interface flexibility, or the ability to perform the same interaction in multiple ways, is reduced for map interactions on mobile devices. The mobile version only supports tap-and-click interactions for panning, zooming, and retrieving details from the map, while the non-mobile version supports probing (i.e., ‘mouseover’, ‘mouseout’) and keying for performing these interactions in addition to the tap-and-click solutions included in the mobile version.

The most significant difference between viewing on a smaller-screen versus a larger-screen device is the layout of the page elements surrounding the map. On a larger-screen, there is a persistent panel along the left side of the map that contains a set of menu items (Figure 1.3). On a smaller-screen, this menu must be activated by the user through the ‘Menu’ button (Figure 1.2), with the menu panel then covering the map after activated (Figure 1.5). The menu itself includes several notable interface functions, including: a search feature, a ‘My places’ feature listing the user’s favorite places, a ‘Get URL’ feature allowing users to save and share a URL of the currently displayed view, a ‘Help’ feature providing instructions for using the map, an overlay toggle between a ‘Map’ and ‘Satellite’ basemap, and additional overlay checkboxes for layers of interest (‘Show me…’) and bus routes.

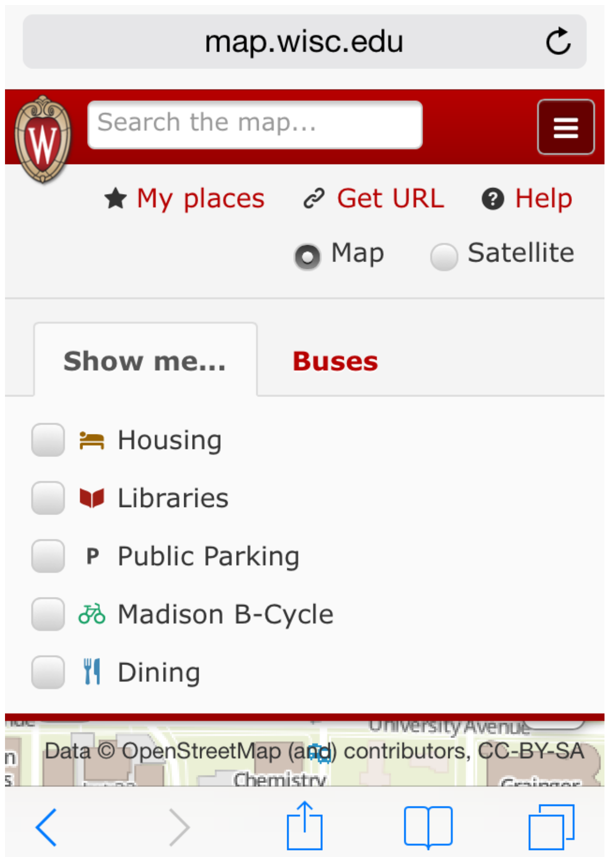

Figure 1.5—The activated menu when viewed on a smaller-screen

Regarding the basemap overlays, the ‘Map’ basemap portrays a highly generalized road map of the area with building footprints and sidewalks, while the ‘Satellite’ option portrays a highly detailed image of the campus showing numerous other contextual features, such as building characteristics (color, texture, etc.), sidewalks, and vegetation. The ‘Map’ basemap is shown by default when the UW interactive campus map is viewed on both larger-screen and smaller-screen devices.

1.3 Research Questions and Significance

The above comparison between the first and second versions of the UW interactive campus map, and between the smaller-screen and larger-screen viewing of the newer version, illuminates several unanswered questions regarding cartographic design on mobile devices. Perhaps the first and most noticeable attribute of a mobile map is the default map scale (commonly referred to as the default zoom level in web mapping). The *default map scale* defines the overall extent that will be shown to the user upon entering the application. This influences the user's impression of their surrounding location as well as how he or she makes use of the application to achieve his or her goals. Therefore, design decisions related to default map scale have to be revised when designing for a mobile environment. Importantly, the default map scale was changed in the updated version of the UW interactive campus map to provide a larger-scale view of the campus upon entering the map, with the center of the map also changing between smaller-screen and larger-screen devices.

In cartographic design, the appropriate default map scale is affected by variation in the map size and extent (related to the screen size of the viewing device) and the amount of generalization in the map, and the user's ability to interactively manipulate this default map scale. The amount of *generalization*—or the degree of abstraction in the cartographic representation—was decreased substantially in the updated UW interactive campus map, with the same amount of generalization provided in both the smaller-scale and larger-scale versions of the newer map. While the interface functionality remained largely consistent in the first and second versions of the map, much of the interface functionality is buried behind a dropdown menu in the new UW interactive campus map when viewed on a smaller-screen device.

Accuracy and response time define user performance with a mobile map. However, several scholars have noted that the mobile experience depends heavily on the user's emotional experience (e.g., Meng et al. 2005; Gartner 2012). Users are expected to have the ability to comprehend their surroundings while also understand the map or visualization in front of them. This can be difficult for users depending on the task and often times, the user's 'cognitive load' is overlooked. Participants need to have mobile maps they can understand while completing a specified task without feeling lost or overwhelmed.

In order to examine the relationship between screen sizes and mobile mapping, and thus improve the user experience of mobile maps, I addressed the following research questions:

1. Should the default map scale of a web map vary with mobile device screen sizes?
2. Should the amount of generalization of a web map vary with mobile device screen sizes?
3. Are there differences in emotional experiences across device screen sizes?

There are a growing number of researchers proposing specific mobile visualization techniques or reporting on specific mobile applications (e.g., Chittaro 2006; Raubal and Winter 2002; Van Tonder and Wesson 2009). However, research is limited on mobile map design broadly and influences of default map scale, amount of generalization, and emotional experience specifically. I addressed the questions mentioned above by examining the mobile versions of the UW interactive campus map on both an iPhone 4S (smaller-screen) and an iPad 2 (larger-screen). The results of this research generated recommendations for designing maps across mobile devices with varying screen sizes.

1.4 Overview of Research

The thesis proceeds with four additional chapters. Chapter 2 is a review of literature relating to mobile maps and provides a broad overview of 'mobile' in Cartography as well as specific sections on scale, generalization, and the limitations of mobile maps. Chapter 3 describes the method design of the research; a controlled wayfinding experiment with thirty-six (n=36) participants was administered to investigate the impact of screen size on the appropriate default map scale, level of detail, and supported interactions in mobile maps. Chapter 4 presents the results of the study and discusses potential explanations for these findings. Concluding remarks are offered in the fifth and final chapter.

Chapter 2. Literature Review

2.1 Mobile Maps: Overview

This research focuses upon mobile maps that are digitally native, with the intention of being viewed on mobile devices like smartphones and tablets. Several definitions have been offered for a digital ‘mobile map’. Winter & Tomko (2004 pg. 1) define a mobile map as “maps on a mobile handheld device” while Reichenbacher (2001 pg. 2) describes them as “a mobile GIS [that] will answer the questions and support the task performance of a mobile user”. Reichenbacher (2004) subsequently enumerated the kinds of geographic information that could be visualized on a mobile map, which include but are not limited to: locations and routes, points and regions of interest, search results, events, and relevance or importance as a visual ranking. Each of these kinds of geographically-referenced information is important when thinking about how to design mobile maps.

The topic of mobile mapping is related to emerging research on *location-based services (LBS)*, or applications that provide a customized experience based on locational information provided by the user (Koeppel 2000). Browser-based LBS applications such as Realtor.com or Zillow.com make use of the computer’s Internet Protocol (IP) registered location. Emergency service LBS applications such as E-911 or American Automobile Association’s (AAA) roadside assistance use location within a telecommunication network (3G or 4G). Finally, mobile LBS applications like Apple Maps, Google Maps for Mobile, and Twitter for Mobile, make use of the GPS capabilities of smartphones and tablets (Koeppel 2000). Mobile maps and LBS therefore share partial overlap, but are not synonymous terms. While mobile maps often utilize LBS, the term *mobile map* describes any map that has been designed for viewing on a mobile device. The UW interactive campus map is both a mobile map and a location-based service, as it configures the map around the user's location using the GPS capabilities of a mobile device.

2.2 Limitations of Mobile Devices

Mobile hardware imposes a variety of constraints on cartographic design. Processing power, pixel resolution, color and brightness settings, and network speed are just a few of the many challenges a cartographer faces when designing for mobile devices (Chittaro 2006). One of the largest, and probably the most obvious, limitation is the screen size of a mobile map on a smartphone or tablet compared to a non-mobile or laptop computer (Nagi 2004; Dillemuth 2005; Van Tonder & Wesson 2009). The drastic screen size reduction from a desktop computer to a smartphone requires the map designer to define style rules that are responsive to mobile and non-mobile uses of the map (Chittaro 2006).

Zipf (2005 pg. 41) argues that the small devices and screens make mobile maps "more personalized" than non-mobile-based maps due to the smaller screen size. How the map should be tailored to each individual user is currently an open question, as there are no standards for mobile map design and limited recommendations about user customization for non-mobile maps (Meng 2003). Rather, designers rely on intuition as well as trial and error to determine what content is relevant for the user and how to customize this content in the mobile map. While the method of the designer taking their "best guess" works sometimes, this often can result in unwanted clutter on the screen (Van Tonder & Wesson 2009 pg. 842).

2.3 Scale

Map scale is a fundamental design decision that impacts the way in which the map abstracts reality. *Map scale* describes the relationship of distances on the map compared to distances on the Earth (Slocum et al. 2009). Arguably, choosing an appropriate map scale is more important on mobile maps than non-mobile maps, given the aforementioned hardware limitations. The user could be shown a *smaller-scale map* by default, or a map that depicts a larger spatial extent, if the goal is to present the complete extent of the campus for exploratory wayfinding. In contrast, the user could be shown a *larger-scale map* by default, or a map with a very small extent, if the goal is to present only the most immediate spatial context to the user for wayfinding to a single, known destination.

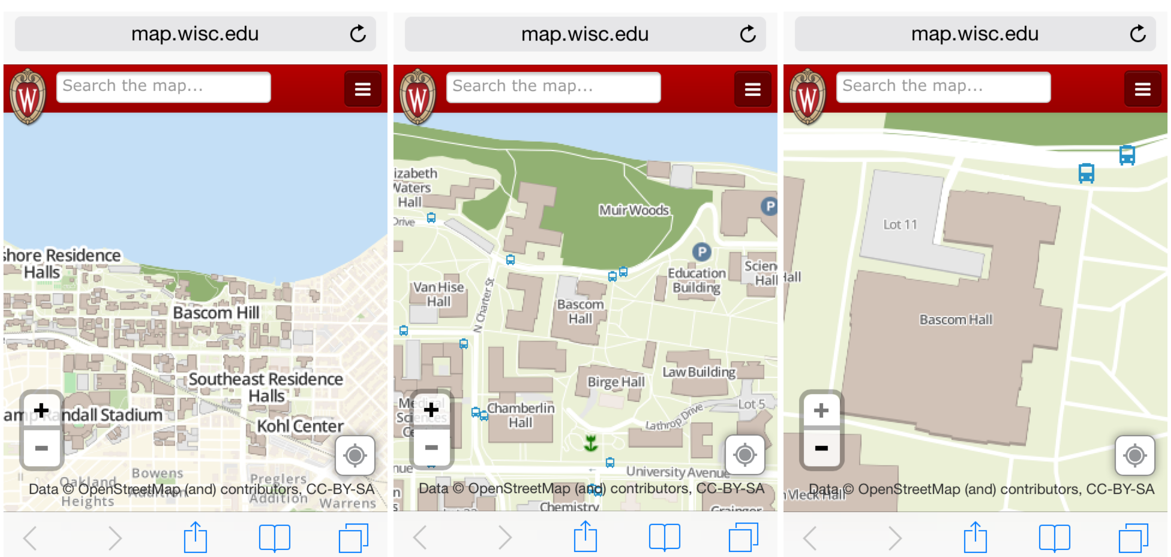

Figure 2.1—The three map scales of the UW interactive campus map used in the experimental study. A: The smaller-scale map (zoom level #2); B: The intermediate-scale map (zoom level #4); C: The larger-scale map (zoom level #6).

The UW interactive campus map contains six scales. The smallest map scale includes only major roads, labels of major neighborhoods and cities, and landmarks such as lakes, cemeteries, and parks, while the largest map scale includes only a subset of proximate campus buildings, all of which have persistent map labels, and proximate roads, walkways, and points of interest. Three of these scales are used in this study, with the zoom level number based on recommendations by Peterson (2014): zoom level number #2 (*smaller-scale*), zoom level #4 (*intermediate-scale*), and zoom level #6 (*larger-scale*). Figure 2.1 provide screenshots of these three scales in the UW interactive campus map.

