CONTEMPORARY PROFESSIONAL PRACTICES

IN INTERACTIVE WEB MAP DESIGN

by

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TABLE OF CONTENTS

TABLES AND FIGURES

TABLES

FIGURES

<u>ACKNOWLEDGEMENTS</u>

Thank you to my parents, Alice and Brian Wertheim, for always telling me that I could do whatever I wanted to do. Thanks to my siblings, Paula and Evan, for making mistakes before I did so that I could learn from them.

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CHAPTER 1: INTRODUCTION

The availability and use of interactive web maps for both expert and general-use has expanded rapidly in recent years, notably since the release of Google Maps in 2005 (Miller 2006). Furthermore, there has been a dramatic increase in the creation and use of interactive maps on smartphones and tablets, collectively referred to as mobile devices (Davidson 2014). However, these recent innovations in web mapping technology have been pushed forward by the technology industry, not by formally trained cartographers or academic researchers (Tsou 2015; Plewe 2007; Haklay et al. 2010). It is time for cartographic research to catch up to the technology and practice of interactive web mapping. Here, I investigate the interactive web map creation process through the lens of those who spend their professional lives creating them.

The areas of user-centered design and usability engineering have long influenced the design of digital interfaces and the accompanying creation of a successful user experience (Hassenzahl 2014). *User-centered design* (UCD) is "a philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable" (Norman 1988: 223). *Usability engineering* (UE) is the related set of methods to create interfaces that have high *usability*, i.e., are easy to use (Nielsen 1994). Insights from UCD and UE recently have been leveraged for cartographic interface design (Roth 2013a), cartographic design, the web as an interactive medium, user-generated content, and an emphasis on user-centered design coalescing into the research thrust of web cartography (Tsou 2011: 255). However, more research is needed to incorporate design insights from across these influences.

Here, I respond to Roth's (2015: 110) call for further research to "integrate theoretical principles and practical guidelines from the field of UX design into the cartographic canon." Specifically, I will address the following three research questions:

1. What are the workflows and processes that professional cartographers use when creating interactive maps?

2. Are there overarching design conventions that professional cartographers use for interactive maps? If so, what are they and in which contexts are different conventions used?

3. Do professional cartographers evaluate the success of their interactive map interface? If so, how?

To answer these questions, I conducted interviews with expert cartographers who create interactive maps. To establish a baseline for current practices, I asked participants to discuss their workflows, the design conventions they follow, and their approach to evaluating the success of their maps. The results of this research include two knowledge products to support interactive map research and design. First, the interview study resulted in a benchmark of current design practices in interactive mapmaking, outlining contemporary design workflows and measures of interface success. Second, the interview study revealed a set of interactive map design conventions employed by professional cartographers. The purpose of this research is not to identify gaps in current literature, but rather to identify gaps between research and practice.

These products are useful to two main groups of people who design and use interactive maps: interactive cartographers and cartographic researchers. Creating a benchmark of current practices of workflows and processes provides professional cartographers with an

overview of best practices and potential opportunities for interactive mapping. This enables these professionals to examine new ideas and possibly incorporate them into their own work. For cartographic researchers, this qualitative research serves as an initial compilation of the opinions and practices of interactive cartographers. It contributes to ethnographic research on the opinion and practices of contemporary web mapping from individuals working in the industry, allowing researchers to determine if and how those opinions and practices change in the future. Completing a snapshot of current design conventions for interactive design also supplies future researchers with a list of conventions to test empirically to determine if interactive map users do, in fact, perform better when these conventions are followed.

In Chapter 2, I provide background research related to the three research questions, including information about the design and development process for interactive web maps, best practices for interactive web maps, and the evaluation of interactive web maps. In Chapter 3, I describe the interview protocol and qualitative data analysis of interview transcripts. In Chapter 4, I present and interpret the results of the interview study. Lastly, in Chapter 5, I synthesize the results of the interviews into the aforementioned knowledge products derived from the study, the benchmark of contemporary practices and the set of design conventions.

CHAPTER 2: LITERATURE REVIEW

In this chapter, I review three themes associated with each of the research questions introduced in Chapter 1: the interactive web map design process (Section 2.1), interactive web map best practices (Section 2.2), and interactive web map evaluation (Section 2.3). The purpose of this literature review is to gain background knowledge on the creation of interactive web maps, including the design process, design best practices and conventions, and the evaluation of the resulting maps. In each section, I review literature both within and outside of cartography to cover the full breadth of areas that influence interactive cartographic design. These outside influences include web design, interaction design, user interface and user experience (UI/UX) design, usability engineering, and project management, among others.

SECTION 2.1: The Design and Development Process

In this section, I review aspects of the design and development process for creating interactive web maps. This section aims to introduce both conceptual and practical background regarding the first research question: *What are the workflows and processes that professional cartographers use when designing interactive maps*?

Section 2.1.1: The Interactive Web Map Design and Development Process

To make an interactive web map, the creator must go through a design process. Design is a creative, iterative decision-making endeavor; as Shneiderman and Plaisant (2010: 102) articulate, "Design is a process; it is not a state and it cannot be adequately represented statistically." The attempt to concretely define the interactive web mapping workflow is inevitably incomplete, as the process is different for each designer and each design context.

Building upon empirical evidence in web map education (see Roth et al. 2014), Donohue (2014) outlines a prototypical workflow for designing a web map that includes five stages (Figure 2.1).
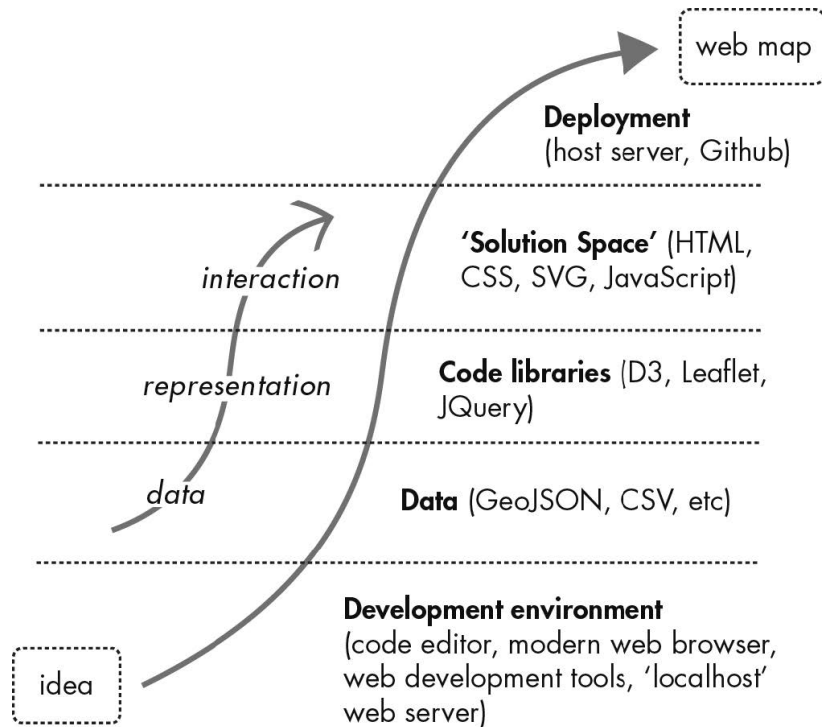
Figure 2.1: Prototypical web mapping workflow (Donohue, 72).

This Donohue (2014) workflow encompasses *full stack development*, or the integration of a range of technology and technical skills required to create a functioning web application. The full stack includes two main components: back-end and front-end. *Back-end*, or server-side, technologies process and send data to the web application. *Front-end*, or client-side, technologies send user and system requests to the server, and then render the returned data and provide interaction to the user to send new requests to the server (Fielding 2000). Back-end technologies include server configuration, hosting, data modeling, and application programming interfaces (APIs), while front-end technologies include user interface (UI) design, primarily rendered using HTML, CSS, and JavaScript (Donohue 2014). The full stack

informs the *data→representation→interaction* process of interactive web map design, which is explored in Section 2.2.

In an ever-changing landscape of web mapping technologies, professionals must determine early in the design process which combination of libraries, frameworks, APIs, etc. they will leverage to implement the *data→representation→interaction* workflow. Further, the popularity of interactive web maps has led to a proliferation of *open* web mapping technologies that are freely available for use and/or extension; the Roth et al. (2014) study identified nearly three dozen open source technologies available for full stack web mapping. Traditionally, developers have allowed the limits of their selected technologies to drive the design of interactive web maps (Haklay and Nivala 2010). However, the user needs of the project must drive the chosen technologies, rather than the other way around (Robinson et al., 2005, Donohue 2014).

Section 2.1.2: User-Centered Design

As stated in the introduction, user-centered design (UCD) places an early and active focus on the needs of the user (Norman 1988). In his seminal work on UCD, Norman argues that the design of an interface greatly impacts the experience the user has interacting with it. The fields of human-computer interaction, information visualization, and web design have become increasingly interested in UCD, or doing "some up-front design to understand users, their goals, and the project vision" (Shneiderman and Plaisant 2010, Hussain et al., 2009: 285). Following this shift towards UCD, numerous scholars have advocated for formally integrating Norman's ideas into the interactive web mapping process to ensure that map design meets user needs (e.g., Slocum et al. 2001, Robinson 2005, Kramer 2008, Nivala et al. 2008, Tsou

2011, Roth et al. 2015). Arguably, this shift towards focusing on individual users' needs in part is explained by the increased use of web maps by non-experts (Tsou 2011).

The goal of UCD is to improve the user experience by soliciting feedback from users throughout the design process. A user-centered approach prescribes a highly iterative design process (Marsh and Haklay, 2010). While numerous UCD processes have been suggested for web mapping (e.g., Gabbard et al. 1999, Haklay and Tobon 2003, Slocum et al. 2003, Robinson et al. 2005), all UCD processes collect input from the interface's target user group at multiple stages in the design and development process, informing the implementation through iterative evaluation and revision loops (see *Figure 2.2*, for example).
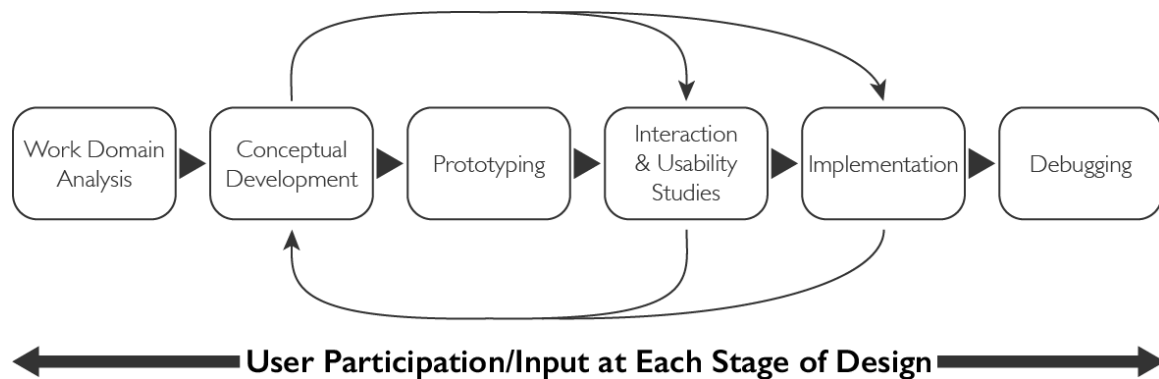
Figure 2.2. One adaptation of the UCD process for cartography, from Robinson et al., 2005. This process draws from other cartographic applications of user-centered design, primarily Haklay and Tobon 2003 and Slocum et al. 2003, but also social science strategies for studying web map usability, such as Suchan 2002, Andrienko et al. 2002, Edsall 2003, and Montello et al. 2003.

The Robinson et al. (2005) UCD process outlines six stages of design. *Work domain analysis*, also known as needs assessment or requirements analysis, covers the initial research into the topic being mapped and includes initial communication with the client, stakeholders, and target user group. The *conceptual development* stage includes the written formalization of requirements for the application based on the user needs established through the work domain

analysis. *Prototyping* is a highly iterative process of creating visual mockups of the proposed functionality, first potentially as paper wireframes and eventually as functioning, though not full-featured alpha and beta releases. *Interaction/usability assessment* is built into the UCD process to receive feedback on prototype from the users, and can be formal or informal. The *implementation* stage involves incorporating changes from the previous assessment stage back into the product. Lastly, *debugging* ensures stability of the interactive web map application. To save time and resources over the course of map development, it is preferable to request feedback from users to inform the interface design throughout its development, rather than only requesting input once the interface is complete (Roth et al., 2015). More information about the feedback and evaluation process is covered in Section 2.3.

The combination of UCD and human-computer interaction (HCI) commonly is referred to as user interface/user experience (UI/UX) design, acknowledging the combined emphasis on the user, the interface design, and the interaction experience (Hassenzahl and Tractinsky 2006). The term UI/UX and its related research is widely employed in the professional design world, but only recently has been evoked in cartography and related fields (Roth 2015). UI design encompasses the layout and design of the interface and the interaction, while UX design approaches "the intangible design of a strategy that brings us to a solution" (Flowers 2012). UI/UX designers understand that the interface itself is not the solution to a problem, but rather the medium through which a user solves problems (Willis 2011, Hubert 2012). UI/UX designers come from a wide variety of educational and professional backgrounds (Farrell and Nielsen 2014), and cartographers are well positioned to step into this role for mapping applications (Roth 2015).

Section 2.1.3: Additional Aspects of the Design Process

The design process does not happen in a vacuum; there are additional forces that affect a design's outcome other than the ideal design process. In the case of professionals who design interactive web maps, these influences can include: budget constraints, time constraints, client requests, project management, team collaboration, and technical knowledge, among others. This section examines some of these outside influences and possible ways to address them. *Agile software development* is one framework for web development that cartographers may be able to draw from, with its emphasis on flexibility as project scope changes (see Figure 2.3).

Original plan

Actual plan
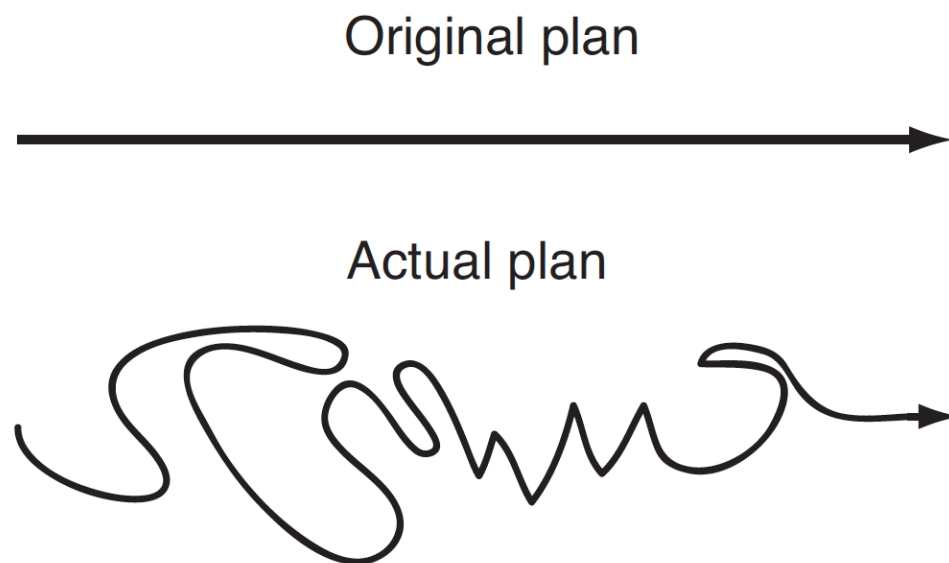
Figure 2.3: From Rasmusson (2010); it is necessary in web development to be flexible as project scope and definitions change.

The Project Management Institute describes a *project* as a "temporary endeavor undertaken to create a unique product, service, or result" (Project Management Institute 2013). *Project management* is an organizational framework that bridges the technical with the logistical aspects of a project. Traditional project management includes five key processes of a project: (1) initiating the project, (2) planning the project, (3) executing the project, (4) monitoring the

project, and (5) closing the project (Project Management Institute 2013). The design process for an interactive web map may be contained within a single, standalone project or included as part of a larger, multi-faceted project. Technology projects in general can be simple or complicated; run by one person or dozens; run by people in one location or multiple; require little planning or complex project management software; and have a tight deadline or flexible one (Holtsnider and Jaffe 2012).

Agile software development is a highly iterative project management methodology that emphasizes delivery of workable code to the customer on a regular basis, flexibility over rigidity in project execution, and open communication with the customer to allow for adjustments as needs change (Rasmusson 2010). While UCD can guide cartographic design decisions at each stage of the Donohue (2014) web mapping workflow, project management can "assist in managing internal workflows inside a corporation and deal with high level tasks, while allowing the monitoring and management of their progress" (Albrecht and Davies 2010: 136). Therefore, UCD describes the cartographic design process for the map itself while project management addresses high level task management across the design team.

When considering project management, it is important to address the "people" aspect of mapmaking, including team management, collaboration, and client management. Different teams divide responsibilities differently; some have dedicated project managers and strictly defined roles, while others have a flatter hierarchy with loosely defined roles. Agile software development promotes a team culture of blurred roles and overall team accountability for the product, while incorporating loose roles that are often found on software development teams, such as programmers, technical writers, project managers, software testers, and UI/UX designers, amongst others (Rasmusson 2010). Agile also aims to tightly incorporate the client

in the product development and considers them as part of the team. Teams that create interactive web maps may have much to learn from the principles of agile software development.

SECTION 2.2: Cartographic Best Practices and Conventions

In this section, I review cartographic conventions and frameworks for interactive map design reported in the literature. Much initial research on interactive maps was offered in the context of exploratory scientific visualization, in which a high level of interactivity is reserved for users attempting to reveal unknown insights (MacEachren 1994). Subsequent research in the 1990s and early 2000s was described under the heading of *geographic visualization* (MacEachren and Kraak 2001), before the ubiquity of public-facing interactive web maps, both on desktop and mobile computing devices. Today, interactive web maps are geared to a variety of users, from experts to novices, in a variety of use scenarios, ranging from visualizations that attempt to untangle complex data to simple, yet beautiful maps about current events (Roth, 2013).

In the following, I discuss design concepts and conventions in the *data→representation→interaction* workflow that are specific to interactive web mapping in Sections 2.2.1, 2.2.2, and 2.2.3, respectively. In Section 2.2.4, I broaden the influences on interactive web map best practices to include web design in general. This section aims to give background knowledge on the second research question: *Are there overarching design conventions that professional cartographers use for interactive maps? If so, what are they and in which contexts are different conventions used?*

Section 2.2.1: Web cartography conventions: Data design

Every step of the web mapping workflow is predicated on the mapmaker acquiring the geospatial data, converting it to a suitable format, and connecting it with the interactive web map. Sometimes, the decision about which data to use for a map is made based on its ease of accessibility, not its quality (Brown et al 2013; Goodchild 2008). Although geographic data has become much more freely available to the public (Gale 2014), the Roth et al. (2014) study demonstrated that the part of the web map workflow that participants spent the most time on was formatting and loading the data. This includes finding appropriate data and making sure that it is in an appropriate format.

