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Beyond the Peel

Combining Art, Storytelling, and Visualization to Convey and Contextualize Map Projection Distortion

Esmé Middaugh

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Beyond the Peel

Combining Art, Storytelling, and Visualization to Convey and Contextualize Map Projection Distortion

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Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"Beyond the Peel: Combining Art, Storytelling, and Visualization to Convey and Contextualize Map Projection Distortion"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

München, 18.09.2022 Esmé Middaugh

BEYOND THE PEEL

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ABSTRACT

The public is increasingly familiar with the concept that "all maps lie." Awareness of distortion, however, is only part of the equation. Cartographers must be able to demonstrate the specifics of map distortions, and do so in a way that is *engaging and relevant* to map readers. Specifically, cartographers must be able to demonstrate how distortion shapes the narratives consumed on a daily basis. To demonstrate this, cartographers must examine currently available techniques and consider others. This thesis presents the current research on map projection literacy before offering a thematic, artistic, storytelling-based alternative.

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ACRONYMS

D3 Data-Driven-Documents

FMPL Functional Map Projection Literacy

MPD Map Projection Distortion

TI Tissot's indicatrices

TPF The Projection Flipbook

Part I

BACKGROUND

1

INTRODUCTION

The truth is not distorted here, but rather a distortion is used to get at truth.
—Flannery O'Connor

Confronted with a map, what does the average person think? Do thoughts of map projections and possible distortions cross their mind? Do questions surface of how the map's projection might be shaping the story they are consuming? Based on the current state of map projection knowledge (Battersby, 2006, 2009), this seems unlikely.

Map projections portray all or part of the round earth on a flat surface (John Parr Snyder, 1987). The inevitable distortion that results from this process (it is mathematically impossible to transform points from 3D to 2D without some form of distortion) affects one or more of direction, distance, area, and shape (International-Cartography-Association, 2022). Due to viral videos and articles, the public has greater awareness and exposure to map projections than ever before (Vox, 2016). However, there still appears to be a large gap between awareness and understanding (Battersby, 2009).

A basic understanding of map projections includes "knowledge about types of map projections [...] and the ability to judge the accuracy and appropriateness of map projections for different purposes." (Hawkins et al., 1998). Beyond this, it is critical to understand that all maps distort and that they must (Monmonier, 2018; John Parr Snyder, 1987). That some projections are better suited than others, but all have their strengths and weaknesses (Burkalow, 1955). That there can be no perfect projection (Battersby, 2021; Monmonier, 2018) and that a projection is not inherently good or bad, but that it depends on a map's context and content.

Critically considering a map requires some degree of map projection literacy. A public with an ability to critically consider the ever-growing number of maps they are confronted with daily is important (Muehrcke, 1974) for two seemingly contradictory reasons. On the one hand, placing inordinate faith in maps and uncritically accepting them as true and complete representations is dangerous, for throughout history maps have been used time and time again as persuasive tools (Tyner, 1982). With the increasing prevalence of news maps (Monmonier, 1984) and viral cartography (Muehlenhaus, 2014; A. C. Robinson, 2019), it is perhaps now even more important that map users can look at maps critically.

On the other hand, map projection literacy is necessary to avoid the reactionary dismissal of maps and cartographic endeavors. Cartographers have long argued that maps confer on their contents an irreproachable air of truth, authority, and completeness (Griffin, 2020; Tyner, 1982). However, the current environment filled with cries of

'fake news,' the proliferation of viral maps—some with admittedly questionable projections—from amateur map makers, and a public with a limited but reactionary view of map projections (Walters, 2017) seems to create a perfect situation for the pendulum to swing to the other extreme. As the International Cartographic Association Committee on Map Projections notes, the very term used to describe the effects of map projections, "distortion" is an unfortunate choice as it has undesirable connotations of deception (Arthur H. Robinson and John P. Snyder, 1997). A half-formed understanding of map projections leads to reactionary dismissal of maps without cause, or well-intentioned but questionable policy changes (Vujakovic, 2003; Walters, 2017). The discourse and education surrounding map projections must make it clear that distortion is not automatically equivalent to deception.

Many tools exist that effectively convey map projection distortion (Mulcahy and K. C. Clarke, 2001). However, to the vast majority of people, map projections are dull. The public at large has "little to no interest in, or ability to, understand/compensate for map projection distortion" (Battersby, 2021). Crucial to the question of increasing map projection literacy, then, is the question of how to make projection distortion interesting and relevant to people outside the cartographic sphere. This thesis explores the possibilities of alternative approaches such as art and storytelling further this approach.

1.1 MOTIVATION AND PROBLEM STATEMENT

My motivation for selecting this topic can be best summarized by my experience explaining my planned thesis topic to people outside of cartography. Upon uttering 'map projections,' the responses have overwhelmingly been some derivation of the following:

- Projections? Hmm, that sounds confusing ...
- Oh, how Mercator is bad and makes Greenland way too big, right?
- Like that scene in *The West Wing*![1]

Perhaps like most master's students, I originally had an entirely different thesis on projections planned. Coming from a background of data visualization and aware of Stephen's power law, the idea that different stimuli—length, volume, area, etc.—are perceived differently, with certain stimuli like length being perceived at a 1:1 ratio, with others being perceived at different power ratios (Stevens, 1957),

1 *The West Wing* was a popular early 2000s serial political drama television show. In one episode, there is a scene where the 'Cartographers for Social Equality' argue that the Mercator projection has "fostered European imperialist attitude for centuries and created an ethnic bias against the third world."

I wanted to examine if one could modify or scale Tissot's indicatrices (TI) to be perceived correctly according to the law. As I looked more into what this would entail, however, I quickly realized that there are complications with Stephen's Power Law that would have made this a questionable endeavor. Searching for alternatives, I knew the area of map projection distortion was ripe for exploration given people's reactions when hearing the term 'map projections.'