It may be appropriate to change the default map scale between mobile device screen sizes as well as mobile and non-mobile versions of a web map, given the increased amount of information that can be displayed in the non-mobile version and the relevancy of the user's location in the mobile version (Reichenbacher 2004). As introduced in Chapter 1, a larger default map scale is used for the UW interactive campus map for viewing on a smaller-screen (Figure 1.2) compared to viewing on a larger-screen (Figure 1.3).

2.4 Generalization

The generalization of features should be considered when looking at the scale of mobile maps. *Generalization* is the practice of exaggerating aspects of the landscape that are important to the purpose of the map and that can remain legible at the chosen map scale (Hardy et al. 2000). This also includes removing any irrelevant detail that would clutter the map and potentially confuse the user. General guidelines have suggested that the goal of generalization is to "…reduce visual clutter while preserving clarity and logical consistency" (Brewer & Buttenfield 2007 pg. 4). Topfer's radical law suggests that, as map scale is reduced (i.e., moves to a smaller scale), the *amount of generalization* at which a feature layer is depicted on the map should reduce in a geometric progression (Töpfer & Pillewizer 1966). Therefore, smaller-scale maps that contain many relevant map features within the mapped extent must be highly generalized to avoid visual clutter. The UW interactive campus map provides users with two basemap representations at different amounts of generalization. The first is the ‘Map’ view, which comprises a highly abstracted and cartographically designed view of the campus. The other is the ‘Satellite’ view, which shows the user an aerial image of the surrounding area and has minimal cartographic generalization compared to the ‘Map’ view. Overall, generalization improves clarity, but should be applied only when the task at hand is not inhibited by the decreased amount of generalization in the map.

When it comes to generalization on mobile maps, most users require not only detailed context of the immediate surroundings, but also a generalized overview of the entire area of interest in order to orient themselves (Shneiderman 1996). As Harrie et al. (2002 pg. 111) state, “…the user often requires both larger-scale and smaller-scale cartographic data”. Hardy et al. (2000) advise that the usability of mobile maps can be improved by suppressing irrelevant details, generalizing features of lesser importance, and exaggerating important details for clarity. Switching between the ‘Map’ and ‘Satellite’ basemaps in the UW interactive campus map is one way in which the user is allowed to interactively change the amount of generalization in the map without changing the map scale.

2.5 Emotion and Mobile Maps

While working with mobile maps, it is important to account for the user’s emotional experience. Collecting information about the user’s emotion when using a mobile map informs developers about anything that needs to be changed in order for users to feel ‘happy’ and ‘satisfied’ with the mobile map. Emotion also has significance while a user is trying to complete a wayfinding task presented to them. Landmarks often carry emotional meaning to a user, which can either be positive or negative. This emotion can assist in the user creating their cognitive map or can hinder their ability to navigate an area (Gartner, 2012). According to Meng and colleagues (2005), mobile maps should be adaptive to the user, reducing the user’s cognitive load and making a better connection between the map and the real world.

Emotion is a difficult variable to measure. While frameworks have been developed to capture user emotions, there is limited empirical research investigating how emotion affects a user’s ability to complete wayfinding tasks (Griffin 2014). Some ways to measure and sense emotion include capturing behavioral observations, asking the participant to ‘talk aloud’ while completing a task, administering a post-test questionnaire, and measuring physiological responses created by the body with a medical device, such as an electrocardiogram or electromyogram (Gartner 2012).

Chapter 3. Methods

3.1 Overview of Experiment

A controlled experiment was conducted to measure the variation in performance and emotional experience with the UW interactive campus map when viewed on different mobile screen sizes, with different default map scales, and with different levels of detail. The experiment required participants to make use of the map on a mobile device while walking on campus and to complete a series of building identification and wayfinding tasks. The accuracy of responses, response time, and emotional verbalizations were collected as each participant completed the tasks. Participants also were administered an opening online survey to ensure they were eligible for participation and a closing exit survey to collect feedback on user preferences and overall satisfaction with the map.

3.2 Participants

A total of thirty-six (n=36) UW students, faculty, and residents of Madison, Wisconsin completed the experiment. Participants were recruited through in-class presentations, listservs for large enrollment courses, and flyers placed in prominent locations around campus and in campus buildings. Participants were required to be in their first two semesters on campus to avoid recruiting individuals with extensive knowledge of the UW campus. An online survey was administered first to ensure that participants met this eligibility. A total of 64 participants completed the online survey, 51 of whom were deemed eligible to participate and 36 of whom ultimately completed the experiment. One participant did attempt to complete the study, however voluntarily removed themselves from the study due to high stress levels and low temperatures. This participant's data was not included in the analysis. Participants were compensated $10 for their participation.

Participants were given an introductory survey to determine their eligibility to participate in this study. The survey consisted of seven questions asking participants about any prior coursework in cartography, their experience with mobile devices, and their prior knowledge of campus; participants were asked to rate themselves according to these criteria on a Likert scale from one to seven. If a participant was eligible for participation in the study, they were contacted via e-mail to proceed in the study. A full list of questions asked in the introductory survey can be found in Appendix A and a breakdown of responses can be found in Appendix B.

Participants who self-rated their prior knowledge of campus as '5' or less on a 7-point Likert scale were allowed to participant in the study. Within the 36 participants, 42% of participants rated themselves as '5', 42% as '4', 13% as '3' and 3% as '2', with no participants rating at '1: Novice (I do not know where anything is on campus)'. Regarding education, 33% of participants were first-year freshman, 28% were undergraduate transfer and foreign exchange students, 36% were graduate students, and 3% were not associated with the university. Regarding prior knowledge of mobile devices, 3% of participants rated themselves at '1: Novice (I do not understand how to use those devices)', 0% at '2', and 3% at '3'. '4: Intermediate (I am aware of how to operate one, however I do not know all the available features)' and '5' had the highest frequency at 27%, while 17% rated themselves at '6', and the remaining 23% at '7: Expert (I understand everything about the device and how it works)'.

3.3 Materials

Participants were assigned to one of two experimental groups using a between group design (Montello and Sutton 2006). One half (n=18) of participants completed the experiment using an iPhone 4S (i.e., the *smaller-screen* group) and one half (n=18) of the participants completed the experiment using an iPad 2 (i.e., the *larger-screen* group). The iPhone 4S had a pixel resolution of 960 by 640 pixels at 326 pixels per inch (ppi) with a screen size of 3.5 inches diagonally. The iPad 2 had 1024 by 768 pixel resolution at 132 ppi with a screen size of 9.7 inches diagonally. Thus, the iPhone and iPad had a comparable *pixel resolution* but a different *screen-size*. Both the iPhone 4S and iPad 2 were running iOS 7.0.6 and contained an Apple A5 processor chip. The UW interactive campus map was viewed in the Safari 7 web browser on both devices. On both devices, the brightness value was set by default to 50% and the 'Auto-Brightness' feature was selected to allow the screen brightness to adjust to changes in lighting conditions. A limited list of specifications applicable for this study can be found for each device in Table 3.1. For a full list, please visit http://www.apple.com/iphone-4s/specs/ for information on the iPhone 4S and http://support.apple.com/kb/sp622 for information on the iPad 2.

Specification	iPhone 4S	iPad 2
Weight	4.9 oz.	1.33 lbs.
Dimensions	Height: 4.5 in Width: 2.31 in Depth: .37 in	Height: 9.5 in Width:7.31 in Depth: .34 in
Processor	1GHz dual-core A5 processor	1GHz dual-core A5 processor
Wi-Fi Capabilities	Wi-Fi (802.11 b/g/n) (802.11 n 2.4 GHz only)	Wi-Fi (802.11a/b/g/n)
Display size	3.5 in	9.7 in
Resolution	960x640 at 326 ppi	1024x768 at 132 ppi
Operating System	iOS 7.x	iOS 7.x

Table 3.1 – Comparison between iPhone 4S and iPad 2

The updated UW interactive campus map was used as a case study mobile mapping application for the experiment (http://map.wisc.edu); a description of the map can be found in Section 1.2. Within the pair of mobile device groups, the default map display was balanced by the map scale and amount of generalization across each individual experimental task. Three different conditions were used for the default map scale: scale #2 (i.e., the *smaller-scale* condition), scale #4 (i.e., the *intermediate-scale* condition), and scale #6 (i.e., the *larger-scale* condition). Scale #2 was used instead of Scale #1 to maintain labels of major features such as Bascom Hall and Lakeshore Residence Halls. Two different conditions were used for the default amount of generalization: the ‘Map’ (*map*) basemap option and the ‘Satellite’ (*satellite*) basemap option. Appendix C provides twelve screenshots illustrating the twelve possible map configurations by device (2), scale (3), and amount of generalization (2).

Assignment to the scale and amount of generalization conditions was balanced within the device groups such that all participants viewed all six combinations of scale (3) and amount of generalization (2) for one pairing of identification and wayfinding tasks. Table 3.2

shows the distribution of tasks across participants. The first half of the code relates to the map's zoom level set prior to the start of the experimental task, while the second half of the code relates to the map's amount of generalization set prior to the start of the experimental task. Before beginning a new pair of experimental tasks (identification + wayfinding, as explained in Section 3.4), the investigator reconfigured the map to the appropriate scale + amount of generalization condition. In total, there were six different combinations of scale, amount of generalization, and task pairings, resulting in six (n=6) participants completing the same ordering of map configurations, three (n=3) for each of the two devices.