The search for data is twofold: the acquisition of the given geographic geometry as well as any relevant attribute or temporal data to join to these geometries. Free geographic data (e.g., country borders, urban areas) open for public use has become increasingly available. Open sources include Natural Earth Data (Natural Earth 2016) and OpenStreetMap (OpenStreetMap 2016), both of which include worldwide coverage. For thematic data, many governments and international organizations have data portals for free download of geographic data, including the United States government (http://data.gov), the World Bank (http://data.worldbank.org), and the OECD (http://stats.oecd.org/). Additionally, there is a push for geographic data to be exposed via *application programming interfaces*, which allow data to be displayed dynamically in a map (Bostock and Davies 2013).

Simply acquiring data is not enough to include it on an interactive web map; it must also be processed and displayed in a web browser. At the time of this writing, one popular format for geographic data for the web is GeoJSON, which is supported natively by major web browsers (Bostock and Davies 2013, Butler et al. 2013). The TopoJSON format is related

to GeoJSON, but preserves topology of geometries, drastically reducing file size (Bostock and Davies 2013). Attribute data can be included in the GeoJSON or TopoJSON itself, or can be joined with geographic data dynamically in the browser (Sack et al. 2015).

Section 2.2.2: Web cartography conventions: Representation design

Representation design on the web flows directly from the data, or is *data-driven* (McConchie 2016). The following discussion of representation design is divided in two broad categories: page design and symbolization. The page design refers to map elements and map layout, while symbolization refers to the graphical design of geographic data on a map. This section summarizes aspects of map design that have had to receive careful attention in the transition from traditional print cartography to web cartography.

Map elements are the individual components that constitute a map, including the map title, the map frame itself, the map legend, scale, and north arrow, and any supplemental information and metadata (Muehlenhaus 2013). Many map elements employed in traditional print cartography have been reconceptualized for the web (e.g., interactive legend), and there are some map elements that are new to web mapping (e.g., zoom buttons to change the scale of the map). A general rule-of-thumb for map elements is to style them to have a cohesive look and feel between the map, its elements, and the accompanying website (Muehlenhaus 2013). Table 2.1 provides a list of map elements and how their use on the web may differ from traditional cartography.

Map element	Possible web map adaptation(s)
Map title	● Web maps can use a temporary splash screen that disappears when the user begins to interact with the map rather than using a static map title that remains in view.
Mapped area	● Because of the ability to pan some web maps, the map user can have control of which part of the map they are looking at. Click-and-drag is the most common form of panning, or adjusting the mapped area in the current view. ● Many web maps with thematic data overlays often use base maps composed of map tiles, which may be provided by corporate or open-source contributors. Thematic design is discussed in more detail below.
Map scale	● With interactive maps comes the possibility of multi-scale mapping, i.e., the design of a map to be seen at multiple zoom levels. Mapmakers should design their map differently for different zoom levels and only allow for zoom levels that are necessary for the purpose of the map. ● Zoom buttons are the most commonly visible map element to allow users to change the scale of the map. ● Some web maps display the given map scale at each zoom level, but many do not.
Supplemental information	● Supplemental information can include embedded text, links, images, graphics, videos and be displayed interactively, e.g., when the user clicks on a button or map feature. ● This information can be presented as information windows or as a tooltip (on top of the map itself, moves with the pointer).
Labels	● The quantity and size of place name labels can change at different zoom levels.
Inset/Locator map	● The locator map can change to match the current view as the user interacts with the map. ● Locator map can help with zooming, allowing the user to zoom into the main map by drawing a rectangle of the desired area on the inset.
Map metadata	● Metadata includes the cartographer(s)' name(s), data sources, map projection, etc. It does not need to be shown directly on the map, but can be easily available in a splash screen or on a linked webpage.
North arrow	● Rotates interactively as the user rotates the map. ● Many interactive maps do not have north arrows, as it is assumed that north is up.
Neat lines / frame lines	● For mobile, when the map takes up the full size of the screen, the neat line is the screen itself.
Supplemental graphs	● Users maybe have a better understanding of thematic data through the inclusion of graphs or charts that are linked to the thematic map through simultaneous highlighting or brushing. ● These linked graphs or charts to the map should not be shown directly on top of the map, but rather in a side or bottom panel. ● *For more information about linked graphics and highlighting, see Opach and Rød 2014 and Robinson 2011.*
Legend	● Allow for interaction with the legend to affect the map, such as being able to turn/off layers, adjust the timeline of temporal map data, etc.
*Menus	● Provide the map user with additional options and interactivity in the form of menus.
*Help	● Provide link to information for map users who need help learning how to use the map. ● *For more information about the use of learning materials for web maps interfaces, see Mead 2014.*

Table 2.1: Summary of map elements commonly found on maps, with a description of how they may be employed for web maps. Elements marked with an asterisk (*) are those that are specific to web maps and are not found in traditional cartography. Adapted from Muehlenhaus, 2013.

Map composition and layout have changed in nature in the migration of maps from paper to the web. *Map composition* refers to visual hierarchy, or the decisions to emphasize certain map elements over others; *map layout* refers to the placement of map elements on the screen, including placement of non-map elements (Dent et al. 2009, Muehlenhaus 2014). Traditional visual hierarchy must be adapted for the web, recognizing that many map elements

can be hidden/displayed upon initial map view or by the user. See Table 2.2 for suggested

visual hierarchy levels for web maps, based on the type of map.

Visual Hierarchy Level	General Interest Web Maps	Thematic Web Maps
Level 1	Title / splash screen Map symbology Key reference data Information windows	Title / splash screen Thematic visualization Legend
Level 2	Base map (including labels and navigation tools, as needed)	Base map Information windows Supplemental graphs
Level 3	Map interactivity (i.e. interaction operators)	Base map labels Map interactivity (i.e. interaction operators)
Level 4	Locator maps Supplemental graphs	Locator maps Supplemental graphics (e.g. videos, photos)
Level 5	Map metadata Tool tips	Map metadata Tool tips

Table 2.2: Suggested map composition, as adapted for the web. Adapted from Muehlenhaus, 2013, with references to Dent, 2009.

Map layouts can be divided into two general types: compartmentalized and fluid

(Muehlenhaus 2013, Dondis 1973). Though these layout types draw from traditional print

cartography, there are challenges unique to web maps. *Compartmentalized layouts* place most of

the map elements into separate boxes, whereas with *fluid layouts*, the map elements are placed

on top of the map itself (Muehlenhaus 2013).

Symbolization, the core of the representation stage of the web mapping workflow, refers

to the styling of points, lines, polygons, and raster images to convey information about the

underlying data (Slocum et al. 2009). The most recognizable point symbol specific to web

maps is the "push pin," which has been in use since the launch of Google Maps in 2005 (Gale

2013). However, like in print cartography, web maps can also use icons to more accurately

represent the mapped feature. For web design, it is important to make the icons simple, such

that they are recognizable on different screens and at different sizes (Muehlenhaus 2013).

Icons "should aim to suggest the functionality" and attempt to convey the same idea to

different users (Poplin 2015: 12).

Representation of thematic data for web maps is similar to thematic map design for traditional print cartography, with the possibility of mapping data using choropleth maps, dot maps, proportional symbol maps, isarithmic maps, flow maps, cartograms, and multivariate maps, or a combination of these representation methods. However, there are often technological limitations on the type of representation that can be used, such that mapmakers may choose "a representation technique that is available to them rather than...using a more insightful method" (Muehlenhaus 2013). More research needs to be done to understand more about how different representation methods can be optimized for web maps.

Section 2.2.3: Web cartography conventions: Interaction design

This section explores interaction design for interactive web maps. Interaction design "tries to make sure that people can *do the right things at the right time*" (Rosson and Carroll 2001: 159). Interaction design therefore ensures that the user and map can "speak" to one another in an understandable manner. To this end, the user "says" something to the map (e.g. clicks a zoom button on the map) and the map "responds" (e.g., increases the zoom level on the map) in a way that the user can clearly understand. This back-and-forth prompts the user to probe the map for further questions and possibly influences the user's understanding of the represented geographic phenomenon.

To fully understand interaction design, it is important to distinguish between a user interface and a user interaction, treated in Section 2.1.2 together as UI/UX design. A *user interface* (UI) is any digital component of a computer program—graphic or otherwise—that enables user input, such as buttons, sliders, drop-down menus, or form fill-in boxes (Howard and MacEachren 1996, Shneiderman and Plaisant 2010). Interface design of digital tools

focuses on the "graphics, sounds, haptics, etc., that constitute the interface widget" and their general layout on the screen (Roth 2013). A *cartographic interface* is any digital interface that allows the user to interact with a map, and can include direct manipulation of the map itself (e.g., grabbing the map to pan and zoom) or an interface widget to the side of the map (Haklay 2010; Roth 2013). An *interaction* is broader than an interface, and can be considered a "cooperative endeavor between person and machine," allowing for an exchange of information between the two participants (Norman 1988: 173). Following the conversation metaphor introduced above, *cartographic interaction* therefore is defined as "the dialogue between a human and a map mediated through a computing device" (Roth 2012, 377). The interactive dialogue between the user and the map impacts the *user experience* (UX), while the interface is the digital tool supporting this experience.

There are a finite number of design decisions available for supporting interaction at each stage of the human-map dialogue (Crampton 2002). These design decisions, or *cartographic interaction primitives*, are the fundamental components of interaction that are combined in succession to characterize a complete interaction sequence (Roth 2012). Several scholars in cartography have sought to develop a taxonomy of cartographic interaction primitives to support interaction design of web maps (e.g., Dix and Ellis 1998, MacEachren et al. 1999, Edsall et al 2008). In an empirical study with UI/UX designers, Roth (2013) identified three types of cartographic interaction primitives: (1) *objective-based*, or the goals that the user wants to accomplish by using the map, including identify, compare, rank, associate, and delineate, (2) *operator-based*, or the functionality that is provided to interact with the map in order to fulfill the user's objective, (3) *operand-based*, or the part of the cartographic interface with which the user interacts. This research focuses on operator interaction primitives, since they describe the

components of an interface that a designer would choose to include in their interface design

(*Table 2.3*).

Operator interaction primitives are further delineated into overarching categories: enabling and work operator primitives (Whitefield et al. 1993, Roth 2013). *Work operators* allow the user to achieve their objective, while *enabling operators* help the user set up and save their work (Roth 2013). When creating an interactive map, the designer must decide which of these operators to implement, which ultimately enables and constrains the dialogue between the user and the map. The interview study aims to understand which operator primitives professional mapmakers typically use and in which scenarios.

	Interaction operator primitive	Description
Work Operators	Pan	Changes the geographic center of the map; adjusts the part of the map that is in the current view, since part of the map is off the screen
	Zoom	Changes the scale and/or resolution of the map; "zoom in" commonly refers to changing from a smaller to larger scale, while "zoom out" refers to changing from a larger to a smaller scale. Zoom can also describe a change in map detail without a change in map scale.
	Retrieve	Requests details about a particular map feature or features of interest, usually through direct manipulation (e.g. clicking on the feature).
	Filter	Identifies features or places on the map that meet one or several conditions, defined by the user. Can be confused with Search, see below for clarification.
	Search	Identifies a specific place or feature of interest on the map. Similar to Filter (see above), with the difference that Search identifies a specific feature, while Filter produces multiple results that match specific characteristic(s).
	Overlay	Adds or removes features in the current map view (e.g. toggle layer visibility).
	Reproject	Changes the map projection.
	Resymbolize	Changes the design of a map, but does not change the map type itself (e.g. a change in color scheme for a choropleth map, while still using the choropleth map type).
	Reexpress	Changes the map representation type (e.g. changes from choropleth to proportional symbol).
	Arrange	Changes the layout of different views in a linked visualization.
	Sequence	Creates a set of related maps that are placed in a particular order (e.g. small multiples showing change over time).
	Calculate	Computes new information about map features (e.g. calculates new statistics).
Enabling Operators	Import	Loads a new dataset or map to the current map view.
	Export	Pulls out geographic information or a map created by the map interface to be used in different map setting or interface.
	Save	Conserves the current state of the map, including its associated geographic information and/or the current system status.
	Edit	Alters the underlying geographic or attribute information of the map.
	Annotate	Allows the user to add text or graphics to the map interface.

Table 2.3: The cartographic interaction operator primitives, adapted from Roth 2013.

While operator primitives enable the user to interact with a map, how do users actually know that interaction is possible? The interface design must also include clues about which parts of the map are interactive and how the user should interact with it, known as *affordances* (Poplin 2015). Affordances indicate to the user that interaction with a particular part of the

interface is possible and implies the type of functionality provided. The corresponding notion

of *feedback* immediately indicates to the user the result of the interaction, i.e., if it was successful

or if it failed (Norman 1988). More research is needed to specifically look at the use of

affordances and feedback in interactive maps, particularly when designed for mobile.

Section 2.2.4: Usability engineering and general web conventions

While it is important to look at the UI/UX design considerations that are specific to

interactive maps, it is also helpful to examine the design of web interfaces generally. The field

of usability engineering (UE) has long influenced the design of digital interfaces and the

accompanying creation of a successful user experience (Hassenzahl 2014). Such insights from

UE increasingly are translated to the cartographic context (Robinson et al. 2005; Haklay 2010;

Roth et al. 2015).

In agreement with the insights from UCD in Section 2.1, UE emphasizes the

importance of understanding the user when designing an interface. UE also encourages

employing *heuristics*, or general rules of thumb, both when designing and evaluating an interface

(Nielsen 1992). Shneiderman and Plaisant (2010: 70-71) offer Eight Golden Rules of interface

design, a useful heuristic framework building on other heuristic taxonomies that is specifically

tuned to web interface design (see Table 2.4).

Rule	Description
Strive for consistency	The interface should have a cohesive look and experience throughout. This includes consistent terminology, color, layout, fonts.
Cater to universal usability	The interface should adapt to different user types, from beginner to expert, including different ages, disabilities, and technological knowledge.
Offer informative feedback	When the user completes an interaction with the interface, the system should provide a response to the user to acknowledge the result of the interaction.
Design dialogs to yield closure	A sequence of actions should have a clear beginning, middle, and end, and inform the user when they have completed the sequence.
Prevent errors	The interface should be designed such that users are not able to commit serious errors. If a user does make an error, the interface should offer a simple solution for how to correct it.
Permit easy reversal of actions	The interface should allow for an action to be undone.
Support internal locus of control	Users, especially experts, want to feel like they are in control of the interface and that their actions produce the intended results within the interface.
Reduce short-term memory load	Interfaces should not force users to remember large amounts of information when moving between different screens or states of the interface.

Table 2.4: The Eight Golden Rules of interface design, from Shneiderman and Plaisant 2010.

While the Eight Golden Rules cover the most important principles to keep in mind when designing an interactive interface, there are additional design suggestions that are geared to allowing users to quickly find what they are looking for. In his book on effective web design, Krug (2014) emphasizes that web users do not typically thoroughly read web pages, but rather scan then for the most pertinent information. He outlines principles to design web interfaces that enable this type of web interaction; the following can be applied to interactive maps:

1. *Take advantage of conventions:* "When applied well, Web conventions make life easier for users because they don't have to constantly figure out what things are and how they're supposed to work as they go from site to site" (Krug 31). This paper aims to create a list of conventions used by professional mapmakers.

2. *Create effective visual hierarchies:* "A good visual hierarchy saves us work by preprocessing the page for us, organizing and prioritizing its contents in a way that we can grasp almost instantly" (Krug 35). This directly relates to Muehlenhaus's discussion of map composition, as noted in Section 2.2.2.

3. *Make it obvious what's clickable:* "As we scan a page, we're looking for a variety of visual cues that identify things as clickable" (Krug 37). This relates to the discussion of affordances, as discussed at the end of Section 2.2.1.

4. *Eliminate distractions:* "It's probably a good idea to...get rid of anything that's not making a real contribution" (Krug 38). In interactive maps, this can mean only including geographic areas and data that are relevant to the purpose of the web map.

Complicating these principles is the fact that people view the web across different devices and screen sizes. In 2015, 64% of American adults owned a smartphone, almost double the percentage in 2011 (Smith 2015). As a result, effective web design must adhere to *responsive design*, or the set of design principles that allows websites to work properly on a variety of devices (Marcotte 2011). The increased use of mobile devices means that designers must "ensure smooth conversion across different display sizes" and accommodate both older and newer devices (Shneiderman and Plaisant, 9). There are three main principles involved in responsive design: (1) *media queries*, the way that the website code detects the dimensions of the device that the user is using and then adjusts the design accordingly, (2) *flexible media*, or setting the sizes of photos or other media elements as a percentage of the width of the webpage rather than a certain number of pixels, which allows the size of an element to adjust as the screen size changes, and (3) *fluid grids*, the concept that the overarching page layout should change as the screen size changes; for example, a website that has three layout columns on a desktop can adjust to have one column on a smartphone (Tolochko 2015, Roth et al., 2014). While there has been some research on the design of mobile maps (Davidson 2014), more research is needed to develop best practices around responsive interactive map design (Roth 2015).

SECTION 2.3: Interactive Web Map Evaluation

This section discusses the evaluation of interactive maps. It is important to evaluate interactive web maps throughout the design process to avoid creating "a cartographic interface that looks great and works well, but does not support the objectives of the intended end users" (Roth 2013: 85). Section 2.3.1 examines the way in which interface success can be conceptualized, Section 2.3.2 discusses the points in the design process when success should be evaluated, and Section 2.3.3 considers methods for evaluating interface success. In the review, I draw from research and best practices for evaluating interactive maps specifically as well as web interfaces broadly.

Section 2.3.1: What is interface success?

Evaluations are the primary way to determine if an interface is successful in its purpose. During an evaluation, information is collected through observation or other means about the way in which target users interact with and generally respond to the interface (Demšar 2007). The purpose of evaluation is to "provide feedback in software development, supporting an iterative development process" and to "help designers recognize that there is a problem…and plan changes to the correct the problem" (Rosson and Carroll 2001: 227). To this end, what are the characteristics that define interface success that can be measured during evaluation?