Outside of the cartographic sphere, map projections seem to be a hazy and somewhat misunderstood topic. All too often, people are either completely unaware of them or have a half-formed, polarized lens, formed by television shows or click-bait titles. The more I researched the area, the more I became convinced of the importance of focusing not just on the basic understanding of how map projections distort, but the understanding that a single map is never the whole truth "but one of an indefinitely large number of maps that might be produced for the same situation or from the same data" (Dunlop, 2008). Giving a more complete picture of map projections that seemed an interesting challenge.

Crucial to the question of increasing understanding and knowledge of distortion was the question of how to make projection distortion interesting and relevant to people outside the cartographic sphere. I wanted to explore alternative ways to present map projections, one that linked map projections and distortion to perception and understanding of thematic maps. I have always been interested in design and the artistic side of cartography and was interested in approaching the topic from this perspective. As my supervisor was supportive of taking an artistic approach, I decided to structure my thesis around two key items. First, a literature review covering how projection distortion has been conveyed in the past and the current state of map projection literacy and its importance. And second, creating a project that offered an alternative approach.

1.2 RESEARCH IDENTIFICATION

1.2.1 *Research Objectives*

The key goals of this project are to examine current distortion visualization techniques, illustrate the importance of distortion understanding, and provide an example of how art and storytelling could be integrated to address the two former points. Art can "address significant concepts and prompt viewers to think about them, perhaps for the first time or more deeply than they have before"(Marshall and Donahue, 2014). What then, could an artistic approach to conveying distorting look like? A final artistic product will be created by combining and employing a range of information visualization, design,

storytelling, and artistic methods. The specific research objectives are below.

R01 To present the benefits and limitations of current distortion visualization offerings. This will include a review of current literature on visualization techniques, the importance of understanding distortion, the current level of projection distortion awareness, and the current visualization techniques themselves. The techniques used to convey map distortion will be examined from a theoretical (including perceptual science perspective), as well as from a personal standpoint of understandability, use, appeal, etc.

R02 To explore how distortion can be conveyed artistically within the context of a thematic cartographic story. Distortion is often presented in isolation, explained and visualized separately from the thematic stories that it shapes. What happens, however, when a map reader can explore distortion in context? Here I will utilize and/or modify existing techniques, within an appropriate thematic story. By doing so, I aim to explore and offer one possible solution of how to make distortion relevant, personal, and understandable to the everyday map reader. By embedding different projections and distortion visualizations within a thematic story, this project offers a different solution to conveying distortion. One that hopefully provides the viewer with a more nuanced and critical view of projections and their role in shaping a map's narrative.

1.2.2 *Research Questions*

RQ 1 In which ways could the general public benefit from a better understanding of map projections and their distortions?

- RQ 1.1 Why is an understanding of map projections important to those outside the cartographic sphere?
- RQ 1.2 What are some examples where knowledge, or lack of knowledge, regarding map projection distortion shaped public events or has an impact?
- RQ 1.3 What is the layman's knowledge of map projection distortion?

RQ 2 What key methods are currently used to convey the effect of distortion?

- RQ 2.1 What are the strengths and limitations of these technical methods?
- RQ 2.2 How could alternative methods help to overcome the existing limitations?

RQ 3 How might artistic and storytelling methods help to make distortion interesting, understandable, evocative, and relatable beyond the theoretical level?

RQ 3.1 How could this help people to be more conscious consumers of maps?

RQ 3.2 What are the benefits and limitations of an artistic approach as opposed to conventional methods?

RQ 3.3 What are the benefits and limitations of a storytelling approach as opposed to conventional methods?

RQ 4 What could an artistic, thematic, storytelling approach to conveying distortion look like?

RQ 4.1 Which visualization techniques are well suited to said alternative approach?

RQ 4.2 What requirements would data need to fulfill to relay distortion effectively?

RQ 4.3 How can the juxtaposition of different projections be used to help emphasize the narrative impacts of distortion?

RQ 5 What possible insights could be gleaned from the creation of such a project and how might one evaluate said project?

1.3 THESIS STRUCTURE

This thesis is structured as follows. First, a literature review covering map projections and their importance is presented. This begins by offering a definition of functional map projection literacy, its importance in today's society, and the current state of map projection literacy. Research on increasing levels of map projection literacy outside the cartographic sphere is then presented, including an overview of existing methods to convey distortion and their strengths and limitations. Possible alternative methods to address the problem are then presented.

Following the literature review, a detailed description of the process of exploring alternative method implementations is presented. This chapter details the artistic ideation phase and the decision to pursue the creation of *The Projection Flipbook*. The data, technical, and aesthetic choices behind *The Projection Flipbook* are then detailed, and screenshots of the final product are included.

The results chapter outlines how the project was evaluated and lays out the qualitative results. The discussion chapter explores themes presented in the results, outlines limitations of this project, and offers possible future paths of research, both for *The Projection Flipbook* itself and the area of alternative methods for conveying distortion.

2

LITERATURE REVIEW

What is the importance of map projection understanding to those outside the realms of cartography? What is their current state of understanding? What efforts are being made to increase functional map projection literacy on a broad scale? And what techniques exist to help convey distortion and broaden this understanding? These questions, more formally stated in Chapter 1, form the basis of this literature review. First, I present research on the importance of functional map projection literacy generally and in today's climate, followed by an examination of the current status. Finally, I present research as to the possible benefits and limitations of two alternative approaches, namely art and storytelling.