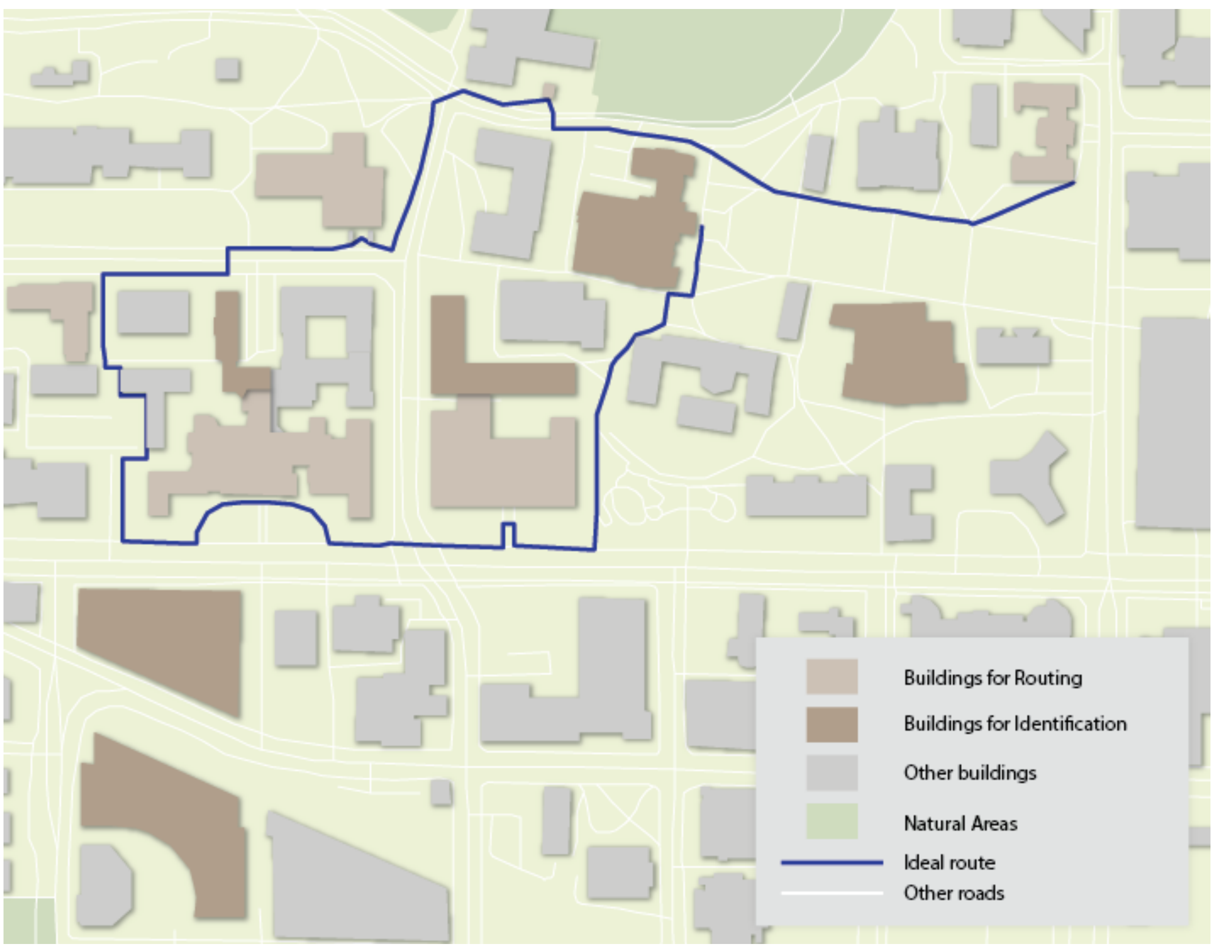

Figure 3.1—Optimal route of locations used for testing

	Task Pairing #					
Participant #	**1**	**2**	**3**	**4**	**5**	**6**
1	6, M	6, S	4, M	4, S	2, M	2, S
2	2, S	6, M	6, S	4, M	4, S	2, M
3	2, M	2, S	6, M	6, S	4, M	4, S
4	4, S	2, M	2, S	6, M	6, S	4, M
5	4, M	4, S	2, M	2, S	6, M	6, S
6	6, S	4, M	4, S	2, M	2, S	6, M
7	6, M	6, S	4, M	4, S	2, M	2, S
8	2, S	6, M	6, S	4, M	4, S	2, M
9	2, M	2, S	6, M	6, S	4, M	4, S
10	4, S	2, M	2, S	6, M	6, S	4, M
11	4, M	4, S	2, M	2, S	6, M	6, S
12	6, S	4, M	4, S	2, M	2, S	6, M
13	6, M	6, S	4, M	4, S	2, M	2, S
14	2, S	6, M	6, S	4, M	4, S	2, M
15	2, M	2, S	6, M	6, S	4, M	4, S
16	4, S	2, M	2, S	6, M	6, S	4, M
17	4, M	4, S	2, M	2, S	6, M	6, S
18	6, S	4, M	4, S	2, M	2, S	6, M
19	6, M	6, S	4, M	4, S	2, M	2, S
20	2, S	6, M	6, S	4, M	4, S	2, M
21	2, M	2, S	6, M	6, S	4, M	4, S
22	4, S	2, M	2, S	6, M	6, S	4, M
23	4, M	4, S	2, M	2, S	6, M	6, S
24	6, S	4, M	4, S	2, M	2, S	6, M
25	6, M	6, S	4, M	4, S	2, M	2, S
26	2, S	6, M	6, S	4, M	4, S	2, M
27	2, M	2, S	6, M	6, S	4, M	4, S
28	4, S	2, M	2, S	6, M	6, S	4, M
29	4, M	4, S	2, M	2, S	6, M	6, S
30	6, S	4, M	4, S	2, M	2, S	6, M
31	6, M	6, S	4, M	4, S	2, M	2, S
32	2, S	6, M	6, S	4, M	4, S	2, M
33	2, M	2, S	6, M	6, S	4, M	4, S
34	4, S	2, M	2, S	6, M	6, S	4, M
35	4, M	4, S	2, M	2, S	6, M	6, S
36	6, S	4, M	4, S	2, M	2, S	6, M

Table 3.2—Balancing of participants by scale and amount of generalization: 2=zoom level #2 default; 4=zoom level #4 default; 6=zoom level #6 default; M=Map default; S=Satellite default

Given the desired within groups balancing by scale and amount of generalization, six pairs of building sites, or *landmarks*, were selected on the UW campus. The landmarks used for this study were balanced according to a measure of *difficulty*, or the perceived salience of the landmark in the landscape based on the building color, shape, and size, and the overall visibility of the landmark from the prior landmark (Raubal and Winter 2002). Three categories of difficulty were established qualitatively using these salience characteristics: *easy*, *medium*, and *hard*. In total, four landmarks were identified for each of the three difficulty categories, two used for identification tasks and two used for wayfinding tasks within the difficulty category. Figure 3.1 illustrates the optimal route through the six pairs of landmarks and Table 3.2 lists the campus buildings used as landmarks and their assigned difficulty.

Landmark	Type	Difficulty	Question Set
Chamberlin Hall	WAY	Hard	1
Wisconsin Discovery Institute	ID	Hard	1
Medical Science Center	WAY	Medium	2
Union South	ID	Medium	2
Nutritional Science	WAY	Hard	3
Bradley Memorial Building	ID	Hard	3
Van Hise	WAY	Easy	4
Sterling Hall	ID	Easy	4
Carillion Tower	WAY	Easy	5
Bascom Hall	ID	Easy	5
Science Hall	WAY	Medium	6
Law Building	ID	Medium	6

Table 3.2—Locations and difficulties of sites selected for participants

3.4 Experimental Protocol

The experiment began with a demonstration of the UW interactive campus map on one of the two mobile devices, with the map shown at a scale that was not used in testing. During this demonstration, participants were instructed that they were allowed to use only a subset of the available interface functionality. Functionality that participants could use during the experiment included panning by tapping/dragging the map and retrieval of details about a building by tapping directly on the building of interest. Participants were not allowed to use any other functionality during testing, including the supported zoom interactions (to control for map scale) and the advanced menu options (to control for amount of generalization).

Following the demonstration, participants were given an overview of the types of tasks they were required to complete. As stated in in Section 3.3, the experiment included two types of tasks: identification and wayfinding. Within each pairing, the participant first completed a *wayfinding* task in which the participant was required to plan and execute a route from his or her current location to one of the landmarks listed in Table 3.2. The participant was instructed to walk to the front entrance of the given landmark to complete the wayfinding task.

Once participants believed they had reached the listed location, they were told whether they were correct or incorrect. If incorrect, the participant would continue to route to the appropriate location. If correct, they were then given an *identification* task in which they were required to locate one of the landmarks listed in Table 3.2 on the UW interactive campus map, point to it in the landscape, and verbally proclaim which building they believe the landmark to be. After a wayfinding/identification pairing, the investigator reconfigured the map to the next map scale/amount of generalization pairing, as indicated in Table 3.1. This was completed for all six pairs of landmarks.

Once testing was completed, participants were taken inside the ending location and given an exit survey. The exit survey consisted of eight questions, four multiple choice questions and four open-ended questions. The questions were designed to address the usability of the UW interactive campus map and the participants' general satisfaction with the application.

3.5 Metrics and Analysis

Three metrics were calculated for each experimental task: (1) accuracy for wayfinding and identification tasks, (2) response time, and (3) emotion. Each of these metrics is defined below.

Accuracy describes whether the participant navigated to or pointed at the correct building during a wayfinding or identification task. Participants were asked to guess until they were able to navigate or identify the building in question. Participants were allowed as many guesses as they wanted, however only the first guess was used to determine whether the map was useful in the participant finding the appropriate location. Accuracy was coded in a binary measure with '1' meaning the participant was successful in locating the building on their first try and a '0' meaning the participant was not successful on their first try. When aggregated across participants, accuracy is reported as the percentage of correct identification tasks out of the total number of identification tasks, with 100% being optimal.

Response Time was captured during the testing and verified through audio recordings of each participant. During testing, the investigator read a question in order to indicate what the next task would be for the participant. Participants were exhorted either “Using that same map, I’d like you to identify the ______ building” to indicate an identification task or “Using this map, I’d like you to route us from here to the _____ building” to indicate a wayfinding task. Once the question was read, a stopwatch was started by the investigator. Participants had to correctly identify or route to the appropriate location in order for the stop watch to stop and the next question to be read.

Emotions of participants were measured through audio recordings taken during the task completion process. Participants were directed at the start of each session to think aloud while completing the tasks, or to be vocal in their thoughts and emotions throughout the entire testing process. If participants were not being vocal, the investigator would prompt participants to say what they were thinking by asking questions like “What do you think of this map?” or “How do you feel right now?” After the session, the audio recordings were transcribed and verbalizations were coded based on if the emotional cadence was positive or negative. *Positive* emotion codes included emotions and feelings such as happy, confident, and excited. *Negative* emotion codes included emotions and feelings such as defeated, frustrated, and unsure. For example, if a participant said “Ugh!”, “This map isn’t working like I wanted it to work!” or gave an exacerbated sigh, these were considered to be phrases that would fall under the *negative* category.

The three metrics first were aggregated according to the landmark saliency (*easy* vs. *medium* vs. *hard*) for basic reporting of the experimental results. The three metrics then were aggregated in three different ways for statistical analysis, with each aggregation relating to one of the three research questions presented in Chapter 1: (1) mobile device screen size (*larger-screen* versus *smaller-screen*), (2) default map scale (*larger-scale* vs. *intermediate-scale* vs. *smaller-scale*), and (3) amount of generalization (*map* vs. *satellite*). Chapter 4 reports on experimental findings across landmark saliency, device, default scale, and amount of generalization, as well as usability and satisfaction responses in the exit survey.

Chapter 4. Results and Discussion

4.1 Overall Performance

An average accuracy of 90.47% (SD: 29.05%) was calculated across all identification tasks, with an average response time of 0:46.00 minutes (SD: 1:13.34), suggesting that participants were largely able to make use of the UW interactive campus map to identify landmarks on campus (Table 4.1). Identification tasks using *larger-scale/map*, *larger-scale/satellite*, and *intermediate-scale/satellite* resulted in the highest accuracy rates at 94.44% (SD: 23.23%), while identification tasks using *larger-scale/map* resulted in the fastest response time, with an average response time of 0:29.02 minutes (SD: 0:40.33 minutes). Identification tasks using *smaller-scale/map* resulted in the lowest accuracy rate at 83.33% (SD: 37.80%) as well as the slowest response time at 1:12.52 minutes (SD: 1:51.05). These preliminary findings suggested that participants were more effective and efficient in performing the identification tasks when viewing mobile maps that included only their proximate surroundings (*larger-scale*) and portrayed a large amount of information (*satellite*).

Average accuracy across all wayfinding tasks was 95.37% (SD: 21.06%), with an average response time of 5:36.88 minutes (SD: 4:09.16 minutes). Thus, while participants required an expectedly longer amount of time to complete the wayfinding tasks, as compared to the identification tasks, they were slightly more successful in completing the wayfinding tasks. Such high accuracy on wayfinding tasks again points to the general usability of the UW interactive campus map. Wayfinding tasks using the *larger-scale/map* mobile map resulted in a perfect accuracy rate of 100% (SD: 0.00%), and the highest average response time of 4:28.71 minutes (SD: 2:07.23). Wayfinding tasks using the *smaller-scale/satellite* mobile map resulted in the poorest accuracy at 88.89% (SD: 31.87%), while those using the *smaller-scale/map* mobile map resulted in the slowest response time, with an average time of 6:36.89 minutes (SD: 4:44.70 minutes).

Condition	**Accuracy (Identification)**		**Response Time (Identification)**		**Accuracy (Wayfinding)**		**Response Time (Wayfinding)**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Larger-scale/ Map	94.44%	23.23%	0:29.02	0:40.33	100.00%	0.00%	4:28.71	2:07.23
Larger-scale/ Satellite	94.44%	23.23%	0:36.31	0:47.70	94.44%	23.23%	5:38.27	3:23.77
Inter-scale/ Map	86.11%	35.07%	0:40.31	0:55.57	97.22%	16.67%	4:48.08	2:24.82
Inter-scale/ Satellite	94.44%	23.23%	0:38.31	0:47.18	94.22%	23.23%	5:59.27	4:58.51
Smaller-scale/ Map	83.33%	37.80%	1:12.52	1:51.05	97.22%	16.67%	6:36.89	4:44.70
Smaller-scale/ Satellite	91.67%	28.03%	0:59.54	1:40.46	88.89%	31.87%	6:10.06	4:46.30
Total	90.74%	29.05%	0:46.00	1:13.34	95.37%	21.06%	5:36.88	4:09.16

Table 4.1—Overall performance by default map scale and amount of generalization pairings.

4.2 Landmark Saliency

As described above, the twelve landmarks constituting the experimental route were organized into three categories according to their landmark saliency: *easy*, *medium*, and *hard* (Table 4.2). Performance differences by landmark saliency first were investigated for the identification tasks. Participant responses to the *easy* identification tasks resulted in an average accuracy of 95.83% (SD: 20.10%) and an average response time of 0:20.30 minutes (SD: 0:26.70 minutes). Participant responses to the *medium* identification tasks resulted in a slightly lower average accuracy of 93.06% (SD: 25.60%) and a longer average response time of 0:32.14 minutes (SD: 0:48.64 minutes). Not surprisingly, the *hard* identification tasks yielded the poorest performance, with an average accuracy of 83.33% (SD: 29.10%) and an average response time of 1:25.57 minutes (SD: 1:43.71 minutes).