To create a successful user experience, designers should consider an interface's *utility*, or usefulness, and *usability*, or ease of use (Furhmann and Pike 2005). According to Nielsen (1994: 24), "utility is the question of whether the functionality of the system in principle can do what is needed, and usability is the question of how users can use that functionality." The

Usability.gov guidelines, adapted from Nielsen, for usable government websites and interfaces lists five measures of usability:

1. *Learnability:* the speed at which an interface can be learned by a user upon first use;

2. *Efficiency*: the speed with which a user can execute desired tasks, after learning the interface;

3. *Memorability*: the ability of a user to remember how an interface works the next time he or she uses it;

4. *Error frequency* and *error severity*: the prevalence of user mistakes, and the degree these mistakes critical impact using the interface;

5. *Subjective satisfaction*: the degree to which a user enjoys using an interface.

While usability measurements #1-4 assess observable barriers that must be crossed to interact with an interface, #5 takes a nuanced look at the user's enjoyment of the experience. Increasingly, satisfaction with a map is related to aesthetics (Roth 2015). As its name implies, the field of UE concentrates on usability measures over utility, but both need to be considered during design.

The guidelines for measuring utility are less robust in the literature, but generally relate to how well the interactive map provides the user with what they are looking to get out of their interaction with the map. Roth et al. (2015) describes two general approaches for measuring utility:

1. *Benchmark tasks*: the ability of the user to complete concrete, discrete tasks using the interface;

2. *Analytical products*: the abstract, open-ended hypotheses (for example) or

   solutions that the user derives from the overall interaction session.

The following sections go into more depth about when and how these evaluations are

conducted.

Section 2.3.2: When are interfaces evaluated?

With an understanding that interface success rests on its usability and utility, I now

turn to understand *when* the evaluation of the interface takes place. According to the UCD

process outlined in Figure 2.2, interaction and usability studies should be integrated into the

design process, and results from the studies should inform further conceptual development,

creating iterative evaluation and revision loops. *Formative evaluation* occurs throughout the

design and development process, informing the project's priorities and design decisions

(Rosson and Carroll 2001). *Summative evaluation* typically occurs at the end of the process to

gauge the overall success of the interface (Gabbard 1999).

Finally, an interface may be evaluated after deployment while it is being actively used,

described here as *post-deployment evaluation*, which can lead to interface improvements even after

it has formally launched (Buttenfield 1999). This feedback can be retrieved in multiple ways,

including interviews and focus groups with users of the interface, continuous user-

performance data logging, online or telephone feedback, and wikis (Shneiderman and Plaisant

2010). Many companies offer continuous user-performance data logging services, called *web*

analytics, to allow web developers to track how users interact with web interfaces. Web analytics

for interactive maps, *map analytics*, are gaining more traction (Veregin and Wortley 2013). For

example, map analytics showed that in the city of Denver, Colorado, users prefer single-topic

maps to map portals with lots of geographic layers and that most map users come to the map to retrieve a specific piece of information and then leave (Timoney 2012). Map developers have increasing access to tools to allow them to see how users interact with their maps, including for specific platforms (e.g., Mapbox mobile apps, https://www.mapbox.com/help/map-statistics/) and for integration with a variety of mapping platforms (e.g., Maptiks, https://maptiks.com/). Monitoring and evaluation during active use allows for continuous interface improvements, though "as user numbers grow, major changes to the interface should be limited" (Shneiderman and Plaisant, 156).

Section 2.3.3: Who evaluates interfaces and how do they do it?

There are numerous methods for evaluating interface success, each with trade-offs according to the stage in the development process, the goals of the evaluation, the type of feedback the evaluation provides, and the cost of conducting the method (Buttenfield 1999; Robinson et al. 2005). Roth, et al. (2015) argue that the best way to describe evaluation methods is to look at the person performing the interface evaluation, and that different methods are better suited to different kinds of interface evaluators. They go on to organize evaluators and their related methodologies into three main categories:

User-based evaluation methods rely on feedback from current or potential users of the interface. It is always preferable to include input from the users themselves, as they are the ones who will actually use the map interface and may have feedback that the map designers or outside experts would overlook. User-based methods include participant observation, surveys, interviews, focus groups, card sorting, think-aloud studies, and interaction studies. Nielsen

warns, "it is important to reach the people who will actually use the system, not just their managers" (Nielsen 1992: 15).

Theory-based evaluation methods are those that the designers and developers of the interface carry out themselves. These methods include scenario-based design, secondary sources, and web analytics. These methods should be used to complement user-based methods or when access to users is limited.

Expert-based methods involve usability experts in the interface assessment. These methods include heuristic evaluation (e.g., the Eight Golden Rules discussed in Section 2.2.4), conformity assessment, and cognitive walkthroughs. The expert performing the assessment should not be a member of the design team, "as it is necessary that he or she has little or no prior knowledge about the interface under evaluation in order to provide a fresh and unbiased perspective" (*ibid.*).

In an ideal UCD process, multiple methods are used to evaluate a map interface's usability and utility, and the evaluations take place throughout the design process (formative evaluation), after the design process (summative evaluation), and throughout continued use of the map (post-deployment evaluation). Importantly, map designers must maintain "a willingness to be flexible and open in the development process" in order to allow the results of the evaluations to influence their implementation of the map design (Shneiderman and Plaisant, 99).

CHAPTER 3: METHODS

Section 3.1: Participants

To answer the three research questions—and relate the reviewed state of science to practice—I interviewed seventeen professionals who make interactive web maps about their workflows and practices for creating and evaluating maps. All participants met four criteria for participation: (1) must have designed or supervised interactive web map design within the last year; (2) must have at least one year of professional experience in the creation of interactive web maps; (3) must not be academic faculty (although teaching as an adjunct faculty member or teaching in informal settings was accepted if complemented with applied design experience); and (4) must be at least 18 years of age. Participants came from a variety of fields, including government, journalism, and web technology, among others. I recruited individuals via email, with their email address acquired either from publicly available websites, from previous communication with them, or through mutual contacts. The interviews aimed to gather the subjective opinions of the individuals throughout their professional experience, not just their current position.

Participants were asked to provide information about their educational background and current professional position. All participants (17/17) had completed at least one bachelor's degree, and nine participants had completed a graduate degree (eight completed a Master's, one completed a PhD). The most common area of study for the most advanced degree was in geography or a related field (7/17), followed by design or a

Number of people in organization	Number of participants
1-10	2
11-50	4
51-200	3
201-500	1
501-1000	0
1001-1500	3
1500+	4

Table 3.1: Sizes of organizations where participants are currently employed

related field (4/17). The most common words used in participants' job titles were journalist/editor (5/17), cartographer (4/17), designer/design manager (4/17), followed by developer (2/17) and data (2/17). Participants work at organizations that range widely in size, as shown in Table 3.1.

Section 3.2: Materials and Procedure

Each interview used a semi-structured protocol following similar expert-based cartographic studies (e.g., Robinson 2009, Mead 2014, Roth 2015). The semi-structured interview format allowed me to formulate a list of structured *key* questions, as well as a set of follow-up *probe* questions for discussion as needed (Robinson 2009, Roth et al. 2013). The interviews were conducted via Google Hangouts and/or telephone. The first two interviews served as a pilot for the questions, some of which were rephrased after the initial interviews.

The interview proceeded in five sections: (1) background (i.e., biographical information, reported in Section 3.1); (2) workflows and processes (including typical workflows for creating an interactive web map and how workflows were managed within the team); (3) interactive web map best practices (including questions about data, representation, and interaction design); (4) interactive web map evaluation (including discussion of what makes an interactive map successful and how the interviewee performs evaluations of their own maps); and (5) concluding thoughts (including probes about the type of research the participant wishes was being conducted). The interview protocol was designed to last one hour. Table 3.2 shows the key and probe questions for each section of the interview protocol.

Background	
Key	What is your highest level of education? What degree do you have?
Key	What is the size of the company or organization where you work?
Key	What is your official job title?
Key	If you could change your job title to more accurately reflect what you do, what would it be?
Web mapping workflow & design process	
Key	What is your typical workflow when creating an interactive map?
Probe	How do you determine the needs and requirements of a new project? How do you scope out the project?
Probe	Do you create mockups, wireframes, or prototypes of your map as part of your process? How?
Probe	What is your process for implementing the design?
Probe	Do you have a process for handling debugging of the interactive maps you design?
Probe	What are your pain points when designing an interactive map?
Probe	When have you deviated from your typical workflow and why?
Probe	If you had unlimited time and resources, what would you do differently in terms of your workflow or process for creating an interactive map?
Key	How do you manage workflows internally within your team?
Probe	How do you collaborate with others within your organization in creating interactive web maps? What different roles do people have on the team?
Cartographic conventions and best practices	
Key	Do you think that interaction design / interactive map design is coalescing around a set of conventions or best practices? What are they?
Key	What do you think makes an interactive map well designed?
Probe	What about page layout, do you have any best practices around fitting an interactive into a larger interface?
Key	Do you have any best practices you would recommend about working with data?
Probe	How does data inform your design?
Key	What types of interaction do you usually provide on maps? When do you decide to provide certain types of interaction but not others?
Probe	What about for panning and zooming?
Probe	Do you have any recommendations for designing information popups or panels? When do you decide to include something like that in your design?
Probe	Do you follow any design conventions around letting the user search for and filter map results?
Probe	Are there other types of interaction that you provide for the user that we haven't talked about yet?
Probe	Are there any design conventions you've been seeing that you disagree with?
Interactive web map evaluation	
Key	What do you think makes an interactive map successful?
Probe	Do you consider how easy it is to use a map? What makes a map easy to use?
Probe	Is usefulness or utility more important than usability? What makes a map useful?
Probe	Is there anything else you consider in the success of a map other than usefulness/ease of use?
Key	Do you evaluate if your interactive map is successful? If so, how do you evaluate it and who do you involve in the evaluation?
Probe	Do you solicit feedback about the effectiveness of your map? Who do you solicit feedback from?
Probe	Do you integrate this feedback back into the design or implementation? How?
Probe	When in the design process do you perform evaluations?
Probe	What would you like to integrate into your evaluation process if you had unlimited time and resources? What part of your current evaluation process would you change?
Conclusion	
Probe	Is there anything else about interactive maps you think I should know about that we haven't covered?
Probe	Is there something that you wish people were doing research about? Are there questions about interactive mapping that you wish you knew the answers to?

Table 3.2: The interview protocol

Section 3.3: Qualitative Analysis

I applied tenets of qualitative data analysis (QDA) methods to analyze the interviews. QDA is used to code and interpret qualitative information in a systematic way (Caudle 2004). To perform QDA, I transcribed the recorded interviews and then unitized them by statement. A coding scheme was then applied to these unitized statements to describe and categorize the content to reveal insights and patterns. If one statement can be categorized by two different codes, it was given both codes. Although redundant coding is recommended in QDA to develop inter-coder reliability, I did not redundantly code the transcripts due to limitations in project resources.

The audio of the interviews was recorded using QuickTime on a laptop computer. I then transcribed each interview and coded the unitized statements according to a 21-part coding scheme derived from the Chapter 2 literature review (Table 3.3).

Web mapping workflow & design process		
W1	Needs assessment / Requirements Analysis / Work Domain Analysis	Initial research into the topic being mapped or the general requirements of the project
W2	Conceptual development	Written description of desired features
W3	Prototyping	Creation of working models of the application
W4	Implementation	Incorporation of changes discovered during the evaluation stage or general polishing of the application
W5	Debugging	Ensures stability of the interactive web map
W6	People workflow	Non-technical aspects of the design process, including team roles, client relations, project management, communication
Cartographic conventions and best practices		
Donohue interactive mapping workflow		
C1	Data design	Collecting, preparing, exploring, manipulating, editing, or linking data
C2	Representation design	Symbolization, map type, map layout, map composition, user interface
C3	Interaction design	Enabling the "conversation" between the user and the map; includes interaction primitives, e.g. pan, zoom, retrieve, overlay, search, filter
Other best practices		
C4	Responsive / mobile map design	The design of maps for various screen sizes
Interactive web map evaluation		
What is being evaluated?		
E1	Usability	Ease of use of the interactive web map
E2	Utility	Functionality or purpose of the interactive web map
E3	Aesthetics	Beauty of the interactive web map
When is it being evaluated?		
E4	When	Statement about when an interactive web map is evaluated. Includes: • Formative evaluation: Feedback is gathered before the map has been built • Summative evaluation: Feedback is gathered at the end of the map creation process • Post-deployment evaluation: Feedback is gathered after the map has been released to active users
How is it being evaluated?		
E5	Expert-based	Evaluation methods that involve usability or domain experts, including colleagues
E6	Theory-based	Evaluation methods that the designers and developers carry out themselves
E7	User-based	Evaluation methods that rely on feedback from current or potential users

Table 3.3: The coding scheme

CHAPTER 4: RESULTS

In this chapter, I present the results of the interview study with seventeen professionals who make interactive web maps. The results are presented in three sections, reflecting the three sections of the above literature review and the three sections of questions asked during each interview. Section 4.1 presents the results of discussions about map design and development workflows, Section 4.2 presents the results of discussions about best practices and conventions for interactive web map design and development, and Section 4.3 presents the results of discussion about the evaluation of interactive web maps. The most frequently discussed category of codes was regarding best practices and conventions, with a total of 729 statements, followed by workflows (extensiveness = 419) and evaluation (extensiveness = 301). Table 4.1, below, presents the basic statistics of extensiveness, i.e. how many participants made a statement regarding that code, and frequency, i.e. the total number of statements that received that code. Codes marked with an asterisk (*) were added during the transcription process and will be discussed in their respective sections.

Description	Code	Extensiveness	Frequency
Workflow	**W**	**17**	**419**
Needs assessment	W1	15	101
Conceptual Development	W2	4	12
Prototyping	W3	16	65
Implementation	W4	13	25
Debugging	W5	8	18
People workflow	W6	17	198
Best practices	**C**	**17**	**729**
Data design	C1	17	145
Representation design	C2	17	155
Interaction design	C3	17	262
Responsive/mobile design	C4	14	46
Simplicity*	C5	13	30
Other best practices*	CX	15	91
Evaluation	**E**	**17**	**301**
Usability	E1	14	44
Utility	E2	16	44
Aesthetics	E3	9	13
The "when" of evaluation	E4	17	57
Expert-based	E5	14	41
Theory-based	E6	7	9
User-based	E7	16	56
Informal evaluation*	E8	10	16
Client-based*	E9	5	21
TOTAL		13.5	2898

Table 4.1: The coding results. Codes marked with an asterisk (*) were added during the transcription process.

SECTION 4.1: The Design and Development Process

The first section of codes pertains to discussions of interactive web map design and development processes and workflows (W), and comprises six codes: (W1) needs assessment/requirements analysis, which includes discussion of initial research into the topic being mapped or discovering project needs; (W2) conceptual development, which includes

discussion of written descriptions of required features for the interactive web map; (W3) prototyping, which includes discussion of static and partially functioning mockups of the interactive web map; (W4) implementation, which includes discussion of polishing of the application after the prototyping stage, sometimes based on feedback; (W5) debugging, which includes discussion of ensuring stability of the interactive web map; and (W6) people workflow, which includes discussion of non-technical aspects of the design process, including team roles, client relations, project management, and communication and collaboration. Codes W1-W5 each represent stages in the UCD workflow, while W6 captures aspects of the design and development workflow that do not fall within the UCD framework. The evaluation stage, as part of the UCD workflow, is presented separately in Section 4.3. The most discussed codes were people workflow (extensiveness = 17/17, frequency = 198), needs assessment (extensiveness = 15/17, frequency = 101), and prototyping (extensiveness = 16, frequency = 65). Implementation received less attention (extensiveness = 13/17, frequency = 25), while debugging and conceptual development were not discussed very much (extensiveness = 8/17, frequency = 18 and extensiveness = 4/17, frequency = 12, respectively).

Interestingly, the most frequently discussed aspect of the interactive web mapping workflow was people workflow (W6) rather than technical stages of the map design process (W1-5). Statements about people workflow were divided into four categories: team roles, project management, team communication and collaboration, and client relations, which will be discussed in the following paragraphs.

All participants discussed the roles that they and their colleagues fulfill during typical web map design and development. While designer and developer were the most commonly mentioned roles, participants mentioned a wide variety of additional team roles, including:

manager, data analyst, editor, customer support, QA/QC tester, cartographer, project manager, business development, copy editor, researcher, front-end developer, back-end developer, journalist, engineer, creative director, visual designer, data engineer, data scientist, systems administrator, devops, product manager, statistician, writer, and user experience. There was disagreement around how many roles a person should be expected to fill, with one participant saying, "you can't have a developer do everything like the design, the data and everything." Another participant stated that at their workplace, the number of roles that each person fills depends on the project, and that "the bigger the project, the more likely we are to have specialized roles, and the smaller the project the more likely it is that it's just one person doing it." One participant expressed frustration with the lack of specialized roles at their current workplace, but also emphasized that, "being involved in those roles will teach you a lot along the way." One thing is clear: there are a wide variety of roles that contribute to the successful implementation of interactive web maps.

Fifteen of the participants discussed the way that they and/or their workplace manage projects. Several participants discussed the importance of taking a step back from day-to-day project details to "look at a project from a higher level." One participant discussed that at their workplace, "every quarter...we have a set of goals and we have projects aligned around those goals," and then they have an "internal tracker" to keep track of who is responsible for which tasks. There was a broad distinction between workplaces that have formal project management systems in place and those that do not. Participants that characterized their workplace as lacking a formal project management system often described their workflows as "organic" and "iterative." One participant said that the lack of "framework or really structure...is a product of that kind of culture where you're focused on the deadline and...what's right in front of you."

Another participant said of their workplace, "it feels really organic, it's not like that system where you go check things off." On the other hand, four participants identified that their workplace follows a formal project management system, including instances of agile project management. One participant talked about their preference for working on a team with a project manager, who "can dole out what's happening and you do what you're supposed to do." Another participant described the way their workplace organizes tasks according to the Kanban methodology, in which "things are divided up into really bite-sized action items with people assigned to them and a checklist for completing them. Then, as you complete one task, you pass it along to someone else for review and then someone else for final approval, until it gets deployed to the final platform." Alternatively, one participant describes a more deadline-driven agile project management system, "which essentially allows us to plan for the tasks that we need to deliver every two weeks," rather than addressing each task as it arises. Overall, different systems seem to work well for different people, and there is no single prescribed methodology that works across the board.

Sixteen of the seventeen participants discussed some form of communication and/or collaboration with colleagues. One participant emphasized the importance of open communication, both internally and with clients, stating, "the more people are talking, the more expectations are met." Several participants emphasized "constant communication" with coworkers, in a variety of ways, including via instant messaging platforms like Slack, code repositories on GitHub, close proximity in the office, regular meetings, and phone calls. A few participants discussed the challenges of working remotely and the increased need for clear communication lines. There was also a pattern of participants discussing the collaborative nature of their workplaces. One participant emphasized, "our team is very, very collaborative

and there is a sense of shared ownership...There's definitely efficiency that happens just from working with the same people and getting to know them." Several participants that talked about the collaborative nature of their workplace also discussed the relatively flat hierarchy of the team, which encourages people to ask their peers for help when needed. Thus, there appears to be a move towards office cultures of open communication and honesty.