2.1 DEFINITIONS

Map projections portray all or part of the round Earth on a flat surface (John Parr Snyder, 1987). The inevitable distortion that results from this process (it is mathematically possible to transform points from 3D to 2D without some form of distortion) affects one or more of direction, distance, area, and shape (International-Cartography-Association, 2022). For a non-cartographer—or rather, someone unconcerned with the construction of such projections—comprehending the possible effects of this distortion is at the heart of the necessary map projection knowledge. Drawing from D. Clarke's idea of 'functional map literacy,' here we define *functional map projection literacy (FMPL)*. Based upon the *1994 USA NAEP Geography Assessment*'s definition of map literacy, we define the basics of functional map projection literacy to include "knowledge about types of map projections [...] and the ability to judge the accuracy and appropriateness of map projections for different purposes" (Hawkins et al., 1998). Beyond these guidelines of map projections themselves, there is also the crucial aspect of encouraging *critical consideration* of maps and map projections. This critical consideration includes at the bare minimum some concept of the following points:

- that all maps distort, and that they must (Monmonier, 2018; John Parr Snyder, 1987),
- that some projections are better suited than others, but all have their strengths and weaknesses (Burkalow, 1955), and

- that there can be no perfect projection (Battersby, 2021; Monmonier, 2018) and that a projection is not inherently good or bad, but that it depends on context and content.

2.2 IMPORTANCE OF FUNCTIONAL MAP PROJECTION LITERACY

Who requires functional map projection literacy and for which reasons? As John Parr Snyder (1987) writes, it is not only map makers that need to understand projections, map users must also have a basic understanding of projections. Anderson and Leinhardt (2002) are more explicit, asserting that "projections are important to geography, not only as a map convention to be learned, but also as a conceptual tool for reasoning in the discipline." Map projection literacy plays an important function in map literacy (Hawkins et al., 1998), and map literacy is in turn an important aspect of everyday life (D. Clarke, 2003; Dong et al., 2018) and in the teaching of foundational areas such as world history (Battersby and F. C. Kessler, 2012). Furthermore, FMPL also plays a critical role in geographic literacy (Anderson and Leinhardt, 2002; Juergens, 2020). Geographic literacy, or geoliteracy—the terms are used interchangeably throughout this thesis—is "the ability to understand, process, and utilize spatial data" (Turner and Leydon, 2012).[1] Geographic literacy is important for cartographers and non-cartographers alike (Anderson and Leinhardt, 2002; Chiodo, 1993; Shulsky et al., 2017), as it plays an important role in everyday living (Turner and Leydon, 2012). Good geoliteracy allows people to avoid choices that will be costly to themselves and the environment (Edelson, 2014). Poor geographic literacy engenders a society with diminished capabilities to make educated choices about crucial decisions (Turner and Leydon, 2012). The immediate and far-reaching impacts of understanding map projections make FMPL a significant skill for cartographers and *non-cartographers* alike.

2.2.1 *Importance of Functional Map Projection Literacy Today*

Functional map projection literacy and its 'parent' geoliteracy are more important than ever. This has two reasons. The first, and perhaps simpler, reason, is the need to empower people to use geographic tools, which are increasingly prevalent and required in the workforce. In their 2008 paper on the importance of spatial literacy, Schultz, Kerski, and Patterson reference a report from the Geographical Sciences Committee of the National Research Council, *Support for Think-*

1 Edelson (2014) provides a broader definition of geoliteracy as "the understanding of human and natural systems, geographic reasoning, and systematic decision-making." Given that this broader definition includes geographic literacy at its core, it does not feel unnatural to use both terms.

ing Spatially: The Incorporation of Geographic Information Science Across the K–12 Curriculum:

> Given the need for increased scientific and technological literacy in the workforce and in everyday life, we must equip K. 12 graduates with skills that will enable them to think spatially and to take advantage of tools and technologies—such as geographic information systems (GIS) for supporting spatial thinking. (p. 13)

A rudimentary understanding of map projections is necessary to be able to use the "tools and technologies" like GIS. Increasing FMPL can only help better equip people for navigating the workforce. For example, professions like planning require the use of geographic software and the creation of maps, but people in these professions often are not given the training on projections necessary. "Planners often fail to determine the projection, coordinate systems, and 'datums' used to prepare" the maps they have acquired from different sources (R. B. Kent and Klosterman, 2000). Admittedly, such details are not immediately important to planners, but R. B. Kent and Klosterman points out that in reality map projections and coordinate systems used "can be extremely important because GIS system defaults are often spherical coordinates (e.g., latitude and longitude) that produce distorted images for small areas such as states and counties." Greco also notes the difficulty and confusion that map projections cause GIS users, pointing out the vast inaccuracies that arise from missing "map projection file" errors. Similarly, Mulcahy and K. C. Clarke (2001) point out that for any GIS user operating at the continent scale or larger, functional map projection literacy is essential "during the data capture, management (registration, merging, overlay), and analysis stages." FMPL is similarly important in other fields. Muehrcke (1974) calls out environmental design specifically, denoting it as an area where "misuse of maps, or outright map reading abuses, could lead to adverse human and environmental impact." In our interconnected and digital world, the ability to manipulate and work with spatial data—which requires a functional knowledge of map projections—is important to increasingly larger swaths of the population.