A set of one-way between subjects analysis of variance (ANOVA) tests were administered to compare the average accuracy and average response time for identification tasks across the three categories of landmark saliency. The test on average accuracy proved to be significant at alpha=0.05 ($F(2,213)=3.769$, $p=0.025$), indicating that there was a statistically significant difference in average accuracy across the different levels of landmark saliency. A Tukey post-hoc test revealed that participants were significantly better at identifying *easy* landmarks compared to *hard* ones ($p=0.026$), with the difference between accuracy for the two being 12.50%. There was no statistical significance in identification of *easy* versus *medium* ($p=0.830$) landmarks or *medium* versus *hard* ($p=0.107$) landmarks.

The ANOVA test on average response time for identification tasks also proved to be significant at alpha=0.05 ($F(2,213)=18.881$, $p=0.000$), indicating that there was a statistically significant difference in the average response time across different levels of landmark saliency. A Tukey post-hoc test discovered that there was a significant difference in response time when comparing *easy* to *hard* ($p=0.000$) and *medium* to *hard* ($p=0.000$) landmarks, however there was no statistical difference between *easy* and *medium* landmarks regarding response time ($p=0.549$). The difference in response time between *easy* and *hard* landmarks was 1:05.27 minutes and the difference in response time between *medium* and *hard* landmarks was 0:53.43 minutes.

Condition	Accuracy (Identification)		Response Time (Identification)		Accuracy (Wayfinding)		Response Time (Wayfinding)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Easy	95.83%	20.10%	0:20.30	0:26.70	100.00%	0.00%	3:18.04	1:41.67
Medium	93.06%	25.60%	0:32.14	0:48.64	95.83%	20.10%	5:08.92	3:12.30
Hard	83.33%	29.10%	1:25.57	1:43.71	90.28%	29.8%	8:23.68	5:03.51

Table 4.2—Participant performance by landmark saliency

Accuracy and response time also were analyzed to investigate performance differences by landmark saliency for the wayfinding tasks. Participant performance on the *easy* wayfinding tasks resulted in an average accuracy of 100.00% (SD: 0.00%) with an average response time of 3:18.04 minutes (SD: 1:41.67 minutes). Performance on *medium* wayfinding tasks resulted in a slightly lower average accuracy of 95.83% (SD: 20.10%) and an average response time of 5:08.92 minutes (SD: 3:12.30 minutes). Finally, participant performance on *hard* wayfinding tasks resulted in the poorest accuracy of 90.28% (SD: 29.80%) and the longest average response time of 8:23.68 minutes (SD: 5:03.51).

A pair of one-way between subjects ANOVA tests was administered to compare the average accuracy and average response time for wayfinding tasks across the three categories of landmark saliency. The test on average accuracy proved to be significant at alpha=0.05 ($F(2,213)=3.968$, $p=0.020$). A Tukey post-hoc test revealed that participants were significantly more effective at completing the wayfinding tasks when navigating to *easy* landmarks compared to *hard* ($p=0.015$) ones, with the average difference in accuracy between the two being 9.72%. As with identification tasks, there was no statistical significance between *easy* and *medium* ($p=0.453$) landmarks or *medium* and *hard* ($p=0.246$) landmarks.

The ANOVA test comparing average response time of wayfinding tasks across landmark saliency also was significant at alpha=0.05 ($F(2,213)=37.084$, $p=0.000$), indicating that there was a significant difference in the response time across the three levels of landmark saliency. A Tukey post-hoc test determined that there was a significant difference in response time when comparing *easy* and *medium* landmarks ($p=0.006$), *easy* and *hard* landmarks ($p=0.000$), and *medium* and *hard* landmarks ($p=0.000$). *Easy* and *medium* tasks had a difference in response time of 1:50.88 minutes, *medium* and *hard* tasks had a difference of 3:14.76, and *easy* and *hard* tasks had a difference of 5:05.64 minutes.

When examined together, the results indicate that participants were most effective and efficient when searching for or navigating to an *easy* landmark, but made more errors and took a longer amount of time in both identification and wayfinding tasks as the landmark saliency reduced (i.e., as the task difficulty moved through *medium* to *hard*). Though this is not surprising—as a difference in performance by saliency should be expected—the previous analysis confirmed that the landmarks used in this study for the experimental route were properly balanced by landmark saliency. This eliminated any bias this variable could have caused in subsequent analysis. Additionally, the ANOVA tests confirmed the Raubal & Winter (2002) listing of landmark saliency characteristics, such as building shape, color, and visibility, as a useful framework for describing and measuring the saliency of a landmark in the landscape.

4.3 Mobile Device Screen Size

As described above, participants were assigned to one of two groups using a between groups design: the *smaller-screen* group, which used an iPhone for all experimental tasks, and the *larger-screen* group, which used an iPad for all experimental tasks. First looking at the identification tasks, participant performance when using a *smaller-screen* resulted in an average accuracy of 88.89% (SD: 31.57%) and an average response time of 0:50.61 minutes (SD: 1:19.36 minutes). In contrast, participant performance when using a *larger-screen* resulted in an improved average accuracy of 92.59% (SD: 26.31%) and a decreased average response time of 0:41.40 minutes (SD: 1:06.84 minutes).

Independent-samples t-tests were conducted to compare accuracy of identification tasks and response time between participant performances on *smaller-screen* versus *larger-screen* devices. There was no statistical difference in accuracy on identification tasks of users across device at alpha=0.05 ($t(214)=-0.937$, $p=0.350$). There also was no statistical significance for response time during identification tasks across device at alpha=0.05 ($t(214)=-0.923$, $p=0.357$).

For wayfinding tasks, participant performance using the *smaller-screen* device resulted in an average accuracy of 95.37% (SD: of 21.10%) and an average response time of 5:10.89 minutes (SD: 3:38.29 minutes). Participant performance using the *larger-screen* device resulted in the same average accuracy of 95.37% (SD: of 21.10%) but an increased average response time of 6:02.87 minutes (SD: 4:35.18 minutes).

Two separate independent-sample t-tests were conducted to compare wayfinding accuracy and response time between device screen sizes. There was not a statistical difference at alpha=0.05 regarding the accuracy of wayfinding tasks across screen sizes ($t(214)=.000$, $p=1.000$). There also was no statistical significance for response time during wayfinding tasks across device at alpha=0.05 ($t(214)=-1.538$, $p=0.126$). Therefore, the difference in screen size did not result in a different in performance in identification or wayfinding tasks.

Condition	**Accuracy (Identification)**		**Response Time (Identification)**		**Accuracy (Wayfinding)**		**Response Time (Wayfinding)**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Smaller-screen (iPhone)	88.89%	31.60%	0:50.61	1:19.36	95.37%	21.10%	5:10.89	3:38.29
Larger-screen (iPad)	92.59%	26.30%	0:41.40	1:06.84	95.37%	21.10%	6:02.87	4:35.18

Table 4.3—Participant performance by screen size

4.4 Default Map Scale

As described above, the twelve landmarks constituting the experimental route were organized into three categories according to their default map scale: Scale #2 (the *smaller-scale* condition), Scale #4 (the *intermediate-scale* condition), and Scale #6 (the *larger-scale* condition) (Table 4.4). Performance differences by default map scale first were investigated for the identification tasks. Participant performance on identification tasks when using *smaller-scale* maps resulted in an average accuracy of 87.50% (SD: 33.30%) and an average response time of 1:06.03 minutes (SD: 1:45.34 minutes). Participant performance using *intermediate-scale* maps resulted in a slightly higher average accuracy of 90.28% (SD:

29.83%) and a shorter average response time of 0:39.31 minutes (SD: 0:51.19 minutes). Interestingly, participant performance on identification tasks was the best when using *larger-scale* maps, with an average accuracy of 94.44% (SD: 23.06%) and an average response time of 0:32.66 minutes (SD: 0:44.01 minutes).

A set of one-way between subjects analysis of variance (ANOVA) tests were administered to compare the average accuracy and average response time for identification tasks across the three default map scales. The test on average accuracy was not statistically significance at alpha=0.05 ($F(2,213)=1.403$, $p=0.354$), however the ANOVA test on average response time proved to be significant at alpha=0.05 ($F(2,213)=4.304$, $p=0.015$), indicating that there was a statistically significant difference in the average response time across different default map scales. A Tukey post-hoc test discovered that there was a significant difference in response time when comparing the *smaller-scale* condition to the *larger-scale* condition ($p=0.017$), with a difference of 1:19.98 minutes. There was no statistical difference between *intermediate-scale* and *larger-scale* ($p=0.846$) or between *smaller-scale* and *intermediate-scale* ($p=0.070$).

Condition	**Accuracy (Identification)**		**Response Time (Identification)**		**Accuracy (Wayfinding)**		**Response Time (Wayfinding)**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Larger-scale	94.44%	23.06%	0:32.66	0:44.01	97.22%	16.55%	5:03.49	2:52.26
Intermediate-scale	90.28%	29.83%	0:39.31	0:51.19	95.83%	20.12%	5:23.67	3:55.69
Smaller-scale	87.50%	33.30%	1:06.03	1:45.34	93.06%	25.60%	6:23.47	5:15.05

Table 4.4—Participant performance by default map scale

Average accuracy and response time also were analyzed to investigate performance differences across default map scales for the wayfinding tasks. Participant performance on wayfinding tasks using *smaller-scale* maps resulted in an average accuracy of 93.06% (SD: 25.60%) and an average response time of 6:23.47 minutes (SD: 5:15.05 minutes). Performance on wayfinding tasks using *intermediate-scale* maps resulted in a slightly higher average accuracy of 95.83% (SD: 20.12%) and a shorter average response time of 5:23.67 minutes (SD: 3:55.69 minutes). Finally, participant performance on wayfinding tasks using *larger-scale* maps resulted in the highest average accuracy of 97.22% (SD: 16.55%) and the shortest average response time of 5:03.49 minutes (SD: 2:52.26).

A pair of one-way between subjects ANOVA tests was administered to compare the average accuracy and average response time for wayfinding tasks across default map scales. The test on average accuracy was not statistically significance at alpha=0.05 ($F(2,213)= 0.729$, $p=0.484$). The test on average response time also was not statistically significance at alpha=0.05 ($F(2,213)=2.026$, $p=0.134$).

4.5 Amount of Generalization

Finally, the twelve landmarks constituting the experimental route were organized into categories according to their amount of generalization: *map* and *satellite*. First analyzing the identification tasks, participant performance with *map* display resulted in an average accuracy of 87.96% (SD: 32.69%) and an average response time of 0:47.28 minutes (SD: 1:16.93 minutes). In contrast, participant performance on wayfinding tasks with *satellite* display resulted in an improved average accuracy of 93.52% (SD: 24.74%) and a decreased average response time of 0:44.72 minutes (SD: 1:09.89 minutes).

Independent-samples t-tests were conducted to compare the average accuracy and response time of identification tasks using the *map* versus *satellite* mobile maps. The t-test on average accuracy on identification tasks was not statistically significant at alpha=0.05 ($t(214)=-1.408$, $p=0.160$). There also was not a significant difference in response time in identification tasks across levels of detail at alpha=0.05 ($t(214)=0.256$, $p=0.798$).

Condition	Accuracy (Identification)		Response Time (Identification)		Accuracy (Wayfinding)		Response Time (Wayfinding)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Map ('Map')	87.96%	32.69%	0:47.28	1:16.93	98.15%	13.15%	5:17.89	3:24.65
Satellite ('Satellite')	93.52%	24.74%	0:44.72	1:09.89	92.59%	26.31%	5:55.86	4:46.59

Table 4.5—Participant performance by amount of generalization

During wayfinding tasks, participant performance using *map* mobile maps resulted in an average accuracy of 98.15% (SD: 13.15%) and an average response time of 5:17.89 minutes (SD: 3:24.65 minutes). In contrast, participant performance using *satellite* mobile maps resulted in a decreased average accuracy of 92.59% (SD: 26.31%) and a longer average response time of 5:55.86 minutes (SD: 4:46.59 minutes).

Two separate independent-sample t-tests were conducted to compare wayfinding accuracy and response time between levels of detail. There was not a statistical difference at alpha=0.05 regarding the accuracy of wayfinding tasks across screen sizes ($t(214)=1.951$, $p=0.052$) or for response time during wayfinding tasks across device at alpha=0.05 ($t(214)=-1.121$, $p=0.264$).