Seven of the participants discussed the nature of working with clients, including the challenges of creating interactive maps for clients. These challenges can include a lack of clear requirements from the client about the functionality they want in the web map. One participant observed, "I don't think clients know what they want and it's hard to give somebody something they want when they can't articulate it," and went on to discuss the difficulty in designing in this context. Clients may also push for more work than the parties initially agreed to. One participant stated, "clients will kind of report a design bug but it's really them wanting another feature" and another participant stated that some clients "want two, three, four, five, ten different revisions" of an interactive map, after initially agreeing to only one round of revisions. On the other hand, participants also discussed strategies for managing client relations, which boil down to good communication. At the beginning of a project, this can mean requesting that the client send examples of maps or work that they like. During the project, this can mean soliciting a specific type of feedback and asking that the client limit feedback about other aspects of the project at that moment. One participant highlights the importance of asking for clarification from the client if their needs or desires are unclear. Though the general tone of conversation regarding clients seemed to be tinged with frustration, participants also recognized that their relationships with their clients ultimately make their products better.

Moving from the people workflow code to the UCD workflow, the most frequently discussed code was needs assessments (W1), the initial research into the topic being mapped or the requirements of the project. Discussion tended to center around the importance of conducting initial research and exploring initial datasets before delving into map design and development. Nonetheless, needs assessments could also include reading about cartographic best practices, conducting user research, having discussions with clients to understand requirements, determining the functionality that will be included, looking at competitors, researching the topic being mapped, scoping out the story that will be told, and defining the user problem. Several participants mentioned the need to identify the goals of the project as a first step in their workflow. Different participants discussed different types of goals for their maps, highlighting a fundamental difference between those projects where an interactive map is the known solution and those where an interactive map is one possible way to fulfill the needs of the project. Regarding the latter, one participant stated, "the workflow doesn't start with the interactive map, the workflow starts with us figuring out the story. It's figuring out all of the stuff in advance of the map that dictates what kind of map we're going to end up making and how." It seems fitting that the most discussed part of the workflow was the first step, showing that participants take the preparation for creating an interactive map seriously.

Statements about prototyping (W3) were quite common, with all but one participant discussing this topic. Participants distinguished between whiteboarding (rough sketches on paper or a whiteboard), wireframes (basic visual outline of the map and page layout), mockups (more refined graphic with visual style), and prototypes (initial interactive application). Participants typically only go through one or two of these parts of the prototyping stage, and no participant went through all of them. However, most of them talked about the iterative

nature of creating prototypes in order to get feedback to then improve the prototype. Prototyping was discussed as an important step in the interactive mapping workflow both for internal use as well as to communicate with clients. For internal use, one participant talked about how their team always has "a live prototype running somewhere so that anyone on the team can check to see what the current state of the map or the application looks like." Another participant pointed out that mockups are "for the client to get a feel for the product and know what they're getting, know what they're paying for, and for our internal use as a blueprint so that the developers know what they're building." Another participant discussed their use of an interactive mockup tool that allows the client to simulate the interactions of the interactive map will ultimately have rather than simply static images.

Several participants discussed the importance of speed over pixel-perfect design when prototyping. One participant expressed that they have "run into problems when wireframing ceases to become a rough and quick thing and when wireframes become too sophisticated." Another echoed this sentiment, saying that a prototype "may be ugly, but it's something that you can start with and build upon." There was disagreement regarding the amount of time that should be spent at each point in the prototyping phase, with some participants focusing more on wireframing and mockups while others jump into code and interactive prototyping as soon as possible. Those participants that emphasized prototyping with code discussed the advantage of prototyping in the final tool that the map would ultimately be built with so as not to waste energy in the prototyping stage. One participant expressed the importance "to have that prototype be something that you can turn into the actual published graphic instead of, I did a beautiful wireframe, let me go back and start at the beginning and actually build this thing...I tend to do a lot of prototyping in the browser." There seemed to be a general trend towards

moving to an interactive prototype as quickly as possible to ultimately save time in the final development of the map.

The three workflow codes that were least discussed were conceptual development (W2), implementation (W4), and debugging (W5). It was difficult to account for implementation when applying the codes to the interviews, as there was not a clear line between prototyping and implementation. Ultimately, implementation refers to the final design, which was often discussed in terms of "refining," "cleaning up," or "polishing" from the prototyping stage. Less than half of participants discussed debugging. The majority of those that mentioned debugging talked (or joked) about their lack of a formal process for debugging, with one participant claiming that "partly the reason we don't have much of a QA [quality assurance] process is that we don't really have much time to fix bugs anyway." However, one participant described a rigorous protocol for debugging and maintaining clean code, which includes unit tests and continuous integration. Conceptual development was not widely discussed, perhaps because people tended to focus more on the details of the initial needs assessment rather than a written requirements document.

In general, when participants were asked about their typical workflow when creating an interactive web map, many responded that they do not have a "typical" workflow. They emphasized the importance of assessing the particular needs or goals of the project, as well as exploring the data to be mapped. One participant aptly summed up the balance of thinking about the technical implementation with bigger picture goals: "the technical way we might implement it is always somewhat near the surface, but the needs of the map are kind of an equal weight in the decision-making process as we start to design and start to build."

Throughout discussion of workflows, participants inevitably mentioned specific technologies. I tracked how many participants made at least one mention of a particular technology (or group of related technologies), as seen in Table 4.2. It is important to note that I tracked a *mention* of a particular technology, not necessarily an explicit statement of using or endorsing the technology. These are a diverse set of technologies, many of which include both client-side and server-side components. They can be divided broadly into two categories: those that are used for data, design, and/or development, and those that are used for organizational or communication purposes. I am not reporting on technologies that were only mentioned by one participant. It is also important to note that discussion about Google Maps typically centered around the ubiquity of this platform in web mapping, not as a tool for designing and developing interactive web maps.

Technology name	No. of participants who mentioned
Mapping technology	
Google Maps / Google Geocoder	12
D3	10
QGIS	9
CartoDB	8
Mapbox (includes Mapbox Studio Classic, Mapbox Studio, and MapboxGL)	7
Leaflet	6
PostGIS / Postgres	5
JavaScript	5
WebGL	4
ArcGIS (includes mentions of ArcGIS Server)	4
GDAL / ogr2ogr	3
SQL	3
Makefiles	3
Photoshop	3
Illustrator	3
Vector tiles	3
R	2
TopoJSON	2
TileMill	2
Turf	2
Microsoft Excel	2
Organizational / Communication Technology	
GitHub / git	12
Slack	8
Google Analytics	2
Basecamp	2

Table 4.2: Commonly mentioned tools and technologies

SECTION 4.2: Cartographic Best Practices and Conventions

The second section of codes captures discussion of professional cartographic practices

for interactive maps (C), and comprises six codes: (C1) data design, including discussion of

collecting, preparing, exploring, manipulating, editing, or linking data; (C2) representation design, including discussion of map symbolization, typography, layout, and composition; (C3) interaction design, including discussion of the map user manipulating the map interface and interaction operator primitives; (C4) mobile / responsive map design, including discussion regarding the design of maps for different devices; (C5) simplicity, including discussion about the necessary versus unnecessary components of an interactive map; (CX) additional best practices, encompassing any interactive map best practice or convention that does not fall into any of the aforementioned categories. Codes C1-C3 represent components of Donohue's (2015) web mapping workflow and code C4 addresses the rise of responsive design discussed in the above literature review. Code C5 was added during the transcription process, as simplicity in web map design was a best practice repeatedly mentioned by many participants. Code CX also was added during the coding process in order to capture best practices that did not neatly fit into any of the aforementioned codes.

Every participant discussed each of the components of the Donohue web mapping workflow at least twice. The most frequently discussed code was interaction design (extensiveness = 17/17, frequency = 262), followed closely by discussion of data design and representation design (extensiveness = 17/17, frequency = 145, extensiveness = 17/17, frequency = 150, respectively). Mobile/responsive design, simplicity, and additional best practices were discussed less frequently than the three primary codes, but were still mentioned by a majority of participants (extensiveness = 14/17, frequency = 46; extensiveness = 13/17, frequency = 30; extensiveness = 16/17, frequency = 96, respectively).

Section 4.2.1: Interaction Design Best Practices

While nearly all participants offered general statements about interaction design best

practices (16/17), most of the discussion focused on individuals or groupings of interaction

operator primitives (see Table 4.3). The most commonly discussed interaction operator

primitives were pan and zoom, which I analyze together due to the inability to discriminate

statements about map browsing (extensiveness = 17/17, frequency = 65). The next most

commonly discussed interaction operators were retrieve (extensiveness = 15/17, frequency =

62), search and filter (extensiveness = 16/17, frequency = 47; also analyzed together due to

their typical treatment together), and overlay (extensiveness = 13/17, frequency = 24). All

other interaction operators combined were far less common (extensiveness = 8/17, frequency

= 16).

Interaction operator	Extensiveness	Frequency
Zoom / pan	17	65
Retrieve	15	62
Overlay	13	24
Search / filter	16	47
"Geolocate"	5	8
Other interaction operators	8	16

Table 4.3: Coding results of specific interaction operator primitives

In addition to statements about specific interaction primitives, participants also

discussed whether or not to provide interactivity at all on a map. One participant said that it is

important to make sure "that the interactivity is purposeful...the best ones really use

interactivity to their advantage versus just adding interactivity for the sake of adding it." The

intended goal of that interactivity was also carefully considered, with one participant framing it

as two contrasting purposes of providing interactivity: "are we using interactivity to guide you

around, or are we using interactivity to allow you to explore on your own." Many participants

view the purpose of their maps as a more guided experience: "Usually our goal is to clarify...to clarify things and not just throw the reader into it and let them sink or swim." The overall trend is that more interaction should be provided to enable exploration, and interaction should be limited if the purpose of the map is to present a story or to clarify data.

Narrowing into specific interaction operators, participants discussed pan and zoom in two different ways: (1) regarding the general situations in which these operators should or should not be implemented in a web map, and (2) specific ways in which these operators are implemented. Some participants pointed out that pan and zoom should not be implemented in a map when the purpose of the map is to give an overview summary of information, but should be included when the purpose of the map is to allow users to explore the data. Describing one particular project, a participant said, "we decided not to allow [the users] to zoom in on this main map because we want them to focus on the overall comparisons of different countries and not really focus in on one country… but then on the country pages allow them to zoom in more because that's where the more detailed information is presented." Another participant pointed out that it is important to include zoom when different levels of information can be revealed at different zoom levels on the map, an interaction design strategy described in the literature as *semantic zoom* (Harrower & Sheesley 2005). Another participant pointed out that it is important to include zooming when the geography itself would not be visible at a smaller scale (e.g., to view the District of Columbia on a national map of the United States). Regarding election maps, the participant said, "to show precinct-level results, you can do it from far out, you can do it from a statewide perspective, but some of the smallest precincts where most of the people live, and therefore some of the most important precincts are just tiny…so if you don't let a user zoom into those, then the map is really hiding a lot of

that information." Even when panning and zooming is provided, it may make sense to constrain panning and zooming to a finite set of steps depending on the dataset and map purpose. In summary, pan and zoom should be implemented when there is additional information detail that cannot be displayed at the default scale or position of the map.

Participants described two main ways to implement pan and zoom on interactive maps: (1) raster tile-based maps—often described as "slippy" web maps—which provide free panning and zooming for up to 22 zoom scales around the world, and (2) SVG vector maps, which typically allow the user to zoom by clicking on a smaller set of enumeration units to see more detail about the selected unit (however, one participant described making an SVG vector map "slippy"). For slippy maps, several participants warned against allowing the user to zoom with the scroll wheel when an interactive map is embedded on a larger webpage or on a webpage that will be viewed on mobile. One participant described the poor usability of this as "quicksand," wherein the user is scrolling down a webpage until reaching the map, at which point the webpage scrolling is halted by zooming into the map. Two participants described including a "home" button to allow the user to return to the original extent and zoom level of the interactive map. One obvious trend amongst participants regarding zoom is that they overwhelmingly used the term "zoom level" when discussing map scale.

Regardless of the reasoning for implementing or deactivating pan and zoom on an interactive map, several participants mentioned that clients and users have come to expect slippy map interactivity on maps. One participant discussed a situation when they implemented a vector-based interactive map in which clicking on a state zoomed the map to see counties, and clicking on counties zoomed the map to see census tracts. However, the client for that project did not like the implementation, insisting on the familiar implementation

of pan and zoom found on slippy maps. Discussing this client feedback, the participant said, "I think most people expect that now, I can pan and zoom however I want. I think Google has made that kind of the new norm. So it's not really great to try to do something else." Another participant echoed this sentiment, saying that with one of their clients, "if you don't have zoom and pan, they're like, 'Where's the zoom and pan?' Even if they're just looking at something that doesn't require it." The slippy map may be a convention that has become so widely implemented that many users do not like interactive maps that do not have the functionality, even if it is not strictly necessary for the purpose of the map.

Retrieve was the second-most discussed interaction operator. Aligning with the conversation about when to implement panning and zooming, participants asserted that the goal of the interactive map should determine if retrieve should be implemented. Four participants argued that if the purpose of the map is to show overall trends or to provide a guided experience to the user, then the retrieve operator is unnecessary. One participant said, "having some crazy kind of tooltip hover thing where you dive really deeply into the information could actually distract from the larger goal because it doesn't communicate this narrative," while another said that their organization refrains from including "a lot of clicking on icons to reveal information like tooltip type things...what we're trying to do is make the experience more directed." On the other hand, many participants asserted that if the purpose of the interactive map is exploration, then the retrieve operator is extremely important. Additionally, one participant pointed out that this type of interaction has become so commonplace that, "people sort of expect now when they see a map...to be able to see the data underlying each individual shape." Thus, several participants revealed the same internal

conflict about retrieve as pan and zoom: they believed the use of the retrieve operator should be limited, but may not act on this belief because users expect this type of interaction.

There was disagreement among the participants about the way to implement the retrieve operator, with some stating that they disliked information popups that display on top of the map, some stating that they preferred them, and some not stating a preference one way or the other. One participant suggested that whether or not to use a popup on top of the map versus a panel separate from the map depends on the amount of information being displayed, stating, "if it's a lot of information and it's very busy, it shouldn't go in a popup right there where the mouse is, but on the top, to the side in existent space." Another participant, however, said about panels: "I'm not a humongous fan of them…I don't really like things that start to crowd up and make the map more complicated." Participants agreed that it is not advisable to include charts or graphs as part of a popup or tooltip that hovers on top of the map, though it is generally acceptable to have a chart to the side of the map that updates as the user interacts with the map. A couple of participants went further, talking about maps where the chart or panel updates to reveal different levels of information at different scales of the map. For example, at the state level, a corresponding chart reflects state-level data, and at the county level, the chart reflects county-level data. There was disagreement on the exact definition of and distinction between popups and tooltips, and based on the interviews, it was not necessarily clear what type of retrieve design (popup or panel) participants were describing. Several participants cautioned that designers should be intentional about the amount of information provided by the retrieve operator, with one participant stating, "it's important to not pile in a ton of information." Another participant pointed out that cartographers should limit the number of trailing numbers after a decimal point (e.g., 24.3 versus 24.333333). Two

participants discussed designing interactive maps for clients such that the client can configure their own popups, determining the attributes they want to include in an information panel. Many participants discussed the difficulty of implementing the retrieve operator on mobile devices, which will be examined further in Section 4.2.4.

The search and filter interaction primitive operators were analyzed together, due to the typical inability to distinguish which one a participant was talking about. Search and filter were discussed both in terms of when and why it is appropriate to include this functionality on an interactive map and also in terms of specific examples of how to implement them. One participant suggested that search and filter should be included on a map when the purpose of the map is exploration of data or to allow the user to find a specific location, while another participant believed that searching allows the map to "show data to a user on an individual, personal level." Another participant asserted that these operators are important to include when a user would have difficulty finding a location through pan and zoom alone. On the other hand, there was some pushback against including search and filter if the purpose of the map is to tell a story, with one participant stating that "if you need to filter...to see the point that we're trying to make, then we're hiding that point behind this interaction that most people won't actually do." Another participant cautioned against including search and filter as the default, emphasizing that it can be too open-ended: "A lot of times when I see a map with a search bar, I just don't know what to search." It is important to note that when participants discussed the use of search and filter, they referred both to geographic information (i.e., searching for a specific location) and attribute information (i.e., searching for a property of locations).

Additionally, participants discussed design considerations for implementing search and filter. Several participants mentioned the need to decide which data layers can be searched and at which resolution (e.g., ability to search for an address versus a city name). One participant mentioned the difficulty in indicating to the user what data layers can be searched, while another participant recommended providing suggestions or examples to the user of what can be searched via visual affordances. Another participant discussed dynamic searching and filtering, wherein the map immediately updates as the user inputs filtering parameters. A third participant suggested that the map can also serve as the filtering mechanism itself, wherein "the map's extent also filter[s] what's happening in another view," such as a linked scatterplot. Another participant suggested saving a specific search or location in the website URL to allow the user to share the created view with others. The same participant also suggested filtering by enumeration unit (e.g., if the data exists at the county level, allow the user to filter the data based on state). Although these suggestions were not widely echoed across participants, they represent potentially useful design solutions and generally are supported by the literature on visual affordances in interface design (Norman 1988) and the importance of dynamic queries for the interpretation of large datasets (Andrienko et al. 1999).

Notably, there was a subset of participants (extensiveness = 5/17) who discussed "geolocate" as an essential interaction operator to include on interactive maps. This functionality is a spatial search that allows the interactive map to identify a user's current location. Participants discussed the importance of this functionality, "especially if you're trying to relate the content to the user." It is also important for mobile, as one participant pointed out regarding smart phones, "location is so much more, it's kind of built in in a way that it's not built into the web."

The overlay operator was typically referred to in terms of "turning things on and off" or "toggling layers." Similar to other interaction operators, participants see this operator as important to include if the purpose of the map is exploration, with an additional purpose of allowing for comparison of different map layers for context. Several participants discussed enabling the user to overlay their own information, either by uploading a geographic file or by digitizing on top of the map. One participant mentioned the ability to use overlay to visually filter map results, e.g., by drawing a circle on top of the map and only showing specific data within that circle. A second participant cautioned against allowing for the user to add too many overlapping overlays "because it's just too much for the viewer or the user to interpret." Although overlay was discussed by a majority (13/17) of participants, it was not emphasized as an essential component for interactive maps.