Second, and arguably more important given its far-reaching implications, is the need to successfully navigate through the slew of maps shared via social media. In this age of "viral cartography," the power of maps to "lead (and mislead) readers" is only amplified (A. C. Robinson, 2019). The glut of unchecked information available via the web coupled with the widespread availability of map-making software is a potentially dangerous combination. Inappropriate projections can easily be used to make a crises look more severe or threatening to induce "click-bait" and encourage spread. A. C. Robinson (2019) notes a recent swell of maps that "purport to show the range

of North Korean ballistic missiles, some of which use projections appropriately, and some that do not." Readers must be able to distinguish, or at least question, if the information presented in such maps seems plausible or looks more drastic because of the projection used. Another telling example comes from the recent COVID-19 pandemic. The World Health Organization noted that the pandemic was worsened by an accompanying "infodemic" that made it challenging for people to access and know what reliable information was (Mooney and Juhász, 2020). Inaccurate or misleading maps will always circulate the web, but if people have no geoliteracy skills they will have little chance to judge the map accurately. With geoliteracy skills—including FMPL—people can at least consider if a map seems suspect or may be trying to persuade deceptively.[2]

In an age where anyone can make an impressive-looking persuasive map and said maps can be shared via a single click on social media, it is more pressing to educate the public to view maps critically (Muehlenhaus, 2014). The public, as both amateur creators and consumers of cartography, needs to be aware of and have a nuanced understanding of the "idiosyncrasies of map projections" (Brainerd and Pang, 2001). This nuanced understanding that Brainerd and Pang mention is necessary to avoid falling into the dilemma that so often entangles cartography:

> [...] the canons of traditional cartographical criticisms with its string of binary oppositions between maps that are "true and false," "accurate and inaccurate," "objective and subjective," "literal and symbolic," or that are based on "scientific integrity" as opposed to "ideological distortion." (Harley, 2009, p.129)

Pidgeon-holing maps to either side of this dichotomy is not helpful or productive. Unfortunately, map projections and discussions surrounding map projections very often fall prey to this trap. The very articles that aim to explain map projections use clickbait titles such as "Maps Have Been Lying to You Your Entire Life" (Hamilton, 2016) and *Why All World Maps are Wrong* (Vox, 2016), which do nothing but contribute to this view. This is particularly concerning when one considers the constant claims of 'fake news.' At a time when clicks bring money, these titles are not surprising, and yet they do little to help productively broaden understanding. Their contents sometimes do paint a broader picture of map projections—Vox's *Why All Maps Are Wrong*, have propelled *Why All World Maps are Wrong* and *Maps*

2 Maps shared via social media are often persuasive, and indeed persuasive maps and seen more often than scientific-looking maps (Mulcahy and K. C. Clarke, 2001). While projection-misuse is not as prevalent among persuasive maps as one might think—a 2013 study ran by Muehlenhaus found that in a survey of persuasive maps, "more maps used cartographically appropriate projections than inappropriate ones (24% appropriate, 11% inappropriate, 65% undetermined)—it still occurs.

have been lying to you all your life. Yes, even Google Maps both provide excellent explanations later on in the videos—but the headlines merely take mapping from the true, accurate, objective bucket and thrust it instead into the false, inaccurate, ideological bucket, further widening the gap between the two and decreasing trust in cartography at a broader level. This decrease in trust is concerning:

> [...] changes in society (e.g., lower levels of trust in decision makers) and in mapmaking technologies and practices (e.g., anyone can now make their own maps) mean that we need to spend some time thinking about how, when, and why people trust maps and mapmaking processes. This is critically important if we want stakeholders to engage constructively with the information we present in maps, because they are unlikely to do so if they do not trust what they see. (Griffin, 2020, p. 5)

While many studies in cartography have pointed out that maps have long been imbued with an aura of truth (Griffin, 2020; Tyner, 1982), in recent years, there has been a shift to the other extreme (Griffin, 2020). Neither extreme is good. Maps should not automatically be trusted, and nor should they automatically be condemned. A map should be evaluated on its own merits, and cartography and the mapping process should be seen for what it is; an imperfect science and art that has limitations and can be used—intentionally or unintentionally—to enlighten or deceive.

Ironically, the increased awareness of map projections may be partially contributing to this shift from one extreme to the other. Well-intentioned efforts to increase geoliteracy and appropriate use of map projections are themselves guilty of propagating the 'good' vs. 'bad' dichotomous view that can erode general levels of trust. For example, in 2017 Boston Public Schools elected to discontinue their use of the Mercator projection, stating that "in an age of 'fake news' and 'alternative facts,' city authorities are confident their new map offers something closer to the geographical truth than that of traditional school maps, and hope it can serve an example to schools across the nation and even the world" (Walters, 2017). While the desire to include alternatives to Mercator and present a more suitable Global map is commendable, their replacement choice—the Gall-Peters projection—is perhaps equally questionable, to cartographers and aestheticians at the very least (cartography professor Arthur Robinson famously described the projection as "resembling wet, ragged, long winter underwear hung out to dry"). Simply substituting in one projection for another without discussing how the projection process works is not helpful. In another case, Vujakovic (2003) notes how he was once castigated by a colleague for using Mercator instead of Gall-Peters, when in fact he had not used Mercator or Gall-Peters but a different suit-

able equal-area projection. His colleague's understanding of projections stopped at "Mercator is bad, Peters is good," with no ability to look at the map in front of her and see what it actually showed. If education in map projections stops at here, there is no room for the nuanced understanding of map projections that is necessary for FMPL, better evaluation of individual maps, and continued trust in the cartographic process. Both of these cases illustrate how the lack of ability to *critically* look at map projections can cause misplaced distrust. As Griffin (2020) writes, it is now more important than ever for map readers to be "capable of critically interrogating a map" to make decisions about that map's efficacy and to maintain trust in cartography.

2.2.2 *Illustrations of the Importance of Functional Map Projection Literacy*

It is also useful to consider the practical implications of FMPL. Imagine for a moment, someone planning a road trip of the USA[3]. If they trying to take the shortest possible route across the states, their decision to take the north or south route would likely be influenced by the map projection used. Should you be unfamiliar with map projections and planning out your journey based on a zoomed-out view of Google Maps (which uses Web Mercator) it would be difficult to select the shortest route, and your selection could easily add an extra day of driving. Or for a more global perspective, Monmonier (2005) points out that Muslims need to know the direction to Mecca to pray. Should they be consulting a map to determine this and that map uses a projection that distorts direction, it would be difficult to know the correct direction. It is true that we increasingly use spatial tools that have easy answers to these questions. But without functional map literacy, people cannot understand why there could be such differences between a paper map and Google Maps, or between one online map and another.