4.6 Emotion

As stated in the methods section, participants were asked to talk aloud while completing the identification and wayfinding tasks, with their verbalizations audio recorded and transcribed for subsequent analysis. These transcripts then were coded by emotions, with the overall cadence in the participant's tone recorded as a *positive* emotion or *negative* emotion. Across all 36 participants, a total of 232 *positive* emotions were recorded and a total of 400 *negative* emotions were recorded (Table 4.6). Therefore, participants felt 6.44 *positive* emotions during the experimental route (SD: 13.93) and 12.22 *negative* emotions during the experimental route (SD: 48.75), with *negative* statements nearly doubling *positive* statements on average.

Condition	Positive Total	Positive Average	Negative Total	Negative Average
Smaller-screen	102	5.67	170	9.44
Larger-screen	130	7.22	270	15.00
Overall	232	6.44	400	12.22

Table 4.6 - Number of emotions felt by participants as determined by screen size

An independent-sample t-test was conducted to compare the total number of positive and negative emotions across all 36 participants. There was a statistical significance at alpha=0.05 ($t(670)=-34.767$, $p=0.000$) regarding the number of positive emotions versus the number of negative emotions. This indicates that the participants' overall emotional experience was significantly more negative than positive, as articulated through their verbalizations during the experiment. Thus, while high accuracy rates on identification and wayfinding tasks suggested that the participants generally could make use of the UW interactive campus map, their overall negative emotional experience suggests that the map could be improved to support a more satisfying experience. However it is important to note that the relatively negative experience may be an artifact of the experimental design, in particular the decision to constrain user interaction with the map to control for the default map scale and level of generalization.

Emotional responses then were analyzed according to the participant's assigned screen size group. For *smaller-screen* devices, the average number of positive emotions was 5.67 per participant and the average number of negative emotions was 9.44 per participant. For *larger-screen* devices, the average number of positive emotions was 7.22 per participant and the average number of negative emotions was 15.00 per participant. The wide variation in number of emotions per participant is most likely explained by how vocal participants were during the experimental route. The distance traveled during the experimental route also may be related to the variation in emotion. The longer a participant traveled, the more opportunities they had to be vocal with their emotions.

A 2x2 Pearson's chi-square test was conducted to compare the ratio of positive versus negative emotions between the *smaller-screen and larger-screen* conditions. The test indicated there was no significance between the number of *positive* versus *negative* emotions between *smaller-screen* and *larger-screen* conditions at alpha=0.05 ($\chi^2(1, N=676)=1.791$, $p=0.181$). While participants felt more negative emotions overall, there was no statistical difference in the number of emotions felt while using different devices. This shows that overall, participants had a negative experience no matter which device they used. Again, this negative feeling towards the mobile map could have been due to the artificial limitations created for this study.

4.7 Usability and Preference

Additional details about the perceived usability and satisfaction with the UW interactive campus map were collected from participants through an exit survey proctored at the end of the experimental route (Figure 4.1). 67% of participants (n=24) indicated that it took them a while to understand how to use the UW interactive campus map. Thus, improving the initial learnability of the map may be one way in improving the users' emotional experience. Further, 50% of participants (n=18) indicated it took them awhile to get used to the UW interactive campus map on a mobile device. Only 39% of participants (n=14) thought that they would use the UW interactive campus map on a mobile device, instead accessing it solely on a non-mobile desktop or laptop machine. Thus, learning materials designed to educate about both map functionality specifically and mobile device usage generally may improve the user's satisfaction with the map.

Regarding map design, 97% of participants (n=35) indicated that they preferred the 'Map' option to the 'Satellite' option. This is an interesting observation considering that participant performance on identification tasks actually was improved with the *satellite* basemap. Participants noted several map design elements that were particularly useful when completing the experimental tasks, include the map labels (n=17), the information window for retrieving details (n=8), and the blue dot indicating the user's location (n=5). Features that the participants disliked included 'Satellite' view (n=16), connectivity issues while traveling around campus (n=7), and the fact that no labels were present in the 'Satellite' view (n=4). Some of the most requested features included the ability for the map to provide a routing feature (n=18), an orientation button that would create an egocentric map with 'up' pointing in the direction that the user is traveling (n=18), and a ‘Hybrid’ view with linework and labels overlaid on top the ‘Satellite’ basemap (n=8). Histograms of all user preferences can be found in Appendix D.

Chapter 5. Conclusion

5.1 Summary

Despite their omnipresence in today's society, mobile map design is poorly understood. Very few scholars have put solid research into what is now one of the most popular ways for mobile phone users to understand where they are spatially. Across the 36 participants completing the experiment, participants performed better when the maps were at a *larger-scale* setting. These yielded the best response times and most accurate results. For the amount of generalization, participants performed better overall while using the *map* display for wayfinding tasks and the *satellite* map for identification tasks.

When looking at landmark saliency, each question was split up into three levels of difficulty: *easy*, *medium*, and *hard*. There was a statistically significant difference between *easy* to *hard* identification task accuracy and a statistically significant difference between *easy* to *hard* and *medium* to *hard* response times. Across wayfinding tasks, there was a statistically significant difference between *easy* to *hard* accuracy and between *easy* to *medium*, *easy* to *hard*, *medium* to *hard*. While these results were expected, they demonstrated that the landmark saliency itself did not cause differences in performance as well as confirmed landmark saliency as an important consideration for mobile map design.

Participants were divided up into two groups and used either a *smaller-screen* device (i.e. an iPhone) or a *larger-screen* device (i.e. an iPad) to complete the experimental route. There was no statistical significance across wayfinding or identification task accuracy or response times across different screen sizes.

The experimental protocol was balanced according to the default map scale, an included three different scales: *smaller-scale* (Scale #2), *intermediate-scale* (Scale #4), and *larger-scale* (Scale #6). Across the accuracy of identification tasks, there was a no statistically significant difference, however across the response times of identification tasks, there was a statistically significant difference between *smaller-scale* and *larger-scale* maps. There were no statistical differences in wayfinding task accuracy or response times.

Finally, the experimental protocol was balanced according to the default amount of generalization, with two tested conditions: the *map* view and the *satellite* view. There was no statistical significance across wayfinding or identification task accuracy or response times across different amounts of generalization.

The final condition that was examined was participant emotion during the experimental route across mobile device screen size. There was no statistical significance between the number of *positive* versus *negative* emotions between *smaller-screen* and *larger-screen* conditions.

5.2 Limitations and Future Directions

There are several limitations to the experiment design worth noting, as they may impact the generalizability of empirical findings across all mobile mapping contexts. One of the largest limitations was the sample size. Sample size was restricted to n=36 due to the length of the experiment (nearly 60 minutes) and available research funding to compensate participants ($10). As a result, establishing statistical significant differences was inhibited by the sample size. It is likely that significant differences were not found across default map scale and amount of generalization because the sample population was not large enough to detect the difference. In future research, a power study should be conducted to determine the optimal sample size.

Another limitation was participants' prior knowledge of campus. A majority of participants in this study self-rated their knowledge of campus to be a '4' or '5', suggesting that they had a non-trivial amount of knowledge about the campus prior to participating in this study. While this measure was helpful in gauging what participants thought they knew about campus, this also measure unreliably predicted actual performance on experimental tasks, as many participants who rated their knowledge of campus to be a '5' did not take the 'optimal route' as displayed in Figure 3.1. An introductory survey that asked participants to identify maps and photographs of buildings on campus would have been a better alternative to understanding a students' prior knowledge of campus. This not only would test their knowledge of the area being tested, but their map reading ability as well, a factor that was not accounted for in the experimental design.

The final major limitation of this project was the time of year this study was conducted. Participants were tested from November 2013 until March of 2014, the coldest months of the year in Wisconsin. Due to the nature of this study, participants were outside walking around in weather that ranged from 54 degrees Fahrenheit to 5 degrees Fahrenheit. This extreme weather difference potentially affected the ability for participants to perform the appropriate tasks, but was included as a statistical control in the experimental design. Based on the experiences of this study, a ±10 degrees Fahrenheit range would be an acceptable range to test mobile mapping with pedestrians.

Importantly, this research revealed many directions for future research. First, future research could look the impact of different design decisions on mobile map performance, such color choice, type choice for labels, or label placement. Each of these map design decisions may have an effect on a user's performance, emotional experience, and overall preference.

A second area of future research is the interface provided to the user to interact with a mobile map. In this study, participants were limited to the ability to pan, which allowed the participant to move the map to center on a different location, and retrieve, which after the user tapped on a building, the user would receive extra information about the building, such as name, street address, and departments located in the building. All other functionality was restricted. Evaluating user performance in an interaction study would be a useful follow-up to improve our understanding of mobile map design. One aspect of interactive mobile map design to evaluate in particular is the relationship between the map's orientation and the 'blue dot' indicating the user's current location that is commonplace on mobile maps today. Many participants in this study vocalized strong opinions towards the 'blue dot' to represent location. While some participants were strong advocates of the 'blue dot' and followed the dot in order to determine where they were, others wished it were not on the map at all as they would have rather figured out their location and orientation on their own using the interactive functionality.

Finally, it would be interesting to look at how users 'see' themselves in the real world while looking at a map. For this study, map orientation was not restricted, so participants were allowed to rotate the phone as they deemed appropriate. Looking at how users orient themselves in the landscape—whether via rotating the phone itself or having the map dynamically rotate—may reveal insight into orientation preferences and the behaviors and emotions behind mobile map use.

5.3 Design considerations for mobile mapping

As stated earlier, little research has been to determine the appropriate settings for mobile maps, how they should be used, and user preferences when operating a mobile map. This experiment was designed to provide insight into how to design for mobile maps as well as create a positive experience for the user. The following set of mobile map design considerations were collected from both formal insights from, and informal observations during, the experiment:

- Choose highly salient landmarks for points of interest and basemap references. Landmark saliency has a large impact on the successful use of a mobile map, so it is important to make sure users have easy landmarks to identify while using a mobile map.
- Design for use across weather conditions (e.g., temperature, amount of sunlight). The weather affects how participants are able to interact with the map, how they feel while using it, and the overall performance of the device.
- Larger-scale maps are the appropriate default for mobile maps supporting pedestrian use. Using larger-scale maps when the user is walking will assist the user in nearby wayfinding and identification. Zooming outward as the speed of movement increases will allow for seamless transition between walking and other modes of transportation (e.g., bicycle, automobile).
- Allow users to remove the blue locator dot. Some participants did not like this feature due to slow updates and the error circle at larger-scales. Allow participants to disable the blue dot feature if they find it distracting or misleading.

- Prioritize labeling in mobile map design. Users appreciated the ability to see labels on buildings without having to probe map features using the interface. Labels should also be included on all available views (i.e., 'Map' and 'Satellite')

- Design for heavy variation in data connections. Participants had a great number of issues with how frequently the Wi-Fi connection dropped on campus. Client-side architecture of mobile maps should be designed to cache important basemap and context information when connections are strong for later use when connections drop.

- Include a routing feature. Users wanted an easy, no hassle way to route from their current location to another specified location. Successful routing for pedestrians requires creation of a comprehensive walkway dataset.

- Support map rotation. Many users wanted the ability to click the 'Find Me' button twice in order to have the map rotate so the direction they were traveling was up on the map. As browser-based 3D technology improves (e.g., WebGL), this also may include an oblique, three-dimensional perspective.

- Make audio directions available. Many participants indicated that they would like to set their destination and have the map tell them what direction to go.

- Start participants on the 'Map' view. 97% of participants in this study said they preferred the 'Map' view over the 'Satellite' view. Start participants with an abstracted view and allow them to change to a more detailed view as they see fit.

There are still many unexplored facets of mobile mapping, including how people use them, what functionality should be available, and how well participants can operate a mobile map while under stress. This research was designed to reveal the basic design considerations when developing for mobile maps and to open the possibilities for future research on the topic of mobile map design.

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APPENDIX A

1. **Please select the category that best describes your association with the University of Wisconsin**
   a. Undergraduate: Freshman Student
   b. Undergraduate: Non-freshman Transfer Student
   c. Undergraduate: Foreign Exchange Student
   d. Graduate: Masters level
   e. Graduate: Certificate level
   f. Graduate: PhD level
   g. Other

2. **Do you own a phone or tablet with location detecting abilities?**
   a. Yes, I own both (iPhone, iPad, Galaxy S3, Galaxy Tab, etc.)
   b. I only own a smartphone (iPhone, Galaxy S3, etc.)
   c. I only own a tablet (iPad, Galaxy Tab, etc.)
   d. I do not own either

3. **Have you already completed a course on map design, map use, or GIS?**
   a. Yes
   b. No

4. **Does your current job or previous job require you to design maps, use maps, or use GIS in any way?**
   a. Yes
   b. No

5. **On a scale of 1 to 7, please rate your familiarity with The UW Campus:**

   1: Novice (I do not know where anything is on campus)

   2

   3

   4: Intermediate (I am aware of where my classes are as well as the Unions, however I don’t know much more than that.