The remaining interaction primitive operators were discussed far less than the aforementioned operators. Sequence was discussed by four participants as a way to look at "the evolution of the data or other time-based analysis." Two participants mentioned the use of resymbolization between a cartogram and "the actual map," with one of those participants specifically mentioning the increase in use of block equal-area cartograms in interactive news media. Two participants discussed designing map interactions to prevent the users from creating an ugly map, with one stating that in one instance they allowed the users to dynamically change the representation of the map by changing opacity or the saturation of layers. Another participant discussed the functionality of tilting the map when there is three-dimensional information such as building height. One participant was working on an interactive map that allows users to enter and explore buildings, and they discussed the difficulties of indicating to the user the ability to move inside/outside buildings and up/down

different floors. One participant said that they wished they could spend more time working on reproject, allowing the map projection to change depending on the zoom level. Although discussion coalesced around a core set of operators (pan, zoom, retrieve, overlay, search, filter), it appears there is an emerging trend of allowing more unique types of interaction, and many participants discussed the general move towards advanced interactive functionality. However, participants warned that functionality should only be included when necessary, which will be discussed further in Section 4.2.4.

Section 4.2.2: Data Design Best Practices

All participants discussed the importance of data in the interactive web map creation process, with an average of 8.5 mentions per person. The discussion of data often arose in the initial line of questioning about workflows, before the interview reached the questions specific to data design best practices. Many participants mentioned that their workflow begins with data, emphasizing the importance of gathering and exploring data upfront before delving into map design and development. As one participant stated, "my workflow is pretty much gathering the data and then understanding what we're trying to do." Another participant stressed the time intensiveness of working with data by illustrating, "one of my professors told me that 90% of my time in geography was going to be data wrangling, both acquiring and cleaning, and maybe 10% was going to be actual map design, and that's totally still the case." Other participants highlighted that the map design process always begins with data, because "with data that's not interesting, it's hard to make a successful map" and "at a certain point you can't gloss over crappy data...[the map] has got to be engaging at its core and the core of all this is data." This section reviews participants' comments and best practices around the

acquisition, exploration, analysis, processing, verification, and storage of geographic and attribute data, as well as a discussion of how data informs map design.

Some participants discussed the opening stage of data acquisition, although it was not discussed extensively throughout all interviews. One participant stressed the importance of "having your go-to data sources, like Natural Earth, or…using Overpass Turbo and OpenStreetMap, knowing where you can go to get what you need." Several participants mentioned that clients provide them with data, which is often mixed with public data from sources like the Census Bureau or OpenStreetMap. One participant lamented the process of acquiring data, stating that "procuring it…is always a massive pain point." The same participant also gave good advice for acquiring geographic data, saying that it is best to find geographic datasets where "all of the geometries across all the different levels of data are coterminous," for example the U.S. Census Bureau's Cartographic Boundary Files. Overall, data acquisition was not a focus of the interviews, though it is clearly a necessary step in the map creation process.

Several participants discussed the importance of exploring and analyzing the data. One asserted that the purpose of this exploration is "to see what the story is." Two participants discussed the need to examine the data upfront to see if it will serve your needs and to "quickly assess if you're going to have to go to other data sources." One of these participants stressed that "you can't overlook the power of a spreadsheet" for initial exploration of a dataset. Participants explore the data to get an initial sense of the distribution and the type of data (e.g., numerical, categorical). One participant described the way that they explore a large dataset, stating that, "if it's millions of records I'll just take the top 10,000 and look at those…getting an initial sense of what the distribution looks like is really important." Although

participants discussed the importance of exploring data, they generally did not list the criteria used to assess if the data is appropriate for their project.

Discussion about data processing centered on a push to automate data processing workflows, with five participants endorsing an automated workflow as a data best practice. An automated workflow for converting raw data to usable data for a web map serves several purposes: (1) it is easier to update the map when there are new records; (2) it is easier to identify and correct data errors when using a script; and (3) it makes the data processing workflow accessible to others. Several of these participants use *makefiles*, or files that contain a set of executable directives, to automate their workflows. One participant touts the advantages of makefiles by stating, "otherwise I would have to be recording the whole thing just in my own notes anyway so why not make it my notes of what I did, but be in a machine-readable way that can be replicated." Many participants also stressed the importance of not altering the raw data, with one asserting that this is "rule number one of any data processing." This emphasis on automated workflows for data processing seems to be an emerging cartographic best practice.

The interviews revealed two ways that participants check their data for errors: (1) confirming data validity with experts or clients; and (2) spot checking to make sure that the representation on the map matches the underlying data. Regarding the former strategy, one participant warned of the need to make sure the data is truthful, asserting, "if it's an area that you've got no expertise in, you need to make sure you talk about it with someone who has some expertise." Once the data is mapped, several participants mentioned spot checking the data "against the raw data to confirm that we didn't somehow do the map wrong somewhere along the way or we're not coloring something in the way it shouldn't be colored." Although

several participants discussed the importance of checking data, it was not a very widely

discussed topic, and participants did not go into specific detail about what they look for when

checking data.

There was much discussion on the way that data for interactive maps is stored. Many

participants discussed the relative merits and disadvantages of storing data as flat files, such as

GeoJSON or CSVs [comma-separated values], versus use of a database and server-side

architecture. Databases were generally considered to be preferable for larger datasets, with an

emphasis on the use of PostGIS databases. Many participants mentioned CartoDB as an easy

way to set up a PostGIS database to support collaboration across the design and development

team. The downside of storing data in a database is that it cannot be put under version control

in the way that flat files can, with one participant describing the need to capture "snapshots"

of the data in time. Aside from flat files and databases, two participants mentioned pulling data

from APIs [application programming interfaces]. Three participants discussed storing data in

multiple files—geographic data in a GeoJSON and attribute data in a CSV—and joining them

together in-browser. This strategy was especially recommended if the attribute data is used to

power other visualizations linked to the map. However, one participant pointed out that

"merging really large datasets is very hard and resource intensive." One participant, who

wanted to map large datasets but does not like working with databases, claims that "having

data be stored and delivered by Mapbox using vector tiles is I think going to be a bit of a game

changer," allowing for on-the-fly querying of large datasets. Finally, one participant stressed

"being meticulous about trying to be organized with the data that you get, even if you're kind

of in a stressful or pressed-for-time situation…that always tends to make things easier down the

road, even if you feel like you don't have the time." There should be further investigation of the best ways to store and serve geographic data to an interactive map.

Data is necessary for beginning the design process. One participant claimed, "data is probably the number one thing that impacts the design...without data we sometimes don't even start a design [because] we don't even know what we're up against." Another participant went into detail about how they have created qualitative information to capture the subjective importance of different features to supplement attribute data. They use this qualitative information to create visual hierarchy, giving more important features greater visual prominence or displaying them at lower zoom levels before zooming to display all features. The same participant also mentioned, "one thing I'm thinking about is probably how to determine based off your data where there's a high concentration of information," and to generate map labels accordingly. Lastly, one participant disclosed that they have had clients who want the "data to say things that it doesn't…'Well we have this data, can't you just, even though that doesn't really work, can we just put that there anyway, and then just fill in, just fill it all in with something?'…People not quite understanding data and how not to lie with it." While the data of an interactive map is fundamental to its success, it is easy for designers and clients to ignore its validity, as many people who consume maps would never know if the underlying data were trustworthy. It was refreshing to hear in the interviews that participants care deeply about ensuring the quality of the data and spend much time thinking about how best to represent it.

Section 4.2.3: Representation Design Best Practices

All participants in the study discussed best practices for representation design in some way, with an average of 9.1 mentions per person. Discussions about representation included topics such as graphic identity and consistency, map and page layout, visual hierarchy, basemap design, labels, typography, symbolization, and UI design. Though the literature typically considers UI visual design as part of interaction design, participants joined UI design with representation design. Interestingly, several participants expressed that they had a difficult time pinpointing specific best practices for the representation design of web maps, with one saying, "I can tell it's a well-designed map when I see it, but I don't know exactly why." While four participants specifically mentioned the application of print cartography principles to interactive web maps, one participant suggested that there should be design principles specific for the web, asking, "How do you communicate spatial information to people? Whatever those principles are from print cartography, there have to be similar ones for web cartography." This section aims to reveal some of the web map design principles and best practices employed by contemporary web cartographers.

Regarding overall aesthetics, the most discussed best practice was to maintain a consistent design between the map and the rest of the interface, which was mentioned by seven participants. One participant asserted that it is best to avoid designing an interactive web map that looks, "like the map was this separate thing that was designed completely in a vacuum and then dropped in." These participants suggested that they use the same fonts, colors, and UI element design to maintain consistency between the map and the rest of the webpage. Participants mentioned two different motivations for consistent design, including promoting the graphic identity of a particular organization and matching the map to a

particular design theme. One participant emphasized, "graphic identity is critically important, so everything we do has to follow a set of conventions." This participant's organization uses a custom CSS library to ensure consistency across all of their maps. It was striking that the most discussed aspect of map representation design was not legibility or clarity of information, but rather branding.

The interviews made clear that contemporary interactive mapmakers think about maps in terms of layers, with a distinction between basemaps (the bottom reference layer of an interactive map) and the layers that "that live on top of the map." Five participants discussed basemap design in some way, and were split on the value of spending time to design custom basemaps. One designer said "it's easy to use a pretty canned basemap or a default style…[but] I think it's really a best practice to think about the entire aesthetic." Another participant felt that spending lots of time thinking about basemap design was not feasible when there are suitable existing styles: "Basemap design is also a big pain point…there are places that have people that can spend all their time working on map design and tweaking every zoom level…and we just will never have that time…so we have to make do with pretty basic options…or minimal variations that we add." Five participants discussed the importance of ensuring good visual hierarchy amongst the different map layers, encouraging mapmakers to "be thoughtful about the basemap to make sure it doesn't conflict with the layers on top." Several participants linked visual hierarchy with the importance of thinking about *multi-scale mapping*, or the design of interactive maps at different zoom levels (Brewer and Buttenfield 2007). One participant asserted, "to really be successful…you have to design the map to look good and to highlight features of the data at multiple scales." Six participants lamented the fact that the Web Mercator projection is so widespread in slippy maps, but only one of those

mentioned trying to reproject an interactive map on-the-fly. There are not firm conventions for how to design and combine interactive map layers, suggesting a potential area of research moving forward.

Six participants discussed another type of map layer: map labels. Several participants asserted that the label layer should be on top of the other map layers; as one of them stated: "add labels on top so that you can actually see the name of a city and not have it be obscured by your data...by default, that you have a tiled basemap, you've got your data layer, and then you've got a tiled label layer that is on top." Although one participant discussed the importance of "carefully selecting the labels" that make it on the map, rather than simply including a bunch of unnecessary labels, another pointed out that they have had clients say "'Why aren't there more labels?'" when they had carefully selected the most relevant ones. One participant noted that label placement is a big pain point in interactive map design: "on the web I think a lot of tools don't permit a great amount of control over them, and you know different screen sizes and different map scales...it's just a very complicated thing." Visual hierarchy also is important in labeling, with the need to visually prioritize some labels over others.

The design of map layers also includes the design of data layers. The most commonly discussed aspect of the design of data layers was about "visualizing millions and billions of points...there's some really cool aggregation stuff happening on the back-end." Another participant discussed the difficulty in deciding whether to map the raw points or to aggregate them: "You could put all these dots on a map and they'll be completely incomprehensible...you could bin them and color them by neighborhood or by hexagon or something and then you're sort of blurring some important distinctions and what you show may be an artifact of the unit you happened to pick rather than reality." One participant described an interactive mapping

project that involved live updating of the map as new data came in, revealing that "some of the colors and layering and styling we chose actually did not work out in the end just because...it was live results so essentially we had to redo a lot of the styling after seeing the updated data." Several participants mentioned the use of ColorBrewer as a tool for selecting appropriate map color schemes. Other aspects of representational design that were mentioned briefly include terrain, icons, and the inclusion of satellite imagery.

Interestingly, there was extensive discussion as part of representation design best practices on the interface surrounding the map, with eight participants mentioning the design of the elements of the user interface as they relate to the overall success of the map representation and interaction design. A few participants discussed including a clear point of entry, either in the form of introductory text or as UI elements that suggested initial locations on the map to look at. Several participants mentioned the use of legends, but there was disagreement as to whether it was good or bad to include legends. One said, "it makes your map look so much cleaner without some big legend or whatever taking up a third of the real estate on the map." Another participant bemoaned the dearth of legends for interactive maps: "I think [legends] are really not used enough, really not becoming a standard." In summary, although representation design was extensively discussed, there appears to be a lack of concrete best practices or conventions. Rather, participants were more prone to discuss the ways that they think about representation design, rather than specific best practices to follow.

Section 4.2.4: Other Design Best Practices

While many of the discussions about design best practices fit into the *data→representation→interaction* framework, there were many topics that participants discussed

that do not fit neatly into those boxes. The most prominent of these topics is responsive design (extensiveness = 14, frequency = 46). There was also extensive discussion about the move towards simple and clear map design (extensiveness = 13, frequency = 30). The remaining mentions of best practices were categorized as one "other" category (extensiveness = 15, frequency = 91).

Responsive design of interactive maps was widely discussed across participants. I coded responsive design separately from the *data→representation→interaction* workflow, as the discussion spanned all three aspects and thus deserved a dedicated space. Mentions of responsive design generally fell into one of three categories: (1) conceptual, or the way that mapmakers think about design for different screens; (2) practical, or specific tips for how to account for different screens in designing interactive maps and their related interfaces; and (3) problematic, or the issues that arise when designing for different screens.

Participants discussed a move towards "mobile-first," or prioritizing the design of interactive maps for small screens before considering the design for larger screens. One participant revealed that they limit interaction on mobile: "I think in general people do not want to interact with stuff, and that's especially true on mobile devices where it's more annoying to do so." Another participant echoed this sentiment: "Thinking about this stuff in mobile is helpful...because if 'oh we don't really need that on mobile' then it's like, well maybe it's not that essential anyway...Do we really need it on desktop?" One participant described that the mobile experience is not just about screen size, but also about touch interaction: "When you think about the level of resolution that you can get with a fat thumb on a screen, it's so much different than how specific you can be with your mouse...half the people that are experiencing what you're doing are coming on phones and so the experience on a phone with

touch is very very different than with a mouse on desktop and so I think we have to think about what that looks like." The same participant pointed out that, from the beginning, location and maps have been inherent to smartphone use. Cartographers need to take advantage of the built-in location aspect of smartphones and design maps accordingly.

As for best practices for designing mobile maps, several participants discussed the need to remove extraneous elements from the interface and to make the map as big as possible. One participant made this point well, stating, "there's only so much screen space that you have, so the more that's dedicated to the map, the better." One participant mentioned that, for retrieve, they have moved towards having a panel that is dynamically revealed when the user touches the point or area of interest. Another preferred to "dock information to the bottom of the screen...the map will be on the upper portion of the screen and then these popups instead of appearing in situ they'll appear in this universal place down below." Several participants mentioned that exploration is limited on smaller screens, and thus there is more of an emphasis on presenting a clear story with constrained interaction. They said that scroll-based interactions are better for this reason, as they are easier for users to perform on a small touch screen. One participant mentioned an instance when they mimicked an interaction that they had seen on a mobile app, wherein rather than moving a pin to select a location, "you basically flip the surface which you interact with...you move the basemap around with your thumb and the pin was always in the center on top of the place you were interested in exploring, versus trying to drop the pin in maybe a less precise way." One participant talked about designing an interactive map "at a few different break points and then hope it can adapt itself in the middle" and also how they do "custom editing of the data and what's appropriate for different screen

sizes." It is clear that, though many people recognize its importance, mobile map design has not coalesced around specific best practices.

Much of the discussion around responsive or mobile map design centered on the fact that participants do not yet have it figured out. Many mentioned the difficulty with not being able to take advantage of hover interactions that they depend on in maps that are viewed on desktop: "just mouse over a feature and it'll tell you what to do, we can't rely on those anymore...you need to either have things click or not click." However, that click interaction can be confusing as well: "should clicking or tapping when you're in a mobile experience, should it be a select or should it be a zoom?" Several participants simply talked broadly about how responsive and mobile map design is simply really difficult, with one stating: "it's very complicated when you have no idea what the actual experience size of the map is going to be and you have no idea whether someone will have a mouse or a finger...and you have no idea whether they will have internet connectivity or be in an elevator or underground." One general consensus around mobile map design is that interaction should be limited, connecting to the topics of simplicity and clarity.

Most participants (extensiveness = 13/17) mentioned the importance of the principles of simplicity and clarity. These principles were applied across the *data→representation→interaction* framework, and were conceptualized by participants as excluding any unnecessary data, representation, or interaction that does not directly contribute to the success of the map. Regarding clarity of data, one participant said, "I think one of the biggest things is to not overload [the user] with information... a lot of what we've seen for quite a few years now is just, 'Look at all this stuff I can put on here! Look at all this data I can get!' And the picture just becomes really unclear." They went on to emphasize the importance of "being able to

choose wisely what helps and what distracts from the story," and another participant agreed, stating, "Just because we can show all this data doesn't mean we should." Regarding clarity of interaction, one participant said they get rid of as much of the UI as possible, "tossing out sidebars, tossing out popups, tossing out legends, just trying to keep things really clear." Further, many participants discussed the need to limit the amount of interaction and be intentional about why interaction is being included, with one saying, "making sure that the interactivity is purposeful, not just ohhhh we just did a choropleth map and you know hover for a trend...I think the best ones really use interactivity to their advantage versus just adding interactivity for the sake of adding it." One participant made a perfect analogy about the need for simplicity in the context of news mapping, stating that "It's a problem of editing...most maps are the equivalent of a 10,000 word article that should be 2,000 words." Though the push towards clarity can also be applied to static maps, it is especially important in the interactive context when the possibilities are endless and the technology has made it easier over the years to implement.

Six participants discussed the performance, or optimization, of interactive maps. In this context, performance refers to the speed at which the map and the data load and at which the user can interact with the map. This is important because, "you want [the map] to load fast, you want it to feel very smooth." Participants gave a few suggestions for improving performance, including simplifying the geography and being careful about when to load the data into the internet browser (e.g., load all data upfront or incrementally as requested by the user). Performance is especially important to keep in mind if the user will be using the map on a mobile device with poor connectivity.

Three participants mentioned that browser compatibility is a pain point in interactive map development, discussing how difficult it can be to implement an interactive map such that it looks well designed across browsers. However, one participant spoke passionately about the importance of ensuring compatibility, saying, "I know it sucks sometimes to have to support IE9 [Internet Explorer], but…if we look at our analytics, there's still plenty of people out there using those things...so we need to make sure that we're building products that are accessible to everyone, not just the young person who has a new phone or someone who's on a fast internet connection." Searching for better ways to ensure that maps work across a variety of technologies should be an area of further investigation for those who study and build web mapping technology.