The past also provides many examples of the importance of map projection literacy. Or more specifically, where a lack of map projection knowledge enabled questionable mapping practices to go unchecked. Thomas Frederick Saarinen (1988) notes that multiple sources have pointed to projections as one of the reasons why the Axis powers underestimated the geopolitical role of America in WWII. At the same time, azimuthal maps created by Richard Edes Harrison (see Figure 1) for Fortune Magazine helped to change Americans' isolationist view of the world and demonstrate how an air-based war would be fought (KERO, 2018; Nelson, 2020).

In his 1982 article 'Persuassive Cartography,' Tyner provides two more instances.

3 This example stems from a conversation with my thesis advisor Priv.-Doz. Dr. Franz-Benjamin Mocnik.

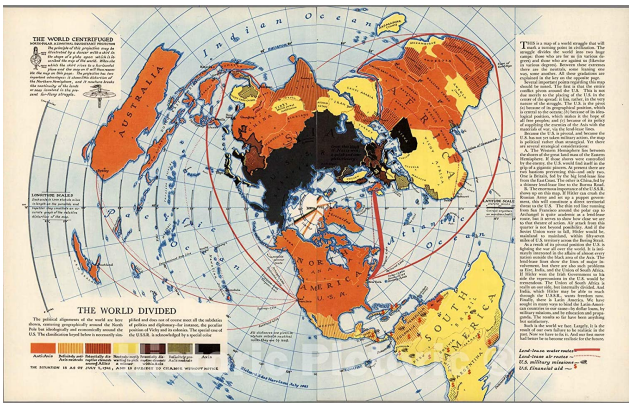


Figure 1: *Richard Edes Harrison's 'The World Divided' first published in Fortune Magazine, 1941. Taken from Cornell University – PJ Mode Collection of Persuasive Cartography.*

> One of the most common forms of map distortion is the manipulation of scale to deliberately stretch or compress distance. Transportation advertising has provided maps with blatantly distorted scales. In the late nineteenth century, many U.S. railroads used advertising maps with distorted scales to give the impression that their routes were more direct and involved shorter distances than competing routes. These distortions required that the shape and size of states be changed as well. Airlines and trucking firms have also distorted maps of their routes in advertisements. In all of these cases, the goal was to persuade the reader to conclude that the advertised line would give more direct and rapid service.
>
> In many instances scale distortion has had far-reaching effects. For example, during Australia's gold rush, the towns of Melbourne and Geelong were in competition to become the main port for the gold fields of Ballarat. A map that falsely, and apparently deliberately, showed Melbourne as the closer town was prepared. As a result, according to the disgruntled citizens of Geelong, Melbourne grew rapidly and became the state capital.

In both these cases, projection and scale distortion was deliberately modified by the map creator. If map readers had a slightly better understanding of distortion and ways in which the map they were reading, they may have been able to question such distorted maps and make more informed decisions.

Examples of the importance of FMPL are not only historical. In a U.S. based study, Bar-Natan, Najt, and Schutzman (2020) found that projection choice can influence a voting district's compactness scores. Should one political party be aware of this and the other not, it is not

hard to conceive of one side using a myriad of different projections (at least across different states if not within) to their benefit, meanwhile the other side is left completely oblivious. In a highly contentious and also narrowly divided political climate, awareness of this fact by all involved parties is crucial when attempting to consider the fairness of redistricting; a lack of MPD knowledge on one side could be quite detrimental to their party.

It is also crucial to consider the interplay between projections and thematic mapping. As Muehrcke (1974) notes, a lack of projection understanding can cause serious damage, and research has pointed out how a lack of understanding could cause map readers to draw wrong conclusions from thematic maps. Lapon, Maeyer, et al. (2020) mention how when mapping thematic quantitative data with polar distortions, an uninformed map-reader could easily be led astray. Similarly, in his classic book *How to Lie with Maps*, Monmonier (2018) provides a rather humorous example of projections combined with dot density graph combined with non-equal-area projections could lead to confusion:

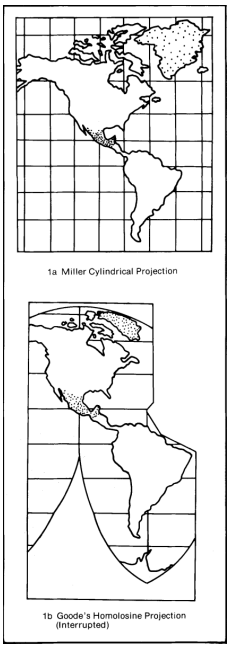


Figure 2: *Showing the misleading effects of projection distortion on dot density maps. Taken from Tyner (1982).*

> On a dot-distribution map with one dot representing five hundred thousand swine, for example, the spacing of these dots represent relative density. Important hog-producing regions, such as the American Midwest and southeastern China, have many closely spaced dots, whereas hog-poor regions, such as India and Australia, have few. But a projection that distorts area might show contrasting densities for two regions of equal size on the globe and with similar levels of hog production; if both regions have forty dots representing twenty million swine, the region occupying 2 square centimeters of the map would have a greater spacing between dots and appear less intensively involved in raising pigs than the region occupying only 1 square meter. Projections that are not equal-area encourage such spurious inferences.

Tyner (1982) explains the same phenomena, noting that one of the easiest ways to mislead with maps—intentionally or unintentionally—is through area-dependent dot-distribution on non-area equivalent projections. In Figure 2, both maps show the same data, but to the untrained eye, it would be hard to realize that the two maps show the same quantities, particularly if only A were presented.