   5

   6

   7: Expert (I know most buildings on campus and where they are located)

6. **On a scale of 1 to 7, please rate your familiarity with mobile devices that are location enabled (iPhones, iPads, Galaxy S3, Galaxy Tab, etc.)**

   1: Novice (I do not understand how to use those devices)

   2

   3

   4: Intermediate (I am aware of how to operate one, however I do not know all the available features)

   5

   6

   7: Expert (I understand everything about the device and how it works)

APPENDIX B

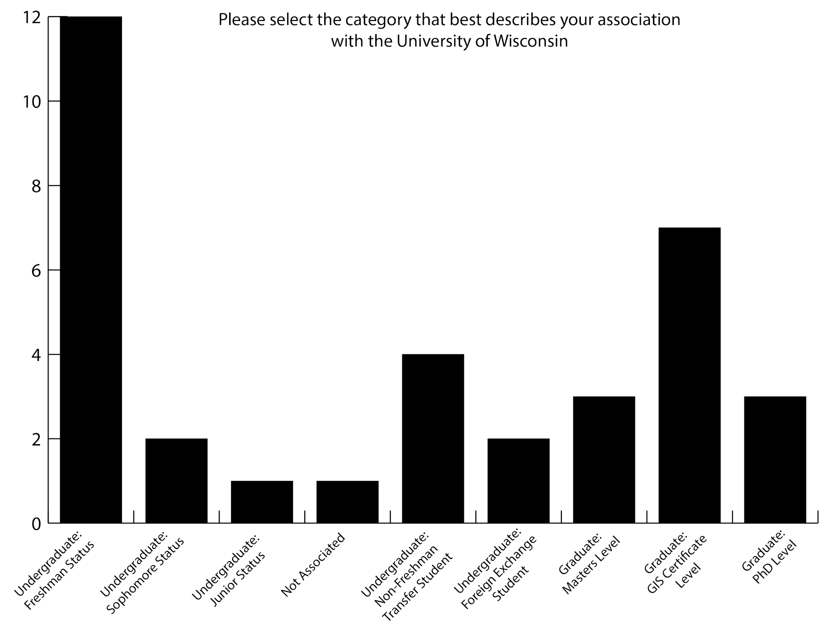

Figure B.1 – Association to the University of Wisconsin–Madison of participants in the study