A wide range of additional best practices were discussed. Six participants discussed *coordinated visualizations*, the concept that additional other UI elements on the webpage can be manipulated to change the map view and that there is a visual link between elements in the map and the UI elements (Hardisty and Robinson 2011). However, there was also a warning that these can be difficult to implement: "I also think that sometimes if not presented properly, it could be really overloaded." Many participants discussed the difficulty of and necessity to keep up with the latest tools and technologies for creating interactive maps, and a few participants mentioned looking outside of the mapping world for inspiration, such as video games and virtual reality. Several participants discussed geocoding or including geocoders in their interactive maps. A few participants mentioned that they wish they knew more about map perception. There were some additional helpful practical tips for interactive maps, including: (1) saving a particular map view in the URL so that it can be shared easily; (2) maintaining coding conventions, especially useful for long-term or collaborative projects; and

(3) keeping in mind accessibility issues, such as being able to use a screen-reader on the map and designing for those with colorblindness. Overall, some participants seemed to be actively setting trends in interactive mapping best practices, while others were hesitant to offer firm guidelines during the interviews, instead waiting to see how conventions develop.

SECTION 4.3: Interactive Web Map Evaluation

The third section of codes looks at discussion of how to evaluate and measure the success of interactive maps (E) and is divided into three sections. The first section of codes captures discussion of *who is doing the evaluation*, covering discussion of the person or people tasked with evaluating the interactive maps, and includes five codes: (E5) expert-based carried out by usability or domain experts; (E6) theory-based, carried out by the designers and developers themselves; (E7) user-based completed by target end users; (E8) informal evaluation relying on feedback from social media or comments; and (E9) client-based. Codes E8 and E9 were added during the transcription process. The second section of codes captures discussion of *what is being evaluated*, which investigates aspects of an interactive map that make it successful and includes three codes: (E1) usability, or discussion of ease of use of an interactive map; (E2) utility, or discussion of the usefulness of an interactive map; and (E3) aesthetics, or discussion of the beauty of interactive maps. The third section of codes captures discussion of *when is it being evaluated*, identifying the point(s) in the mapping process that maps are evaluated and includes one code (E4) capturing all discussion of formative, summative, and post-deployment feedback.

Overall, the codes for *who* is doing the evaluation garnered the most feedback, with a total frequency of 143. User-based evaluation methods were the most discussed (extensiveness

= 16/17, frequency = 56), followed by expert-based (extensiveness = 14/17, frequency = 41), informal (extensiveness = 10/17, frequency = 16), theory-based (extensiveness = 7/17, frequency = 9), and client-based (extensiveness = 5/17, frequency = 21). Codes regarding the *what* of interactive map evaluation were applied a total of 101 times. The most extensive *what* code was utility (extensiveness = 16/17, frequency = 44), followed by usability (extensiveness = 14/17, frequency = 44), and aesthetics (extensiveness = 9/17, frequency = 13). The *when* code (extensiveness = 17/17, frequency = 57) was the most frequently discussed individual code, but overall was the least commonly discussed aspect of interactive map evaluation. The topics of summative, formative, and post-deployment evaluation were not further subdivided into unique codes due to frequent vague responses from participants about when they performed evaluations.

Section 4.3.1: Who is evaluating interactive maps?

Participants discussed who is involved in evaluating interactive maps more frequently than they discussed the other two overarching evaluation categories. Participants most commonly discussed the value of soliciting feedback from target end users (extensiveness = 16/17, frequency = 56). One participant said "success for me there was to see how many people were using [the map] and to see how people understood how to use it and were stoked about using it." However, most participants (10/17) did not conduct user-based evaluations as frequently as they wanted, with several not conducting user evaluations altogether. Of the participants that did not actively perform user-based evaluation, many still acknowledged the potential benefits of doing so. As one participant stated, "It would be really great to be able to talk to more people that actually are the consumers of any map that I've made that is meant to

be consumed for a specific purpose and see if it actually meets that." One participant suggested that there might be a difference in the necessity of user feedback for ongoing mapping applications versus quicker one-off interactive maps, with more of a need for user feedback for the former. Several participants attribute the lack of user testing to a lack of time, with one participant stating that, "All the user testing I've seen...it's a big administrative task...you have to get everyone in the room together, you have to create a testing script for them so they go step-by-step through the process...you have to record all of their comments and then you have to go back and make all those revisions...it's a really huge process, and I understand why a lot of people on our team just skip that part." Nonetheless, many participants acknowledged that if they had unlimited time, they would incorporate user feedback into their evaluation process.

Statements regarding specific methods for gathering feedback from users fit three main strategies: (1) evaluation via direct feedback from the user, such as user feedback forms, customer support, or direct email; (2) evaluation via user or usability testing; (3) evaluation via analytics, which will be discussed in Section 4.3.3. Five participants received direct feedback from users, two of whom mentioned that users had searched for their email addresses and wrote them to give feedback on public-facing maps. Two other participants discussed the inclusion of a formal way for users to provide direct feedback via a button or link on the interactive map or accompanying website, where "anyone who's using the map can report errors." Four participants talked about user or usability testing; I use both terms here because participants used these terms interchangeably. Two of these participants mentioned that they have not been directly in charge of user testing at their organization and thus did not have much knowledge about it, while the two others had more specific knowledge of how user

testing is employed at their organization. These latter two participants work at organizations that develop complex interactive maps with multiple development cycles—rather than one-off interactives—and thus are engaged with user-based evaluation as part of a longer-term process. One of these participants explained that their organization's customer support team performs user testing roughly every six months, wherein they

> *…bring in the user, pay them $50 for their time, but then give them a series of tasks on the application and watch them try and complete them...and as soon as you have even 4 or 5 people do that, the bugs and the challenges as well as the successes of the platform become just glaringly obvious…because you know you aim for a cross-section of your users, older users, younger users, different platforms, different demographic groups, different target audiences for the uses, but with a fairly small number of people, you find agreement about the bottlenecks pretty quick.*

The second participant regularly involved in user-based evaluation agreed that user testing must focus on what the user is able to do, not the user's subjective opinion about the map. While there appears to be interest in and potential for employing user testing as a way to improve interactive maps, the vast majority of participants did not do so. Further, there is a near total lack of knowledge regarding how to do so, identifying a curricular gap in addition to a technical gap.

Although user-based evaluation was the most discussed type of evaluation, expert-based evaluation was the type of evaluation that participants actually relied on the most. These statements can be broadly divided into two categories: (1) feedback from colleagues; and (2) feedback from technical or subject-area experts. All fourteen of the participants who made a statement about expert-based evaluation mentioned getting feedback either formally or informally from colleagues. Additionally, five participants talked about getting feedback from a technical or subject-matter expert, including a cartographer, a visualization expert, and domain

expert on the map topic. One participant summarizes the importance of having a culture of feedback in the workplace, stating:

> *The most valuable feedback mechanism we have for knowing if what we do is successful or not is just the collaborative and honest culture... where you have a large group of people who have done this for a long time and are good at assessing things...hopefully before you publish, shopping it around to your colleagues and having them be very honest with you about what they see as the pitfalls.*

Some participants described an informal approach to soliciting feedback from colleagues, with one participant indicating, "we don't really use any formalized testing process, it's just like 'whatever you catch you catch.'" Another participant prefers to ask colleagues for, "something very specific," feedback on one particular aspect of a map design rather than asking for a general reaction. Other participants recounted a more streamlined process, one of whom said, "we just have regular peer review sessions where you know everyone sits around at a table and we are at various stages of our projects and we're presenting our process and solution and comments and advice and suggestions." Thus, there was near universal agreement amongst the participants that receiving constructive feedback from colleagues improves the final map, although a general acknowledgement that such feedback is not perfect.

Informal feedback (extensiveness = 10/17, frequency = 16) refers to statements that participants evaluate their maps based on public conversations on the internet, primarily via social media. Several participants were vague about the outlets they receive informal feedback from, including statements such as, "people reacting online," and, "from the internet." Seven participants specifically acknowledged that they turn to Twitter as one measure of success of an interactive map, although one participant specifically stated that they do not agree with this way of gauging success. Some participants mentioned that they receive both positive and negative feedback via Twitter. One participant said that they definitely take Twitter comments into account, asserting "if we publish something with actual errors or mistakes in it and then

we see people talking about it on Twitter or whatever, we'll definitely go back and fix those mistakes." Although informal evaluation does not replace more rigorous user-based evaluation, it can be a way to receive quick feedback on a public-facing map.

Discussion was limited regarding theory-based (extensiveness = 7/17, frequency = 9) and client-based (extensiveness = 5/17, frequency = 21) evaluation methods. One participant admitted the difficulty in evaluating one's own map: "it's really hard to evaluate a project, especially right when I finish it, because a lot of times I've been working on it for a week or two, and that's all I've been working on…it takes me a few days to really step back and then be able to…evaluate with fresh eyes and learn for the next time." Discussion of client-based evaluation focused on the iterative nature of the feedback, wherein the participant delivers a version of the web map or a prototype to the client and awaits feedback before continuing onto the next cycle of revisions.

Overall, participants acknowledged the importance of being reflective and seeking feedback on interactive web map designs, repeatedly citing the value of integrating input from others. As one participant summarized: "Just as important as…getting outside opinions is trying to let go as much as possible of your ego or any sense of things needing to be exactly the way that you decided they need to be." The participant went on to assert that, "you make a lot of decisions and a lot of them are probably not the correct decisions and other people might be able to point that out to you…being open to receiving that feedback is a really useful way to improve the map that you're working on in the end."

Section 4.3.2: What is being evaluated?

Participants generally agreed that both usability and utility are important to evaluate when solicit feedback on a web map design, and thus are core aspects of success to consider during design. However, participants weighted these two factors differently in terms of metrics of a successful design. Interestingly, there was the exact same frequency for the usability and utility codes (frequency = 44). I first examine discussion around usability and utility, and I then report on comparisons and relative importance of the two. Finally, I introduce discussion of the aesthetics of interactive maps, a measure of success that did not carry as much weight as usability and utility, but was considered a separate measure of success by participants.

When discussing usability, participants evoked words such as "intuitive", "easy to use", "good experience", and "enjoy". In general, participants agreed that users should know how to use an interactive map without the need for complex instructions, a notion described in the literature as *transparent usability* (Robinson et al. 2011), with one participant saying, "the most successful [maps] are actually the ones where you're not having to think, you're just using it...you're just learning, you're just getting what you want out of it, you're realizing that you're not putting any work into this at all." A second participant asserted that high usability engages users, claiming, "if [a map] is frustrating or if it's confusing, then you also will not have people stick around and keep using it." A few participants related usability back to the previously discussed concept of simplicity, stating that simplicity means transparent usability and vice versa. One participant observed, "I think that kind of trend for something that is super easy to use and easy to interpret is definitely becoming a standard in the industry...I think that's been a good thing, I think the days of putting as much as you can on a map are over, I hope." A second pointed out that maps should be usable for a wide variety of people, stating, "anybody

with a variety of technical backgrounds or tech literacy could visit that map and know how to use it." Most participants focused on usability when web maps are designed for a wide variety of users.

When discussing utility, participants used words such as "understanding", "useful", "achieve a goal", and "purpose". Participants acknowledged that different maps serve different purposes, and that the usefulness of an interactive web map depends on how well the map supports the user's objectives. One participant asserted that, for maps that users are employing to extract specific information, users should be able to "figure out what they need to know, what they need to see as quickly as possible and then get out of there...we don't necessarily want people sitting there, using their maps for 20 minutes or so." On the other hand, another participant contended that "sometimes we're not tasked to be useful, but...if a user stays with the map for a long time and is enjoying it and exploring it, then I think what use they're getting out of it, if their use is entertainment... the fact that someone will dwell with the map suggests that it's useful." One participant described testing an interactive map for its utility, stating that "if you're given a task [that] you're supposed to complete...how difficult is it for the users to complete that task? You kind of have to do a lot of user testing just to make sure that that works really well and if the user can't figure it out then the map kind of fails." This participant went on to say that, as the cartographer, it is important to "get rid of the things that are not important to the use-case and really focus the map on something that gets the user question answered very quickly." Utility relates directly to user needs, further necessitating a clear needs assessment upfront and user-based evaluation.

Overall, some participants prioritized usability over utility while others emphasized utility over usability. One participant who favored usability over utility stated, "First it needs to

be easy to use, because if they can't even use it, if the data's incredibly important...if you can't

figure it out, then what's the point? So easy to use first, second is how important and how

useful the actual content is." Another participant disagreed, placing the utility of the map

above its usability: "If it has a clear purpose and it knows its audience and if it achieves that

kind of purpose, then I think that's successful." However, most participants placed equal

weight on the importance of both usability and utility, with one participant summarizing "I

think it's a combination of those things...it's got to be easy to use and your users need to be

able to get out of it what they want," and another agreeing that "it's definitely a balance of

being useful and being easy to use, I guess when you balance that correctly for your audience,

you've done a good job." Utility is important to give the interactive map purpose, and usability

allows users to achieve their intended goal.

Aside from the measures of usability and utility, some participants mentioned including

aesthetics in their definition of interactive map success. One person offered, "If a map is

beautiful, it draws me in and makes me want to dig around in the map." Another participant

agreed that beautiful maps make the interactive map more successful, stating, "if a map is

designed well, I think people will either share it more or give it a little more thought." That

said, several participants emphasized that no amount of good design can overcome poor

usability or a map with no purpose. As one participant put it: "I think there are times when I

see something that looks really sexy and amazing but I don't understand what I'm supposed to

see...just because something looks really great it doesn't mean that it is useful." Another

participant agreed, asserting, "If the idea that's being conveyed is not that compelling then no

amount of good design can make that a compelling visualization," and went on to say that they

would prefer to see a map with compelling data in a default design than a beautifully designed

map with nothing interesting to say. Thus, aesthetics were considered important, but a secondary measure to consider after evaluating the usability and utility of an interactive web map.

Section 4.3.3: When is it being evaluated?

Participants talked significantly less about *when* they evaluate interactive maps than *who* is performing the evaluation and *what* they are evaluating. Further, the line between formative, summative, and post-deployment feedback in the interviews was not always obvious, ultimately requiring that I collapse the *when* into a single code. Some participants also discussed map products that are constantly updated, in which case it was especially difficult to draw the line between formative, summative, and post-deployment feedback.

Some participants specifically mentioned the importance of formative evaluation early on in the process. One participant urged, "When you're just starting out, making sure that the functionality is clear." A second participant that, "it is valuable to get user feedback early because designing and developing a map is extremely expensive...you want to get your mistakes out at the very beginning." Other participants discussed the importance of formative evaluation, but admitted that they probably do not do it enough. In regards to receiving ongoing feedback from clients, one participant discussed limiting the number of times they request feedback to specific points "so that it's not just free-flowing throughout the whole process." On the other hand, another participant revealed that they hold weekly meetings with clients to get frequent feedback. In contrast, only two participants specifically mentioned summative feedback, specifically discussing that they conduct "postmortems" with their team, assessing the project after it is done to note what they did well and what could be improved

for the next project. Thus, there was a clear consensus that formative feedback was more valuable than summative feedback.

I identified statements as post-deployment evaluation when they referred to evaluation occurring while the interactive map is in active use. Statements about post-deployment evaluation fell into two main categories: (1) web or map analytics; and (2) *A/B testing*, which refers to publishing two different maps to then analyze users' differential reactions to them. Six participants discussed gathering web or map analytics, although there was not consensus on what these statistics actually mean. Of these participants, most of them either do not currently collect map analytics (but would like to), or analytics were passively collected but not actively monitored. One participant mentioned that they have "been prototyping lately gathering analytics about how users are actually interacting with the maps themselves." However, this participant had yet to fully implement such map-specific page analytics and did not have specific suggestions on how to do this. One participant suggested that web analytics are useless without specific knowledge of how the user interacts with the map, asserting that "for maps that we've published online there's traffic numbers, but that's a very subpar measure of success because sometimes there's just stories that are going to get a lot of traffic because they're very dramatic or important stories and anything you publish is going to get a lot of traffic even if it's a failed map or a successful map." There was also disagreement about the interpretation of map analytics, and whether more time spent on the map means that it is successful or not. One participant argued that more time on the map meant that the user was engaged with the content, while another participant argued that more time on the map meant that a user could not quickly extract the information that they were trying to acquire.

Six participants mentioned A/B testing, with half of those mentioning that they do A/B testing and the other half saying that it is something that they would like to try if they had more time and resources. One participant questioned the purpose of A/B testing, stating, "we can A/B test things, but I don't know how to A/B test whether someone understood something or not, and that's what we care about the most." Another participant mentioned that they occasionally perform an A/B test on one small aspect of the interactive map, like the implementation of a specific interaction, but that they could not remember a specific instance when there was a noticeable difference in user reaction. Other participants mentioned that that there is simply not enough time to perform A/B testing, both in terms of creating two separate interactive maps and the time needed to analyze the results. Discussion surrounding A/B testing was limited, as it is only effective at a large scale, when tens or hundreds of thousands of people interact with an interactive web map.

It was clear that there are not established best practices for when and how to perform post-deployment evaluation. The few participants who seemed to be in strong favor of post-deployment evaluation primarily perform active usability testing for mapping applications that require continuous updates. Although six participants discussed post-deployment evaluation, its full value and practicality did not have consensus in the professional community.

CHAPTER 5: CONCLUSION

This research aimed to consolidate knowledge regarding current workflows and design best practices for making interactive web maps through interviews with professionals in the mapping industry. Specifically, this study sought answers to the following questions:

1. What are the workflows and processes that professional cartographers follow when designing interactive maps?

2. Are there overarching design conventions that professional cartographers use for interactive maps? If so, what are they and in which contexts are different conventions used?

3. Do professional cartographers evaluate the success of their interactive web map? If so, how?

Section 5.1 provides a brief overview of answers to the three study questions. Section 5.2 presents one of the knowledge products of this research, a benchmark of current workflows and processes. Section 5.3 offers a second knowledge product, a comprehensive list of current conventions for interactive web maps. The chapter concludes with Section 5.4, which includes limitations of this study and suggestions of future directions for research about interactive web maps.

SECTION 5.1: Overview of Study Questions

I devised the interview to answer three research questions facing interactive and web cartography and the related fields of human-computer interaction, usability engineering, user-centered design, UI/UX design, web design, and project management. The goal of the interviews was to establish a contemporary benchmark of interactive web map design

practices, including workflows, design conventions, and measures of interface success. I

provide a summary of insights towards each of the research questions below.