This confusion is understandable. Map projection distortion is not naturally intuitive, and coupled with symbolization techniques it is clear how someone could be confused. However, poor levels of functional map projection literacy coupled with an overabundance of thematic maps from amateur map makers creates a tenuous situation. Without a projection literate society, misleading (unintentionally or intentionally) thematic maps circulate the internet going largely unchecked.

The resulting chaos—maps 'going viral' only to have its distortion eventually pointed out by some interested cartographer—only degrades faith in the mapping process. People must be empowered to make informed decisions about the maps they consume, rather than blindly accepting or rejecting them.

2.3 STATE OF MAP PROJECTION LITERACY

Given the importance of map projection literacy, what is the average person's level of knowledge? In 1945 a report from the U.S. Coast and Geodetic Survey[4] bitingly quipped that "many people, even people of education and culture, have rather hazy notions of what is meant by a map projection" (Deetz and Adams, 1945). There appears to have been little progress over the last eighty years. Recent studies have found that the general state of knowledge regarding map projection distortion is poor (Battersby, 2006). As Nyerges and Jankowski (1989) write, "few people, even few cartographers, commonly know which projection is good for what purpose and the trade-offs involved." Even those who are aware of map distortion[5] have difficulty compensating for said distortion, perhaps "due to the difference between the general problem of recognizing that there is distortion versus being able to recognize the specifics of what is distorted, where, and how" (Battersby and F. C. Kessler, 2012). Battersby (2006, 2009) has also noted the public's limited projection knowledge and lack of skill in transferring projection knowledge to applicable tasks.

Studies focused on examining critical subsets of the population have also found concerning results. Chiodo's (1993) research on the mental maps of preservice teachers found that all of the preservice had difficulties constructing a passable mental map of the world, with female elementary preservice teachers performing the worst. Research from Anderson and Leinhardt (2002) also found poor knowl-

4 This is a global problem. To quote Thomas F. Saarinen and MacCabe (1995) "it is not just Americans who are geographically illiterate" many countries require updates to their geographic education.

5 It could also be the case that the public has trouble identifying distortion due to their own shifted mental image of the world. The most widely cited study on the topic defined the Mercator Effect, an over-inflation of importance placed on areas at high latitudes Thomas Frederick Saarinen, 1988. This study found that "a colonial mentality and a Eurocentric image of the world still remains dominant in many places a quarter of a century after the end of the colonial era" Thomas Frederick Saarinen, 1988. Other research has also found support for the Mercator effect (Chiodo, 1993). Support for the Mercator Effect has also been found through analysis of web maps (Lumley and Sieber, 2019). However, many studies have also not found a Mercator effect. Battersby (2006), Lapon, De Maeyer, et al. (2019), and Lapon, Ooms, and De Maeyer (2020). Lapon, Ooms, and De Maeyer (2020) specifically found that "the accuracy differs with the map projection, but not to the extent that one's global-scale cognitive map is a reflection of a particular map projection." While the debate does not yet seem settled, it does suggest at least the possibility that people's mental maps of the world have been altered by projection distortion.

edge of map projections. On a test designed to measure understanding of maps as representations of the earth's surface (participants were asked to draw the shortest path from one point to another on a Mercator project), "novices and preservice teachers could not solve the problems directly, knew fewer rules, and could not generate useful rules for solving the problem." While the test is perhaps more difficult than a typical projection distortion test—one would have to reason backward regarding where the continents are on the globe vs. how far apart they are on the map and realize how area is being distorted—it does paint at least a partial picture of the current lack of understanding and awareness of projections.

These concepts, coupled with the components of FMPL defined earlier—knowledge concerning types of map projections, ability to accuracy, and appropriateness of map projections for different purposes—would allow a map reader to evaluate the trustworthiness of a specific map projection while still maintaining trust in cartography as a process. As Griffin (2020) points out, without trust in the cartographic process, people might as well disregard all maps. The interaction between projection knowledge, individual maps, and the cartographic process is summarized in Table 2.

	NONE	PARTIAL	FUNCTIONAL
Individual Map	?	✓	✓
Cartography as a Process	?	?	✓

Table 2: *Impact of Map Projection Literacy on Judgement and Understanding of Individual Maps and Cartography*

Past or present, amateur map-makers or map readers, the ability to comprehend and think critically about map projections and their effect is important. Education and transparency of the mapmaking process, including map projections, can help increase trust in maps (A. Kent, 2017). Yes, it is true that "All Maps Lie," and that no single map can tell the whole truth (Griffin, 2020; Monmonier, 2018; Vox, 2016). However, this knowledge alone is not enough. Devoid of context and greater understanding, such knowledge may only contribute to a diminished view of cartography. A map reader must have sufficient knowledge of the mapmaking process to take a more nuanced view and understand how that process affects the map they are currently viewing and the narrative it tells. Map readers must be able to realize that different maps tell different truths, and different projections distort in different ways; one map may distort in a way that is not detrimental to a clear understanding of the story told, while the same projection used for a different purpose could drastically impact

how that story is interpreted. Simple awareness of projection distortion or knowledge that 'Mercator is bad' is not enough; map users must be able to assess the (in)appropriateness of a projection to a dataset (Hawkins et al., 1998) and view maps with "healthy skepticism" (Monmonier, 2018). If cartographers hope for a public that is functionally literate in map projections, then we must move "beyond the peel" in map projection education.

Battersby sums up the public's knowledge of map projection distortion (MPD) in her 2021 article "The Unicorn of Map Projections," saying that the public has "little to no interest in, or ability to, understand/compensate for map projection distortion." And we should not blame the public.