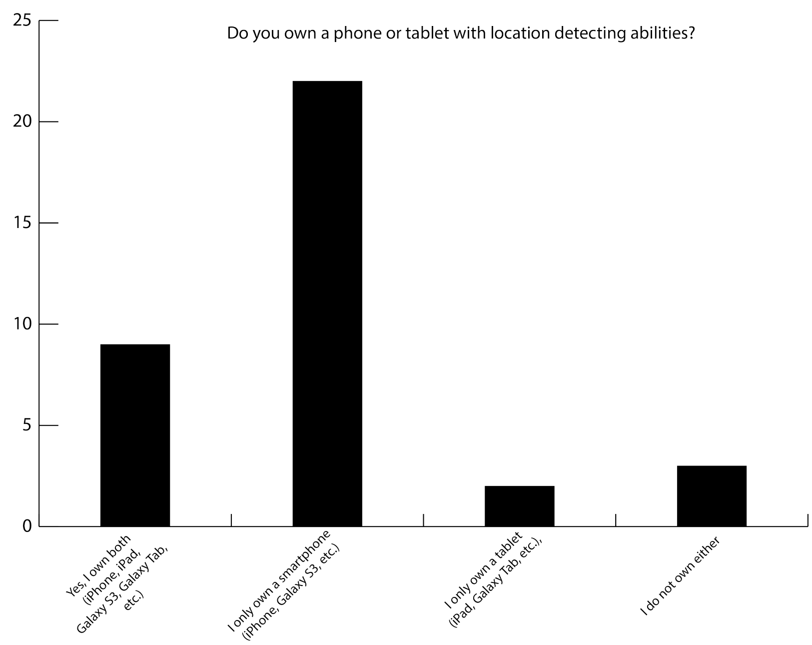

Figure B.2 - Device familiarity of participants in this study

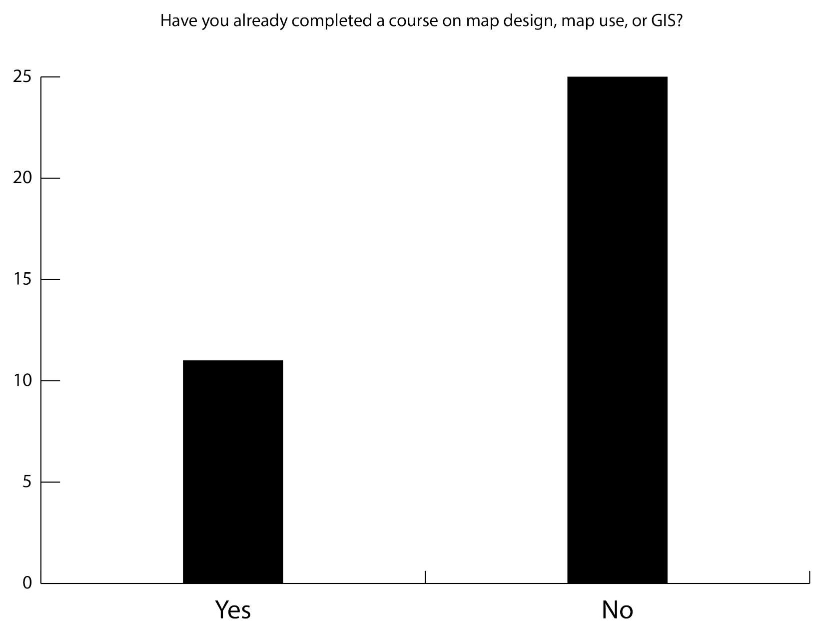

Figure B.3 – Prior coursework of participants in this study

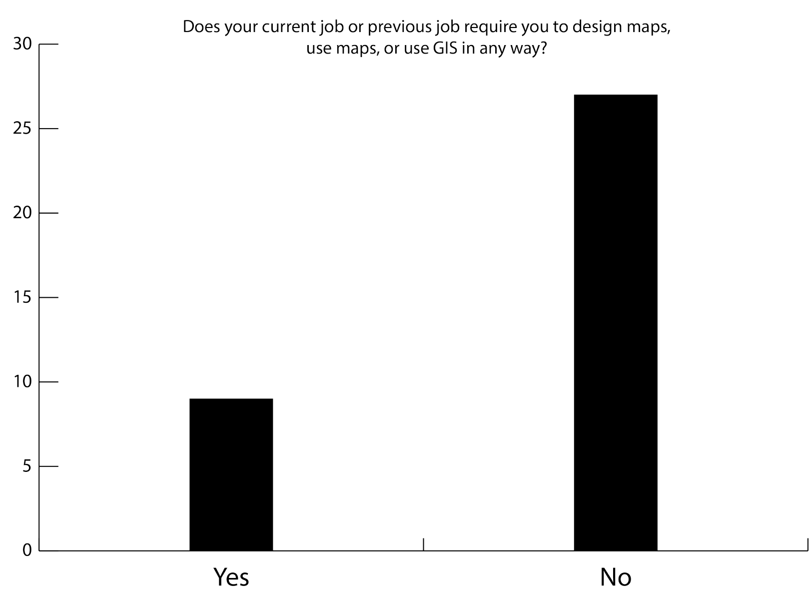

Figure B.4 - Prior job knowledge of participants in this study

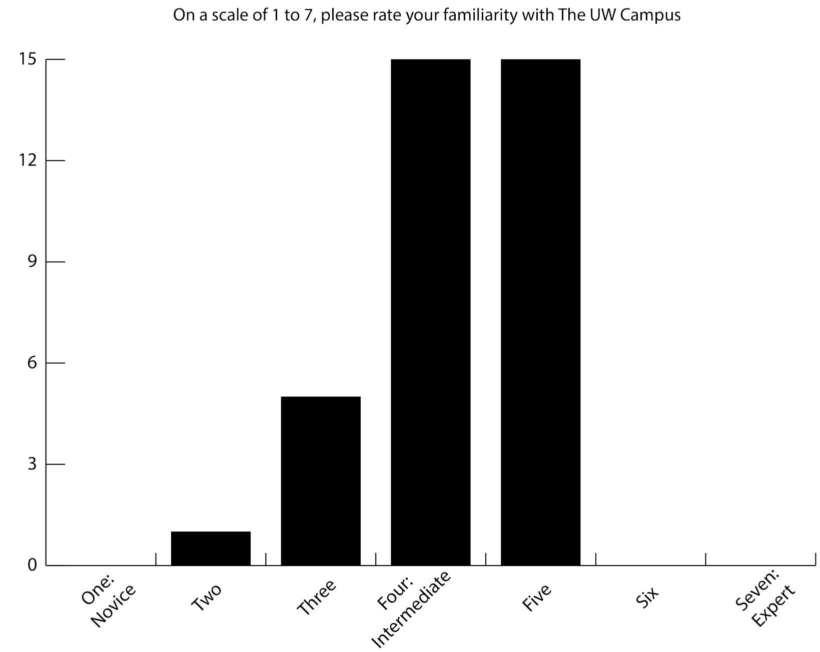

Figure B.5 - Campus familiarity of participants prior to task completion

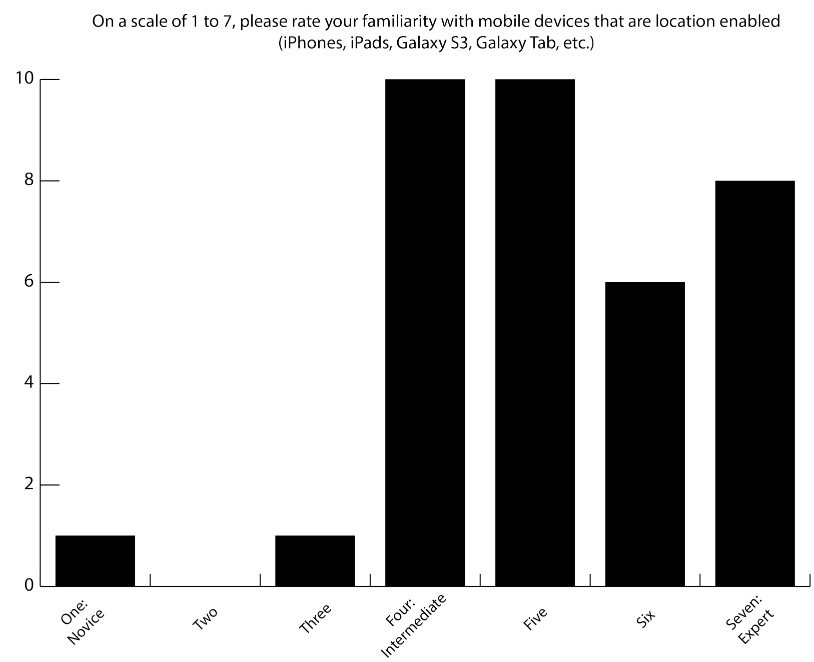

Figure B.6 - Device familiarity of participants prior to task completion

APPENDIX C

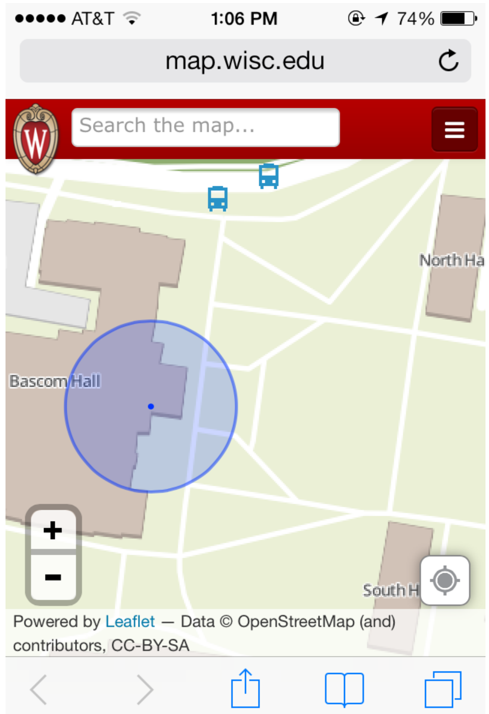

Figure C.1 - Scale #6, Map view on a smaller-screen device

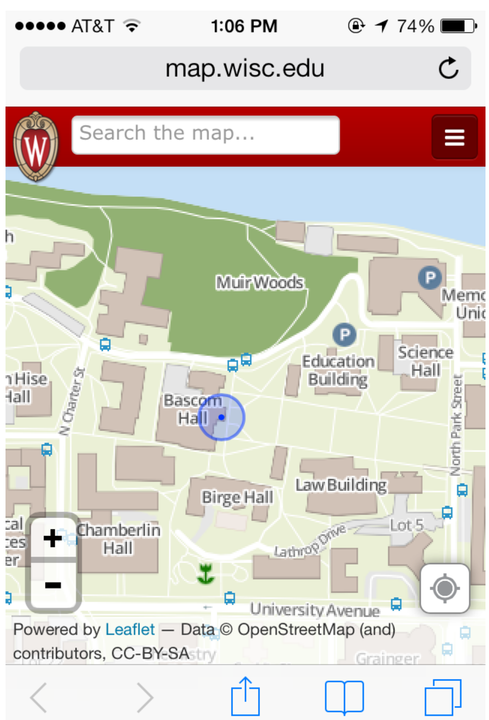

Figure C.2 - Scale #4, Map view on a smaller-screen device

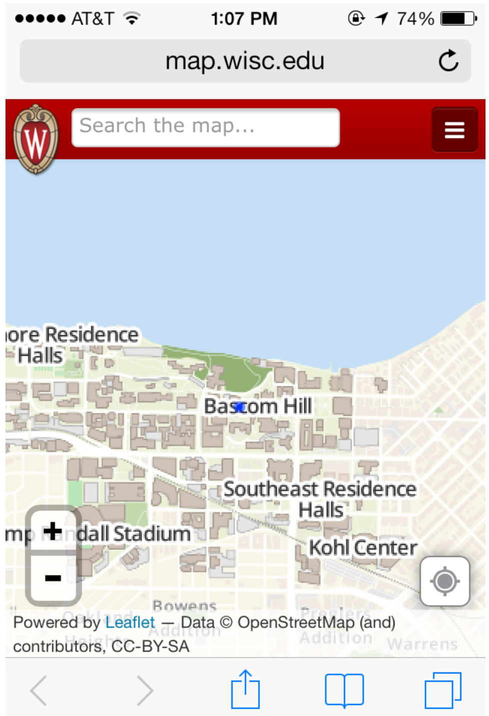

Figure C.3 - Scale #2, Map view on a smaller-screen device

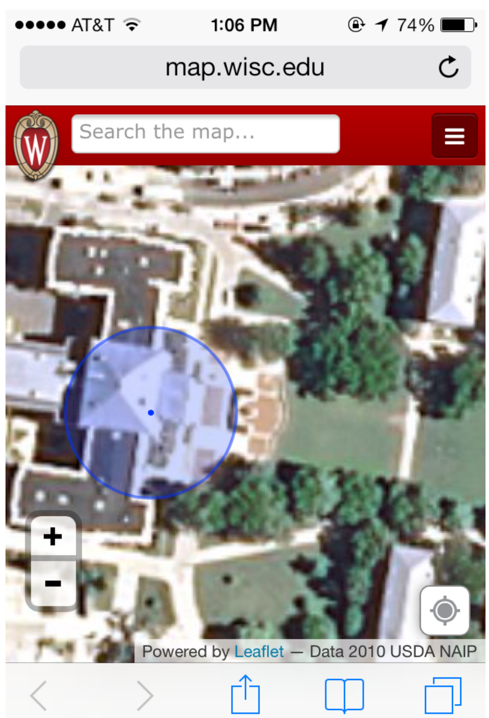

Figure C.4 - Scale #6, Satellite view on a smaller-screen device

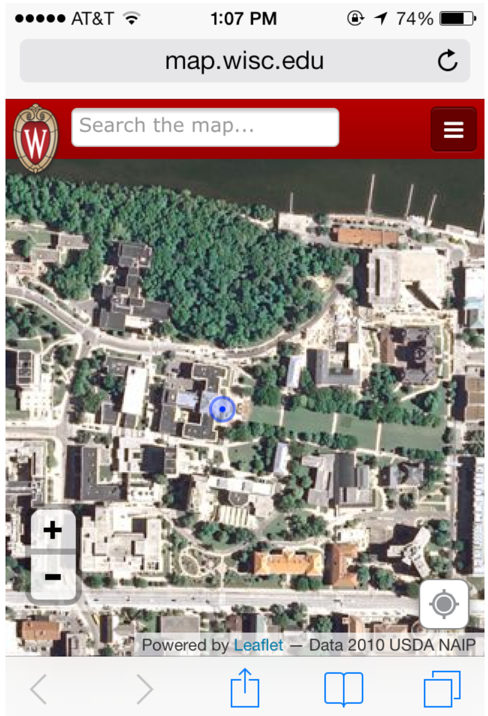

Figure C.5 - Scale #4, Satellite view on a smaller-screen device

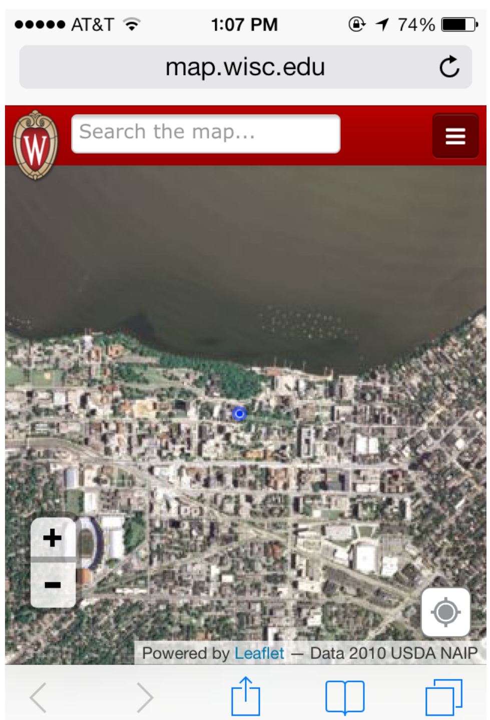

Figure C.6 - Scale #2, Satellite view on a smaller-screen device

Figure C.7 - Scale #6, Map view on a larger-screen device

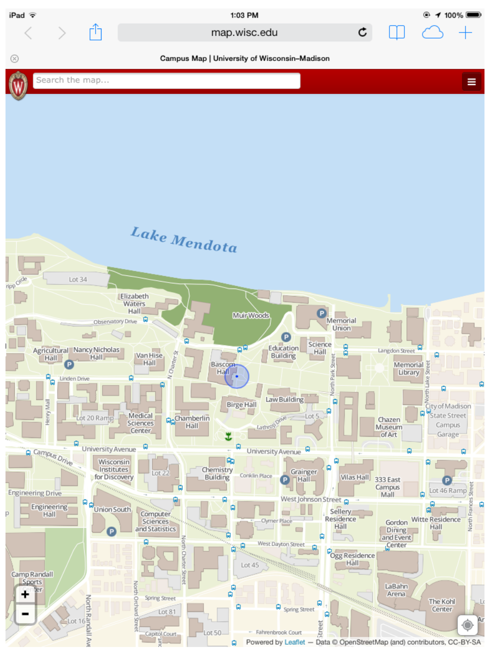

Figure C.8 - Scale #4, Map view on a larger-screen device

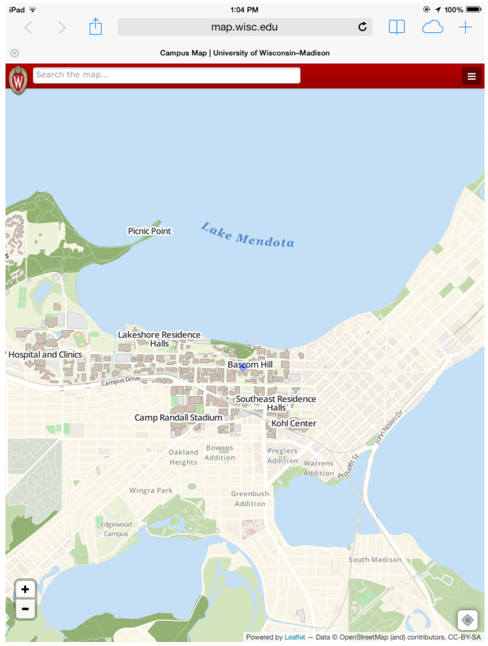

Figure C.9 - Scale #2, Map view on a larger-screen device

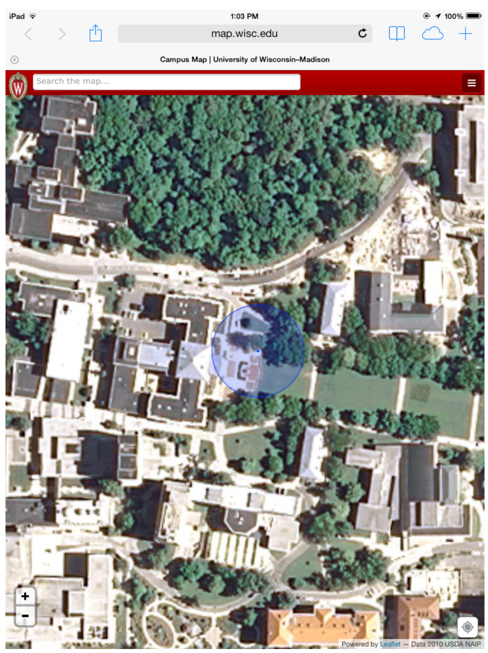

Figure C.10 - Scale #6, Satellite view on a larger-screen device

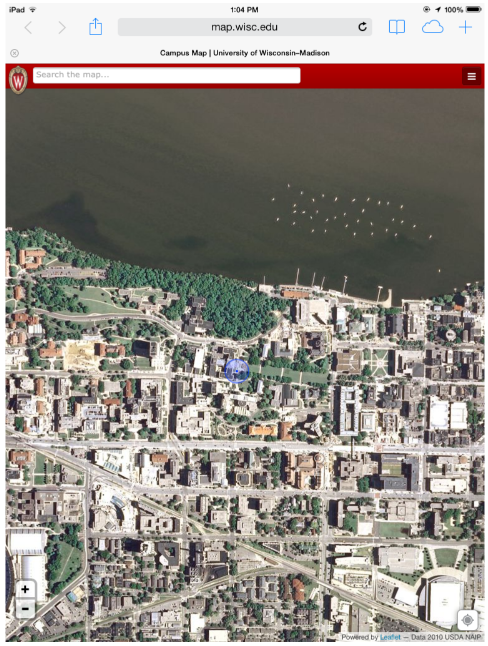

Figure C.11 - Scale #4, Satellite view on a larger-screen device

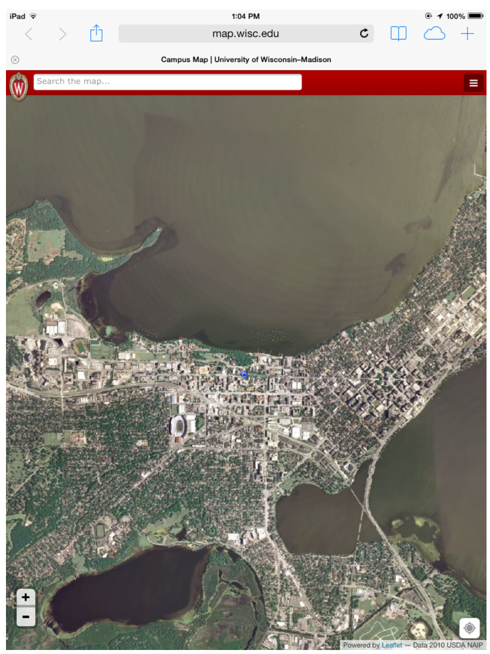

Figure C.12 - Scale #2, Satellite view on a larger-screen device

APPENDIX D

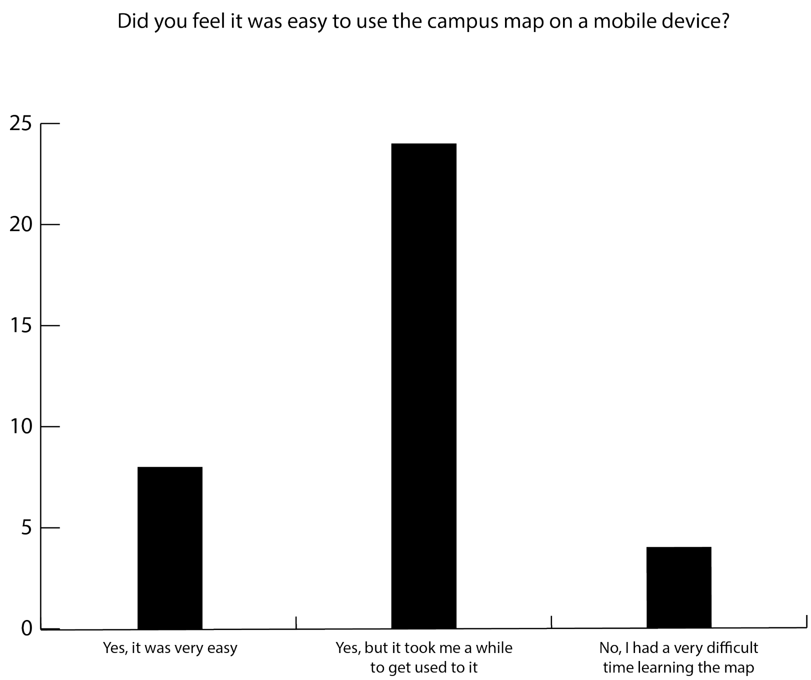

Figure D.1 - Question one of the exit survey discussion ease of use of the campus map