1) What are the workflows and processes that professional cartographers use when creating interactive maps?

One thing was clear from the interviews: professionals who make interactive web maps

do not follow a typical UCD workflow. They do not follow concrete stages, but rather a loose

structure that begins with defining the project goal(s) and ends with web map deployment in

order to complete the project as efficiently as possible. Figure 5.1 illustrates the workflow, with

an interpretation below:
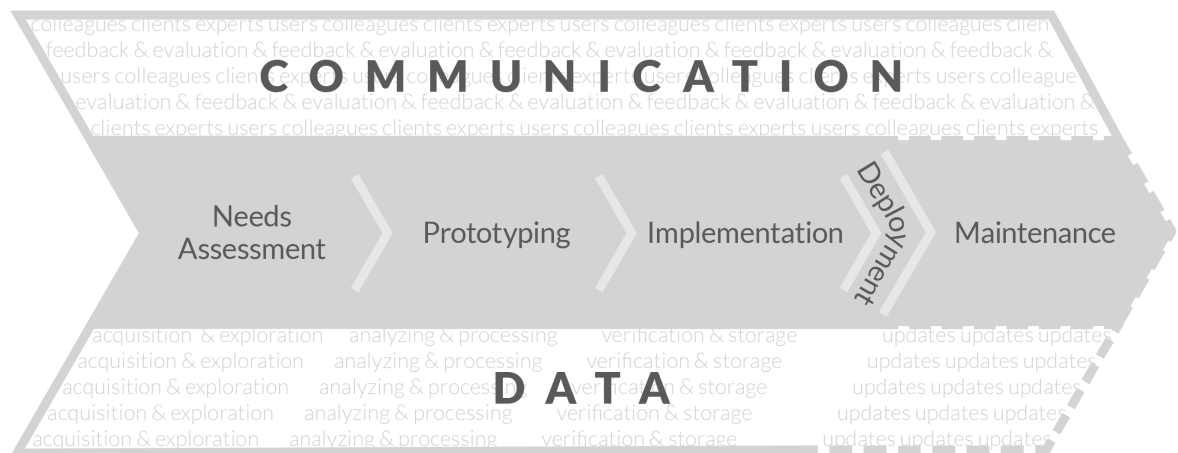
Figure 5.1: The "Get **it Done" contemporary interactive web mapping workflow

The basic structure of the workflow runs through the middle of the figure and includes

four primary steps: (1) needs assessment, which involves defining the objectives of the project;

(2) prototyping, which involves creating static and/or interactive prototypes; (3)

implementation, which involves refining prototypes and debugging; and (4) deployment, which

involves releasing the final interactive web map to the target users. The fifth step, maintenance,

is depicted with a dashed line, indicating that not all interactive web maps are maintained. For

one-off projects, maintenance includes correcting errors that are discovered post-deployment. For ongoing projects, maintenance means that this workflow restarts, with a reassessment of the project needs going forward. It is important to highlight that, though the workflow has directionality, there are no hard divisions between adjacent steps, indicating the iterative back-and-forth throughout different stages of the workflow.

Data is an integral part of all stages of the workflow, with different processes taking place along each step. Data constitutes the base of the workflow; without it, the rest of the process cannot exist. Each stage of the workflow has its corresponding data stage: (1) the needs assessment stage includes data acquisition and exploration to determine if the necessary data exists and is useful for the project purposes; (2) the prototyping stage includes data analysis to determine which data to use and processing to get it in a usable format; (3) the implementation stage includes data verification to assure data quality and storage to determine how the data will be accessed in the final web map. The maintenance stage includes data updates, as necessary. Representation and interaction design are noticeably missing from the workflow. While these parts of the design process are undoubtedly important, they were not mentioned as being as integral to each step of the workflow as data.

The entire workflow depends on regular, open communication and breaks down when this key element is not present. Communication among the team members involved in the project is imperative. Communication with clients and/or users may also apply to some web mapping projects, though not all. This communication includes seeking and receiving feedback from others throughout the map creation process. Though the form of the communication varies from person to person and team to team, strong communication is what unites a fluid

workflow. A more comprehensive overview of contemporary workflows will be covered in Section 5.2.

2) Are there overarching design conventions that professional cartographers use for interactive web maps? If so, what are they and in which contexts are different conventions used?

In short, yes there are design conventions that professional cartographers employ for interactive web maps, however, specific conventions remain in flux. The conventions boil down to one overarching principle: simplicity and clarity of design. The three components of interactive web map design, including data, representation, and interaction, should be implemented on the map only to the extent that they are necessary to meet the intended goals of the map. When designing an interactive web map, before adding any data, representation, or interaction, one should ask, "Is adding this necessary for fulfilling the objectives of the map?" Before deploying the interactive map, one should ask, "Can I remove anything from the interactive map and still allow the user to achieve their goals?" A distilled list of specific design best practices is covered in Section 5.3.

3) Do professional cartographers evaluate the success of their interactive web maps? If so, how?

Professionals who make interactive web maps universally evaluate the success of their work, though the ways in which they do so varies. Regarding *what* professionals measure, they tend to place equal importance on the usability and utility of the interface. Regarding *who* they turn to for feedback on their work, professionals tend to rely on evaluation from colleagues within their organization, though they also recognize the value in getting feedback from users, even if they do not actually do so. Regarding *when* professionals evaluate their maps, they stress

the importance of receiving formative feedback, receiving feedback throughout the map

creation process, and evaluating the project post-deployment.

SECTION 5.2: Benchmark of Workflows for Contemporary Cartographers

The interactive web mapping workflow (Figure 5.1, above) for contemporary

professionals shares some, but not all, of the components of the Robinson UCD workflow (as

seen in Figure 2.2). This newly defined workflow contains fewer steps and distinguishes

between pre-deployment interactive web map development and post-deployment maintenance

of the map. This workflow is highly iterative. For example, during the prototyping phase, there

may be a return to assessing project needs, and some data or interaction may be discarded or

added. Here are specific takeaways for each stage of the workflow:

1. *Needs assessment:* The most important part of the initial needs assessment is the

   definition of clear goals for the interactive web map, which should include

   discussion of whether the primary purpose of the map is exploration or

   presentation. Project requirements should be defined in this stage, which helps

   determine the functionality to be implemented. This stage also involves conducting

   initial user and domain research. The intended goals that emerge from this stage

   should be kept in mind throughout the remaining stages of the workflow.

2. *Prototyping:* This stage includes any combination of whiteboarding, wireframes,

   mockups, and/or interactive prototypes, with a trend of moving towards the latter

   as quickly as possible to save effort during implementation. The prototyping stage

   is highly iterative and may involve multiple rounds of feedback. Prototyping is

   useful for external use (i.e., for showing to clients or conducting user testing) as

well as internal use (i.e., for designers to communicate design direction to developers).

3. *Implementation:* The implementation stage involves refining the interactive prototype, ensuring that the interactive web map contains relevant and accurate data, functions properly, and is styled appropriately. With the move towards interactive prototypes, the line between prototyping and implementation is increasingly blurred.

4. *Deployment:* Deployment is the actual launch of the interactive web map to the intended users. This stage is noticeably absent from the Robinson et al. (2005) UCD process. It is intentionally smaller than the other stages in the workflow, as it represents the moment in time when the interactive web map switches from private development to being in active use.

5. *Maintenance:* The maintenance stage covers any changes that are made to the interactive web map after it has been in active use. It is possible that the maintenance stage involves restarting the entire workflow, beginning with a reassessment of the ongoing project needs. Although many contemporary professionals mentioned a desire to maintain their interactive web maps, several admitted that they do not have time (or are not paid) to do so; therefore, this stage is depicted with a dashed border to indicate that it is not always part of the workflow.

Another difference between this contemporary workflow and the UCD process is the inclusion of data as an as integral component of the workflow. As discussed in Sections 4.2.2 and 5.1, data design is viewed as essential to all workflow stages, with each step of data

management roughly aligning with each part of the interactive web mapping workflow. More details and best practices regarding data will be discussed in Section 5.3.

While the stages of data design make up the base of the workflow, communication is the uniting factor throughout it. Whereas the UCD process promotes user participation at each stage, in reality, many professionals do not communicate directly with users or perform user testing. However, participants widely discussed the importance of communication throughout the interactive web map development process, including communication with colleagues, clients, experts, and/or users. Communication involves seeking and receiving feedback, as well as ensuring that everyone involved in making the interactive web map is on the same page and doing their part. Cultivating a culture of communication is crucial to creating a team that feels open to receiving and giving feedback, which ultimately results in better interactive web maps.

In this contemporary workflow, evaluation of the interactive web map is treated as a possible inclusion within each stage rather than as a separate stage. This is due to the fact that, overall, participants believed that it was important to evaluate the web map throughout the workflow. Participants most frequently turn to colleagues for feedback. However, many also stressed the benefit of receiving feedback from users, even if they did not actually do so. Generally, participants believed that both the usability and utility of an interactive map are important. What is the purpose of a usable map with useless information? Likewise, what is the purpose of a map with lots of useful information that cannot be easily accessed or understood?

SECTION 5.3: Contemporary Conventions for Interactive Web Maps

This study revealed emerging conventions for interactive web map design, which were thoroughly discussed in Section 4.2. This section aims to condense the most salient insights into specific conventions for interaction, data, and representation design, as well as additional best practices.

Conventions for interaction design revolve around specific interaction operator primitives. The underlying heuristic amongst all of them is this: *if the purpose of the map is exploration, you can broaden the amount of interaction that is implemented; however, if the purpose of the map is presentation, you should limit interaction.* I summarize the design conventions for the most discussed interaction operators below:

Pan and Zoom:
When to implement: Provide pan and zoom when different levels of information can be revealed at different zoom levels (e.g., state-level information and county-level information) or when there are features that will be too small to be seen at lower zoom levels (e.g., the District of Columbia on a national map of the United States).
When not to implement: Do not provide pan and zoom when the purpose of the map is to give an overview of a topic and there is no need for the user to change the map's extent.
Tips for implementation: (1) Constrain the number of zoom levels based on your map purpose. For example, if the purpose of the map is to explore a city, do not allow the user to zoom out to see the whole world or pan far beyond the bounds of the city; likewise, if the purpose of the map is to look at information on a continental level, do not allow the user to zoom into a city. (2) Disable zooming with the scroll wheel when the interactive map is the full width of the page and embedded on a larger webpage to allow the user to reach content below the map; otherwise, attempting to scroll with the scroll wheel will instead zoom into the map. (3) On mobile, when an interactive map is embedded on a larger webpage and there is additional content below the map, make sure that the height of the map is shorter than the height of the device to allow the user to be able to scroll past the map; otherwise, when they try to scroll past the map they will be stuck panning it. (4) In addition to the commonly used plus and minus zoom buttons, include a "home" button that returns the map to its original extent and

zoom level. (5) Stick to conventional pan and zoom implementations; provide zoom in/out buttons on desktop, allow users to pinch-to-zoom on mobile.

Caveats: Though the general recommendation is to limit panning and zooming depending on the mapping context and intended purpose, pan and zoom have become so ubiquitous in web maps that users expect to be able to freely pan and zoom. Therefore, you may choose to implement pan and zoom even when it is not strictly necessary.

Retrieve:

When to implement: Retrieve is essential when the purpose of the interactive map is exploration.

When not to implement: When the purpose of the map is to show overall trends or provide a guided experience to the user, retrieve is unnecessary.

Tips for implementation: (1) Popups should be used when there is a minimal amount of information being retrieved. Panels should be used when a lot of information is presented or when there is a linked visualization. (2) Be purposeful about the information included in the popup or panel. Do not simply include attribute information because it is available. (3) Be purposeful about the formatting of the information in the popup or panel. For example, limit the number of trailing decimals after a number (e.g., 24.3% rather than 24.33333%). (4) For mobile, there are two suggested ways to implement retrieve: either as a stationary panel below or above the map, or as a sliding side panel that is revealed upon retrieve.

Caveats: Though not to the same extent as pan and zoom, many people expect to be able to click around on the map to retrieve more information, regardless of whether or not the map purpose "requires" it. Therefore, you may elect to implement retrieve even when it is not considered necessary.

Search and Filter:

When to implement: Search and filter are fundamental when you want the user to be able to find a specific location or when the user would have a difficult time finding a location using panning and zooming alone.

When not to implement: When the objective of the map is to tell a specific story, search and filter are unnecessary.

Tips for implementation: (1) Decide which data layers will be searchable and at which resolution (e.g., at the address level or city level). This should depend on the available data and the purpose of the exploration. (2) Save a specific search or location in the URL so that the user can share it with others. (3) Include a geolocate button if you want users to be able to find themselves on the web map. This is especially important for mobile and increasingly important for desktop maps. (4) Provide suggestions or examples to the user of what can be searched via visual affordances.

Overlay:

When to implement: Incorporate overlay when the purpose of the map is to allow for comparing different map layers or when you want to allow users to include their own data.

Tips for implementation: (1) Limit the number of layers you provide so that the map does not become overwhelmed with too many layers. (2) If the map has multiple overlay layers, design them such that the map is legible if they are all turned on.

Preparing the data for use in an interactive web map is time-consuming. Data drives representation and interaction design; no representation or interaction can replace missing data. There are two overarching best practices for dealing with data for interactive web maps: (1) Never alter the original data, and (2) Be meticulous about organizing data from the very beginning. Additional best practices for data design as they relate to each stage of the data workflow are below.

Data acquisition:

Have your go-to data resources: Create your own list of resources for initial reference. Often-cited resources from the interviews included Natural Earth Data, OpenStreetMap, and the US Census Bureau.

Look for alignment: When possible, look for geographic data where the borders align properly, with the same level of generalization (e.g., where state and country borders match).

Data exploration:

Explore quickly: Quickly assess the data at the start of the workflow to determine if it will serve your needs. This includes quickly assessing the data to see what story it tells and getting an initial sense of the data distribution and type (e.g., numerical, categorical). If the data has millions of records, it might be helpful to look at the first 10,000 to get a sense of what it contains.

Don't just use GIS software: Do not underestimate the power of exploring data in a spreadsheet in addition to looking at it geographically.

Data processing:

Automation: Automate processing of data from a raw to mappable format by scripting the process, possibly using makefiles. Automation eases data updating, error correction, and makes the data processing workflow accessible to others.

Data verification:

Check data validity: Confirm the validity of the data with experts or with the people who provided the data. If some numbers seem off, do not be afraid to ask your client or an expert why.

Spot-check the map: Make sure that the representation on the map matches the data value for a given location.

Data storage:

When to use flat files: Flat files, such as CSV and GeoJSON, are preferable when data needs to be under version control and for smaller datasets. It is preferable to store attribute (CSV) and geographic data (GeoJSON) separately and join them in the browser when the attribute data will power a non-map visualization on the webpage. The downside to this strategy is that merging data in the browser can be difficult and negatively affect performance.

When to use databases: Databases are typically preferable for larger datasets. PostGIS was the database of choice for participants. The downside of using a database is that it cannot be put under version control.

Best practices for representation design tend to have more to do with how to think

about design rather than specific design suggestions. Specific conventions are below.

Consistency of design:

Maintain consistent design between the map and the rest of the interface. Use the same fonts, colors, and UI element design throughout.

Basemaps:

If time and resources permit, it is best to design a basemap from scratch. If not, select an existing design that complements the rest of the map layers and interface design.

Labels:

Map labels should be the top-most layer of a web map so that data layers do not obscure them. Be intentional about the labels that are included on the map, do not simply include labels because you can.

UI design:

Provide a clear point of entry, either in the form of introductory text or as UI elements that suggest initial map locations on the map to view.

The general sentiment amongst participants regarding interactive maps for mobile devices was that the rules have yet to be written. However, there are five general heuristics that emerged from discussion about responsive design for maps regarding how to think about designing maps for a variety of devices.

Think mobile-first:
If you decide that an interaction is unnecessary for mobile, then it is probably unnecessary for desktop, too.

Think touch-first:
When designing a mobile map, imagine a thumb interacting with it, not a mouse cursor. One example of this is in the implementation of selecting a location on a mobile map. Rather than forcing the user to precisely place a map pin in a specific location, instead let them pan the basemap while the pin stays stationary in the middle.

Think map-first:
Because of limited screen real estate, make the map as big as possible while still allowing for the rest of the page content to be accessible.

Think performance-first:
Mobile phones are more likely to have connectivity issues than computers, so make sure to optimize map loading time.

Think presentation-first:
Limited screen real estate restricts a user's ability to really explore a map, so you may adjust your map's objectives if it will primarily be used on mobile. Take advantage of scroll-based interaction to present a clear story to the user.

The following interactive web map best practices fall outside the aforementioned categories:

Accessibility:
Create maps so that they can be read by screen readers and are discernable to people with colorblindness.

Browser compatibility:
Create maps that work across different browsers, as people use a variety of computers and browsers. If you only create maps that work on modern browsers with a fast internet connection, you may miss a lot of your audience.

Coding conventions:
Coding conventions for interactive web maps do not seem to exist across the board. However, it can be helpful to maintain clear internal coding conventions for all of the people who work collaboratively on the same interactive web map to allow for consistency.

SECTION 5.4: Limitations and Future Directions

The interview study reported here has several limitations. One limitation is the subjective nature of the study, with conclusions based on the opinions of people who make interactive web maps. Because the presented workflows and best practices are opinions, they may not actually be optimal, but rather are the most practical under realistic constraints. Another limitation is the expert-based nature of the study, meaning that it did not include the intended users of the maps about which the participants speak. Therefore, it is unknown how the design suggestions that arose from the interviews affect a map's usability and utility. This study did not take into account how interactive web maps should be designed differently depending on different user types. Another limitation is that I did not look at any interactive maps with the participants. Several participants mentioned in their interviews that it was difficult to think of best practices in a broad discussion; I may have been able to extract further specific insights from participants if we had walked through the process and design of one interactive map that they had created. An additional limitation of the study was the sample size. While the sample size of 17 fits with previous cartographic research of this nature, it is

not comprehensive. Finally, I did not take into account the type of organization where participants worked; it is possible that mapping conventions are different in different fields.

Several additional questions and potential future areas of research arose throughout the course of this study. First of all, future studies could test the actual effectiveness of the design conventions identified in Section 5.3. For example, is it actually better to provide less interactivity for purposes of map presentation and more interactivity for map exploration? Also, specific conventions could be tested, e.g., for the implementation of retrieve on mobile, is it better to display retrieved information as a fixed panel below the map or as a sliding panel that appears? Many questions about the evaluation of interactive web maps also emerged from this study. How do you perform usability studies and user testing of interactive web maps? Though there has been some research in this area, many participants did not know how to perform such studies. Additionally, there could be further research about post-deployment evaluation, including the usefulness of map analytics and A/B testing.