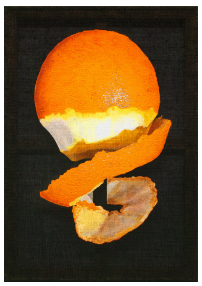


Figure 5: *Maja Vukoje, Orange, 2017*
Acrylic on burlap, 100 x 70cm
Foto: Roland Krauss

2.4 INCREASING MAP PROJECTION LITERACY OUTSIDE THE CARTOGRAPHIC SPHERE

While there has been extensive research on the *importance of map projection knowledge* and the *current state of said knowledge* (Anderson and Leinhardt, 2002; Chiodo, 1993), surprisingly little research has focused on expanding knowledge of map projections outside of the realm of cartography and increasing map projection literacy more broadly. Research on map projection education has largely focused on the topic within the context of cartography or advanced geography courses, for example, a study of cartography textbooks (F. Kessler, 2018) or in the context of GIS education (Greco, 2018). It seems that much attention has been paid to ensuring that maps are correctly made. Attention must also be paid, however, to map readers; after all, far fewer people produce maps than read maps (Burkalow, 1955). It matters little if cartographers are creating maps with well-suited projections everyone is fawning over an ill-projected viral map, oblivious to the possible distortion or deceit within.

Research that has focused on increasing base levels of FMPL has concentrated many times on introductory geography courses. One paper aimed at introductory geography classes proposed an approach somewhat in line with this thesis. Acknowledging that few students in introductory geography classes will go on to be map-makers but all will be map users, Burkalow (1955) proposes teaching students to "make better use of maps and understand not only some of the special functions maps can serve but also some of their limitations." Burkalow argues that rather than memorizing the appearance, properties, and construction of specific projections, students should be equipped with the methods to evaluate (at a basic level) any projection they come across based. In her paper, Burkalow suggests exercises for learning but the proposed exercises seem dry and, understandably given when it was written, out of date with today's modern tools. Similarly, Hirt (1960) focuses on teaching the FMPL in introductory ge-

ography courses and offers a range of exercises, but the exercises themselves are not overly stimulating.

Multiple researchers suggest focusing on graticules as a method of teaching basic map projection skills (Anderson and Leinhardt, 2002; Burkalow, 1955; Arthur Howard Robinson, 1978). Anderson and Leinhardt (2002) also suggests having students "actively engage in connecting the map back to the earth's surface as the primary goal of instruction." A 2012 paper from Beşdok et al. emphasizes the possibilities of using animation for understanding.

2.4.1 *Education Aimed at the General Public*

Despite the overall lack of research in this area, there are still examples of efforts to increase FMPL more broadly. One exemplary example is the 2020 exhibit *Bending Lines: Maps and Data from Distortion to Deception* and article from (Nelson, 2020). This exhibit focuses on examining "how truth and belief are constructed through cartography and the visual display of information." The exhibit's goal was as follows:

> Rather than simply trying to replace the public's faith in maps with a reactionary distrust, however, Bending Lines instead argues in favor of a critically informed trust, showing how maps must always be evaluated in terms of their position within systems of authority and power.

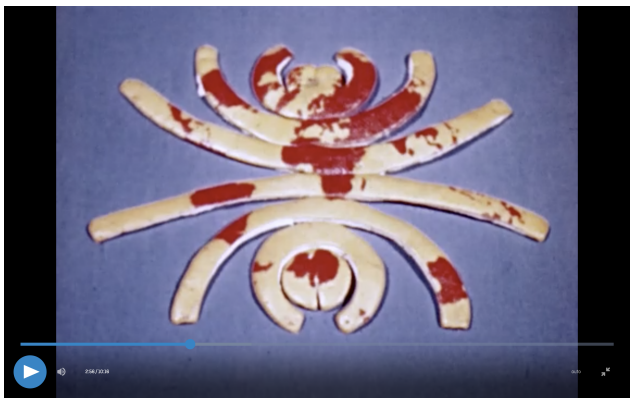


Figure 6: *Evelyn Lambert's The Impossible Map Depicting Grapefruit Peel Projection. Taken from Lambert (1947).*

I would argue that it is successful in this goal. The mixture of media presented (films, images, and interactive cartographic tools) demonstrate how map projections can be made more relatable and intriguing. The film included in the exhibition, Lambert's *The Impossible Map*, shows the difficulties of transforming 3D to 2D in an artful way, showing how different points of tangency and aspects affect which parts

of the globe are distorted (see Figure 6). The images used in the exhibit (Figure 1 is one example) tie map projections to history and the interactive cartographic tool is a well-implemented and intuitive example of how the *familiar shapes* technique can be adapted for the web and broader audiences. The exhibit also manages to avoid the "good vs. bad" trap that so many other introductory explanations often fall prey to, and also discusses how different maps can tell different stories with the same data (Nelson, 2020). While not perfect—the navigation through the exhibit is somewhat confusing—the exhibition offers an example of how map projections can be made more accessible and brought to the general public.

Research on efforts to expand FMPL outside the cartographic realm is limited. It suggests that it is an area ripe with opportunity. Examples like the *Bending Lines: Maps and Data from Distortion to Deception* exhibit demonstrate how alternative approaches to this topic can be successful.

2.4.2 *Methods to Convey Distortion*

Given the importance of MPD understanding to geographic literacy and its current state, we next evaluate which techniques to convey distortion are available. We examine their effectiveness, interesting characteristics, strengths and weaknesses, and how well are they suited towards increasing public knowledge outside the cartographic sphere.