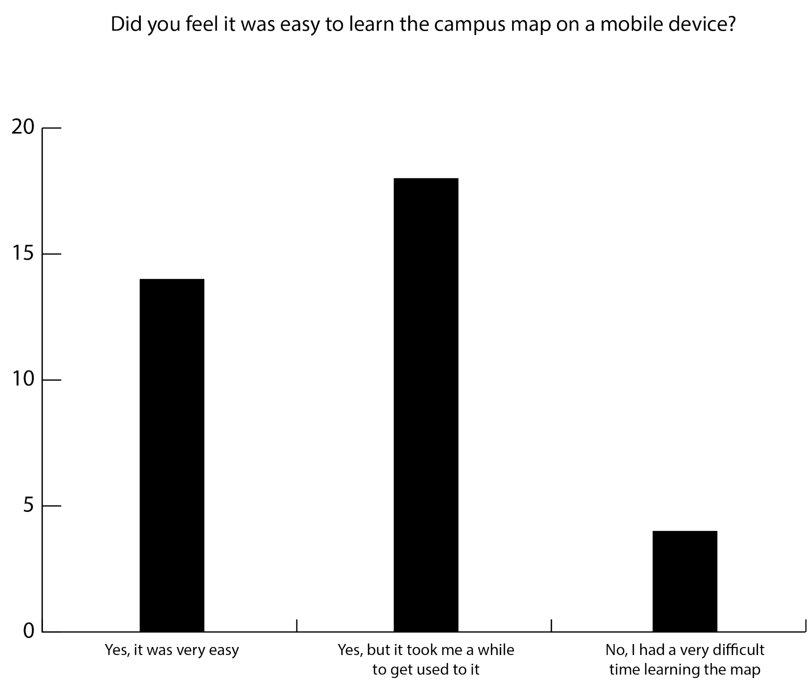

Figure D.2 - Question two of the exit survey discussion learnability of the campus map

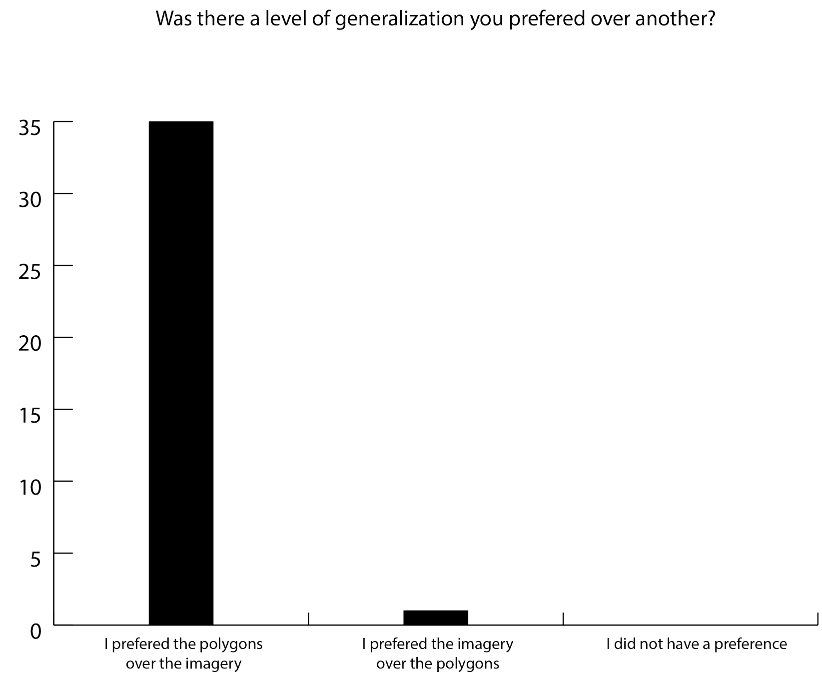

Figure D.3 - Question three of the exit survey discussing amount of generalization preference

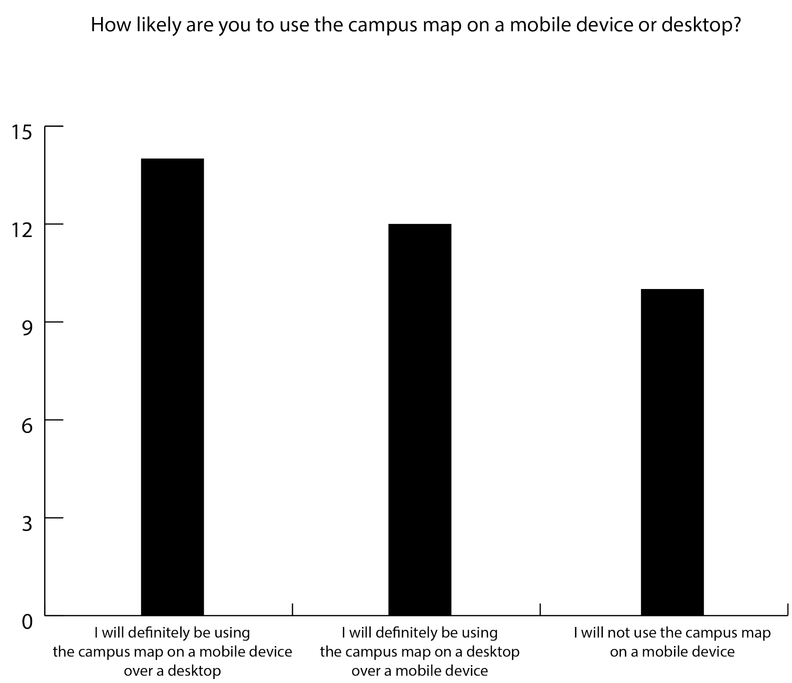

Figure D.4 - Question four of exit survey asking about future use

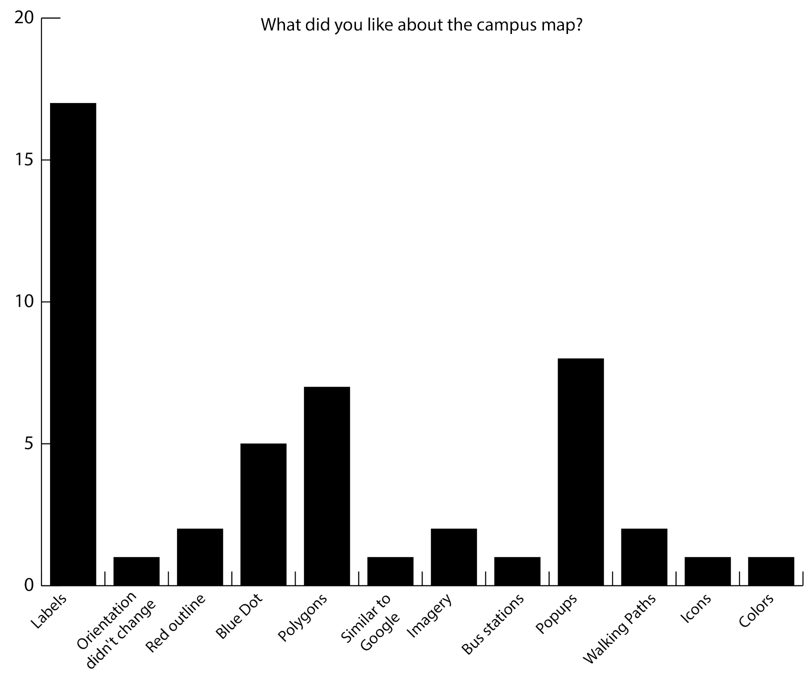

Figure D.5 – Question five of the exit survey asking about what users liked on the map

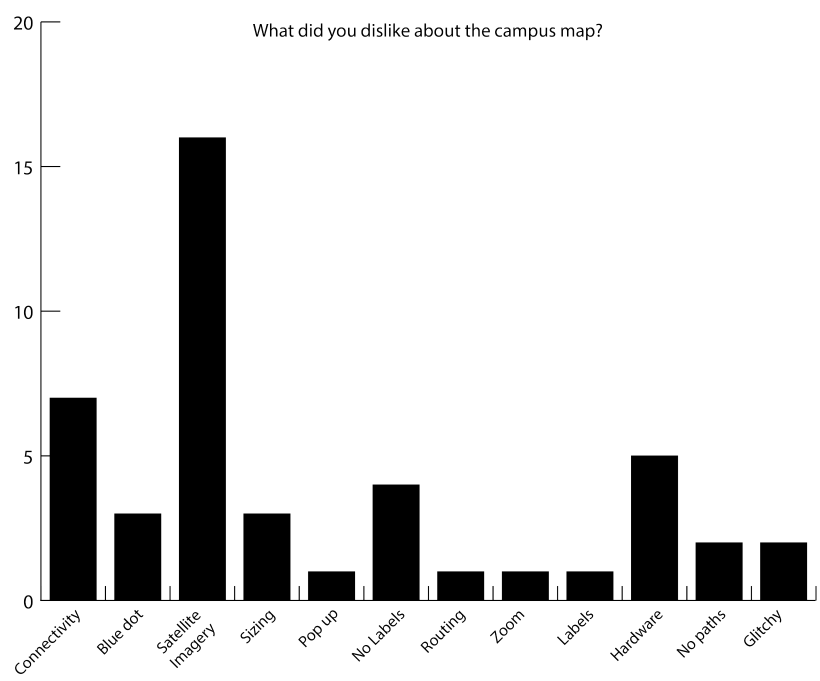

Figure D.6 - Question six of the exit survey asking about what users disliked on the map

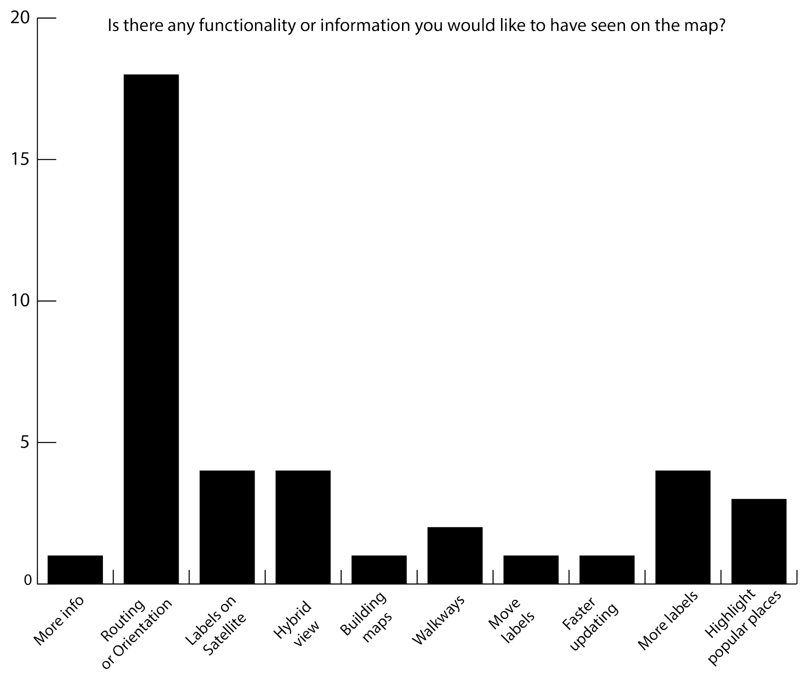

Figure D.7 - Question seven of the exit survey asking about other functionality or information