Wayfinding is another area of potential research in interactive web maps, especially mobile maps. While this study focused on maps with the objectives of exploration or presentation, many people use interactive maps for wayfinding, which does not clearly fit in either of those categories. How should interactive web maps be designed differently for wayfinding than for exploration or presentation?

Additional future areas of study include:

- *Deployment:* As a newly defined part of the contemporary workflow, how to deploy an interactive web map requires more research.

- *Maintenance:* How does the workflow for maintaining a long-term interactive web map differ from creating one from scratch?

- *Vector tiles and WebGL:* One participant mentioned these technologies as the future of web mapping. More research should be done to better understand them and their potential for changing the mapping landscape.

While much of the future direction of this research is in the world of academia, there are many suggestions for the future of the web mapping industry as well. The most significant takeaway is the need to incorporate more UCD and UE principles into web mapping. Though it may not be feasible for many workplaces to perform usability testing, I believe that organizations can gain a better understanding of their users and begin to talk with them. Additionally, the interviews revealed that participants understand that usability is a key component in the success of a web map, but they generally could not articulate what makes a map usable. Therefore, they do not know what they need to do or which principles to bear in mind to make their maps more usable. Professionals should learn about basic UCD principles, like affordances and feedback and usability heuristics, and incorporate them into web map design to make more usable maps. These are changes that professionals can begin to incorporate now, without needing to speak with users, simply by educating themselves.

Web mapping is in its teenage years. It is no longer in its infancy, but still has time left to become fully-grown: some conventions of web mapping have been established, but for the most part they are still being created. This thesis presents the workflows and conventions of today, but it is anyone's guess what they will look like five or ten years from now. The increasing importance of maps in our everyday lives combined with the unknown nature of their future is what makes being a part of this field so thrilling. I hope to be a part of the movement towards more innovative, more usable interactive maps.

REFERENCES

Albrecht, Jochen, Clare Davies, and Mordechai (Muki) Haklay. 2010. "Application Planning." In *Interacting with Geospatial Technologies*. John Wiley & Sons Ltd.

Andrienko, Natalia, Gennady Andrienko, Hans Voss, Fatima Bernardo, Joana Hipolito, and Ursula Kretchmer. 2002. "Testing the Usability of Interactive Maps in CommonGIS." *Cartography and Geographic Information Science* 29 (4): 325–42. doi:10.1559/152304002782008369.

Bostock, Michael, and Jason Davies. 2013. "Code as Cartography." *Cartographic Journal* 50 (2): 129–35. doi:10.1179/0008704113Z.00000000078.

Brewer, Cynthia A., and Buttenfield, Barbara P. "Framing Guidelines for Multi-scale Map Design Using Databases at Multiple Resolutions." *Cartography and Geographic Information Science* 34, no. 1 (2007): 3.

Brown, M., S. Sharples, J. Harding, C. J. Parker, N. Bearman, M. Maguire, D. Forrest, M. Haklay, and M. Jackson. 2013. "Usability of Geographic Information: Current Challenges and Future Directions." *Applied Ergonomics* 44 (6): 855–65. doi:10.1016/j.apergo.2012.10.013.

Butler, Howard, Martin Daly, Allan Doyle, Sean Gillies, Tim Schaub, and Christopher Schmidt. 2008. "The GeoJSON Format Specification." June 16. http://geojson.org/geojson-spec.html.

Buttenfield, Barbara. 1999. "Usability Evaluation of Digital Libraries." *Science & Technology Libraries* 17 (3-4): 39–59. doi:10.1300/J122v17n03_04.

Caudle, Sharon. 2004. "Qualitative Data Analysis." In *Handbook of Practical Program Evaluation*, edited by Joseph S. Wholey, Harry P. Hatry, and Kathryn E. Newcomer, 2nd ed, 417–38. San Francisco, CA: Jossey-Bass.

Crampton, Jeremy. 1995. "Cartography Resources on the World Wide Web." *Cartographic Perspectives*, no. 22 (Fall): 3–11.

Davidson, Brian D. 2014. "Cartographic Design for Mobile Devices: A Case Study Using the UW-Madison Interactive Campus Map." Madison, Wisconsin: University of Wisconsin-Madison. http://briandaviddavidson.github.io/images/Davidson_Thesis.pdf.

Demšar, Urška. 2007. "Combining Formal and Exploratory Methods for Evaluation of an Exploratory Geovisualization Application in a Low-Cost Usability Experiment." *Cartography and Geographic Information Science* 34 (1): 29–45. doi:10.1559/152304007780279069.

Dent, Borden, Jeff Torguson, and Thomas Hodler. 2008. *Cartography: Thematic Map Design*. 6 edition. New York: McGraw-Hill Education.

Dix, Alan, ed. 2004. *Human-Computer Interaction*. 3rd ed. Harlow, England ; New York: Pearson/Prentice-Hall.

Dix, A. and Ellis, G. (1998). 'Starting simple – adding value to static visualisation through simple interaction', in Working Conference on Advanced Visual Interfaces, pp. 1–20, L'Aquila, May 28–30.

Dondis, D. A. 1973. A Primer of Visual Literacy. p. 194. Cambridge, MA: The Massachusetts Institute of Technology

Donohue, Richard G. 2014. "Web Cartography with Web Standards: Teaching, Learning, and Using Open Source Web Mapping Technologies." University of Wisconsin-Madison.

Edsall, Robert M. 2003. "Design and Usability of an Enhanced Geographic Information System for Exploration of Multivariate Health Statistics*." *The Professional Geographer* 55 (2): 146–60. doi:10.1111/0033-0124.5502003.

Edsall, R., Andrienko, G., Andrienko, N. and Buttenfield, B. (2008).'Interactive maps for exploring spatial data', in Manual of Geographic Information Systems, ed. by Madden, M., pp. 837–858, ASPRS, Bethesda, MD.

Fielding, Roy Thomas. 2000. "Architectural Styles and the Design of Network-Based Software Architectures." Doctoral dissertation, University of California, Irvine. https://www.ics.uci.edu/~fielding/pubs/dissertation/net_arch_styles.htm#sec_3_4.

Flowers, Erik. 2012. "UX Is Not UI." *HelloErik Experience Design*. December 15. http://www.helloerik.com/ux-is-not-ui.

Fuhrmann, Sven, and William Pike. 2005. "User-Centered Design of Collaborative Geovisualization Tools." *Exploring Geovisualization*, 591–610.

Gabbard, J.L., D. Hix, and J.E. Swan. 1999. "User-Centered Design and Evaluation of Virtual Environments." *IEEE Computer Graphics and Applications* 19 (6): 51–59. doi:10.1109/38.799740.

Gale, Gary. 2013. "Push Pins, Dots, Customisation, Brands and Services: The Three Waves of Making Digital Maps." *The Cartographic Journal* 50 (2): 155–60. doi:10.1179/0008704113Z.00000000081.

Haklay, Mordechai, and Carolina Tobón. 2003. "Usability Evaluation and PPGIS: Towards a User-Centred Design Approach." *International Journal of Geographical Information Science* 17 (6): 577.

Haklay, Muki. 2010. *Interacting with Geospatial Technologies*. 1st ed. Hoboken: Wiley.

Haklay, Mordechai, and Annu-Maaria Nivala. 2010. "User-Centred Design." In *Interacting with Geospatial Technologies*, edited by Mordechai Haklay, 91–106. Hoboken: Wiley.

Hardisty, Frank, and Anthony C. Robinson. 2011. "The Geoviz Toolkit: Using Component-oriented Coordination Methods for Geographic Visualization and Analysis." *International Journal of Geographical Information Science* 25, no. 2: 191-210.

Harrower, Mark. 2008. "The Golden Age of Cartography Is Now." *Axis Maps*. October 27. http://www.axismaps.com/blog/2008/10/the-golden-age-of-cartography-is-now/.

Harrower, Mark, and Benjamin Sheesley. 2008. "Designing Better Map Interfaces: A Framework for Panning and Zooming." *Transactions in GIS* 9, no. 2: 77-89.

Hassenzahl, Marc. 2014. "User Experience and Experience Design." Edited by Mads Soegaard and Rikke Friis Dam. *The Encyclopedia of Human-Computer Interaction, 2nd Ed.* /encyclopedia/user_experience_and_experience_design.html.

Hassenzahl, Marc, and Noam Tractinsky. 2006. "User Experience - a Research Agenda." *Behaviour & Information Technology* 25 (2): 91–97. doi:10.1080/01449290500330331.

Holtsnider, Bill, and Brian D. Jaffe. 2012. *IT Manager's Handbook: Getting Your New Job Done*. Third. Morgan Kaufmann Publishers.

Hubert, Elizabeth. 2012. "Interaction Design Beyond the Interface." *Experience Design Consulting*. December 12. http://www.elisabethhubert.com/2012/12/interaction-design-beyond-the-interface/.

Hussain, Zahid, Wolfgang Slany, and Andreas Holzinger. 2009. "Investigating Agile User-Centered Design in Practice: A Grounded Theory Perspective." In *HCI and Usability for E-Inclusion*, edited by Andreas Holzinger and Klaus Miesenberger, 279–89. Lecture Notes in Computer Science 5889. Springer Berlin Heidelberg.

http://link.springer.com.ezproxy.library.wisc.edu/chapter/10.1007/978-3-642-10308-7_19.

Krug, Steve. 2014. *Don't Make Me Think, Revisited: A Common Sense Approach to Web Usability*. Third edition. Berkeley, Calif.: New Riders.

MacEachren, Alan M. 1994. "Visualization in Modern Cartography: Setting the Agenda." In *Visualization in Modern Cartography*, edited by Alan M. MacEachren and D. R. F. Taylor, 1st ed. Modern Cartography, v. 2. Oxford, England ; New York, U.S.A: Pergamon.

MacEachren, A. M., Boscoe, F. P., Haug, D. and Pickle, L. W. (1998). 'Geographic Visualization: Designing manipulable maps for exploring temporally varying georeferenced statistics', in IEEE Symposium on Information Visualization, pp. 87–94, Raleigh–Durham, NC, Oct 19–20.

MacEachren, Alan M., and Menno-Jan Kraak. 2001. "Research Challenges in Geovisualization." *Cartography and Geographic Information Science* 28 (1): 3–12. doi:10.1559/152304001782173970.

Marcotte, Ethan. 2011. *Responsive Web Design*. Brief Books for People Who Make Websites, no. 4. New York: A Book Apart.

Marsh, Stephanie Larissa, and Mordechai Haklay. 2010. "Evaluation and Deployment." In *Interacting with Geospatial Technologies*, edited by Mordechai Haklay, 199–221. Hoboken: Wiley.

McConchie, Alan. 2016. "Doing Cartography as Professional Amateurs." February 8. http://www.esri.com/events/cartographic-summit/recordings.

Mead, Rashauna. 2014. "Expert Perspectives on the Design and Use of Learning Materials for Neocartographic Interfaces." Madison, Wisconsin: University of Wisconsin-Madison.

Miller, Christopher C. 2006. "A Beast in the Field: The Google Maps Mashup as GIS/2." *Cartographica: The International Journal for Geographic Information and Geovisualization* 41 (3): 187–99. doi:10.3138/J0L0-5301-2262-N779.

Muehlenhaus, Ian. 2013. "The Design and Composition of Persuasive Maps." *Cartography and Geographic Information Science* 40 (5): 401–14. doi:10.1080/15230406.2013.783450.

———. 2014a. *Web Cartography: Map Design for Interactive and Mobile Devices*. CRC Press, Taylor & Francis Group. https://www.crcpress.com/product/isbn/9781439876220.

———. 2014b. "Going Viral: The Look of Online Persuasive Maps." *Cartographica: The International Journal for Geographic Information and Geovisualization* 49 (1): 18–34. doi:10.3138/carto.49.1.1830.

Nielsen, J. 1992. "The Usability Engineering Life Cycle." *Computer* 25 (3): 12–22. doi:10.1109/2.121503.

Nielsen, Jakob. 1994. *Usability Engineering*. Updated ed. San Francisco, Calif: Morgan Kaufmann Publishers.

Norman, Donald A. 1998. *The Design of Everyday Things*. 2002 kindle edition. New York: Doubleday.

Poplin, Alenka. 2015. "How User-Friendly Are Online Interactive Maps? Survey Based on Experiments with Heterogeneous Users." *Cartography and Geographic Information Science* 0 (0): 1–19. doi:10.1080/15230406.2014.991427.

Project Management Institute. 2013. *A Guide to the Project Management Body of Knowledge*. Fifth. Project Management Institute.

Rasmusson, Jonathan. 2010. *The Agile Samurai: How Agile Masters Deliver Great Software*. Edited by Susannah Davidson Pfalzer. Raleigh, North Carolina: The Pragmatic Bookshelf. http://www.cs.umss.edu.bo/doc/material/mat_gral_130/the_agile_samurai.pdf.

Robinson, Anthony C., Jin Chen, Eugene J. Lengerich, Hans G. Meyer, and Alan M. MacEachren. 2005. "Combining Usability Techniques to Design Geovisualization Tools for Epidemiology." *Cartography and Geographic Information Science* 32 (4): 243–55. doi:10.1559/152304005775194700.

Robinson, A.C. 2009. "Needs Assessment for the Design of Information Synthesis Visual Analytics Tools." In *Information Visualisation, 2009 13th International Conference*, 353–60. doi:10.1109/IV.2009.85.

Robinson, Anthony C., Alan M. MacEachren, and Robert E. Roth. 2011. "Designing a Web-Based Learning Portal for Geographic Visualization and Analysis in Public Health." *Health Informatics Journal* 17 (3): 191–208. doi:10.1177/1460458211409718.

Robinson, Anthony C. 2011. "Highlighting in Geovisualization." *Cartography and Geographic Information Science* 38 (4): 373–83. doi:10.1559/15230406384373.

Rosson, Mary Beth, and John M. Carroll. 2001. *Usability Engineering: Scenario-Based Development of Human-Computer Interaction*. Elsevier.

Roth, Robert E., Richard G. Donohue, Carl M. Sack, Timothy R. Wallace, and Tanya M. A. Buckingham. 2015. "A Process for Keeping Pace with Evolving Web Mapping Technologies." *Cartographic Perspectives* 0 (78): 25–52. doi:10.14714/CP78.1273.

Roth, Robert E., Kevin S. Ross, and Alan M. MacEachren. 2015. "User-Centered Design for Interactive Maps: A Case Study in Crime Analysis." *ISPRS International Journal of Geo-Information* 4 (1): 262–301. doi:10.3390/ijgi4010262.

Roth, Robert E. 2012. "Cartographic Interaction Primitives: Framework and Synthesis." *The Cartographic Journal* 49 (4): 376–95. doi:10.1179/1743277412Y.0000000019.

———. 2013. "Interactive Maps: What We Know and What We Need to Know." *Journal of Spatial Information Science* 0 (6): 59–115. doi:10.5311/josis.v0i6.105.

———. 2013. "An Empirically-Derived Taxonomy of Interaction Primitives for Interactive Cartography and Geovisualization." *IEEE Transactions on Visualization and Computer Graphics* 19 (12): 2356–65. doi:10.1109/TVCG.2013.130.

———. 2015. "Interactivity and Cartography: A Contemporary Perspective on User Interface and User Experience Design from Geospatial Professionals." *Cartographica* 50 (2): 94–115. doi:10.3138/carto.50.2.2427.

———. 2015. "Cartography 2.0 - Overview: Interface Evaluation." *GitHub*. Accessed May 13. https://github.com/ajturner/neocartography-wiki.

Roth, Robert E., and Mark Harrower. 2008. "Addressing Map Interface Usability: Learning from the Lakeshore Nature Preserve Interactive Map." *Cartographic Perspectives* 0 (60): 46–66. doi:10.14714/CP60.231.

Sack, Carl M., Richard G. Donohue, and Robert E. Roth. 2015. "Interactive and Multivariate Choropleth Maps with D3." *Cartographic Perspectives* 0 (78): 57–76. doi:10.14714/CP78.1278.

Shneiderman, Ben, and Catherine Plaisant. 2010. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. 5th ed. Boston: Addison-Wesley.

Slocum, Terry A., Daniel C. Cliburn, Johannes J. Feddema, and James R. Miller. 2003. "Evaluating the Usability of a Tool for Visualizing the Uncertainty of the Future Global Water Balance." *Cartography and Geographic Information Science* 30 (4): 299–317. doi:10.1559/152304003322606210.

Slocum, Terry A., Robert S. Slutter Jr., Fritz C. Kessler, and Stephen C. Yoder. 2004. "A Qualitative Evaluation of MapTime, A Program For Exploring Spatiotemporal Point Data." *Cartographica* 39 (3): 43–68.

Slocum, Terry A., Robert B. McMaster, Fritz C. Kessler, and Hugh H. Howard. 2008. *Thematic Cartography and Geovisualization, 3rd Edition.* 3rd edition. Upper Saddle River, NJ: Prentice Hall.

Smith, Aaron. 2015. "U.S. Smartphone Use in 2015." *Pew Research Center: Internet, Science & Tech.* April 1. http://www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/.

Suchan, Trudy A., and Cynthia A. Brewer. 2000. "Qualitative Methods for Research on Mapmaking and Map Use." *The Professional Geographer* 52 (1): 145–54. doi:10.1111/0033-0124.00212.

Timoney, Brian. 2012. "How the Public Actually Uses Local Government Web Maps: Metrics from Denver : MapBrief™." August 1. http://mapbrief.com/2012/08/01/how-the-public-actually-uses-local-government-web-maps-metrics-from-denver/.

Tolochko, Robin. 2015. "Why We Teach You Responsive Web Design." *Online Professional Master's in GIS and Web Map Programming.* December 8. http://geography.wisc.edu/gisdev/index.php/2015/12/08/why-we-teach-you-responsive-web-design/.

Tsou, Ming-Hsiang. 2011. "Revisiting Web Cartography in the United States: The Rise of User-Centered Design." *Cartography and Geographic Information Science* 38 (3): 250–57. doi:10.1559/15230406382250.

Veregin, Howard, and A. J. Wortley. 2014. "Using Web Analytics to Evaluate the Effectiveness of Online Maps for Community Outreach." *Journal of Web Librarianship* 8 (2): 125–46. doi:10.1080/19322909.2014.873659.

Whitefield, Andy, Anthony Esgate, Ian Denley, and Paul Byerley. 1993. "On Distinguishing Work Tasks and Enabling Tasks." *Interacting with Computers* 5 (3): 333–47. doi:10.1016/0953-5438(93)90014-K.

Willis, Dan. 2011. "The UX Umbrella." presented at the DC Startup Weekend, November 11. http://www.slideshare.net/uxcrank/the-ux-umbrella.