The challenge of flattening the globe from 3D to 2D is not new, nor is the challenge of how to convey the resulting distortion. Map projections date back approximately 2,000 years, with Ptolemy mentioning in *Geography* the difficulties of distortion posed by attempting to map a globe to a flat plane (John P Snyder, 1997). While it does not have as long a history, the challenge of conveying the resulting distortion has also long attracted cartographers and others; Tissot first publishes his mathematical formula for the visualization of distortion more than 150 years ago (Tissot, 1861), and many other techniques have followed suit. The 2001 paper by Mulcahy and K. C. Clarke, 2001, *Symbolization of Map Projection Distortion*, lists many 'traditional' techniques to convey distortion. Each technique is accompanied by an in-depth review, alongside an image. Here, a subset of the techniques—those that seem fit towards increasing FMPL among novices—are presented. Additionally, as more than twenty years and the creation of many web technologies have elapsed since Mulcahy and K. C. Clarke's paper was published, it is prudent to include novel implementations of some of these techniques. Here I call out three that leverage the interactivity of the web to excellent effect, Jason Davies' *Map Projection*, *The Real Size Of* and *Projection Wizard*. While all of these visualizations could reasonably fit into Mulcahy and K. C. Clarke's category of 'Interactive

Comparison,' their uniquely engaging construction and interaction behavior warrant their own evaluation.

Familiar Shapes

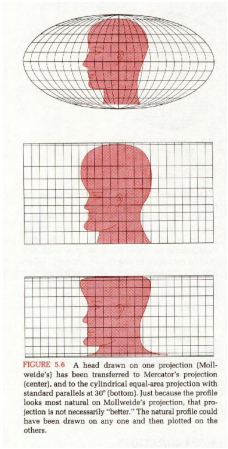


Figure 7: *Use of Familiar Shapes (head) to show difference between Mollweide and Mercator. Taken from Kutztown University.*

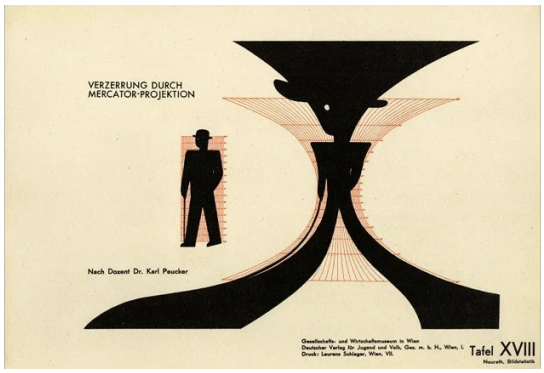


Figure 9: *Otto Neurath's use of Familiar Shapes to show the impact of the Mercator Projection outside of map constraints. Taken from isotyperevisited.org.*

The *Familiar Shapes* technique is a simple but effective one dating back more than a hundred years. In it, a familiar shape—a face, human form, circle, square, etc.—is placed upon a base map. The effects of the projection can then be seen in the distortion of the shapes. This can occur within the constraints of a map, as demonstrated in Figure 7, where a head used as the familiar shape. Familiar shapes can also be used more abstractly, outside of a map as shown in Figure 9. The use of familiar shapes is widely recognized as an effective introduction to the concepts of distortion, and while Mulcahy and K. C. Clarke (2001) find a limitation in the fact that characteristics and quantity are not explicitly communicated with this method, I disagree. If the goal of this visualization was to provide information and it failed to do so then yes, that would be a limitation. As its goal is to be used as a learning device rather than an analytical tool (Mulcahy and K. C. Clarke, 2001), then it is not fair to list that as a limitation. Where familiar shapes are limited, however, depends somewhat on the placement and alignment of the shapes to the projection. For example in Figure 7, the head cannot demonstrate the effects of the distortion towards the farther longitudes, which would be important for instance in the Mollweide projection shown on top. This small quibble aside, Familiar Shapes is an effective and recommendable introduction to projection distortion (Mulcahy and K. C. Clarke, 2001).

Interactive Display of Distortion

Mulcahy and K. C. Clarke offers up Brainerd and Pang's *Floating Ring* as an example of how interactivity can be used to help convey and explain distortion. Their tool involves "a floating ring on a sphere (globe) that can be interactively positioned and scaled. As the ring is

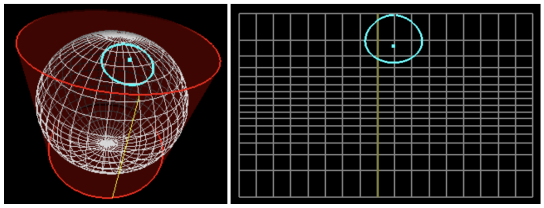


Figure 10: *Floating Ring tool showing the Mercator Projection. Taken from Brainerd and Pang (1998).*

manipulated on the globe, the corresponding projection of the ring is distorted using the same map projection parameters" (Brainerd and Pang, 1998). The *Floating Ring* tool not only avoids problems with obscuring data (central to many of the static visualization methods) but also allows for user control and comparison of the underlying data. Mulcahy and K. C. Clarke (2001) is admittedly somewhat dismissive of the approach, noting "there are theoretical issues that influence its design and reduce its possible effectiveness." While Mulcahy has a point and this particular implementation suffers from a lack of aesthetics with a distinctly dated 90s look, the approach itself of linking user control with displays of distortion is promising.

Comparison

For good or bad, comparison is a natural human tendency. In the context of map projection distortions, it is an effective technique for learning about projections, particularly when the comparison is of "isolines, shorelines, and graticules" (Mulcahy and K. C. Clarke, 2001). The concept is straightforward and does not require much elaboration, except to point out that (as Mulcahy and K. C. Clarke note) it is particularly well suited to projection education.

Isolines

Isolines, or lines that represent equivalency regarding the variable being symbolized, can be used to depict both the magnitude and distribution of any of the four distortion types (Mulcahy and K. C. Clarke, 2001). Mulcahy and K. C. Clarke writes that isolines are an effective technique, with their greatest strength being that they allow for users "to determine absolute values" of distortion for a given line. I agree that the ability to show exact magnitudes of distortion is important and a large benefit from isolines. And for cartographers or advanced map readers, isolines may very well be effective. However, for map novices whose main exposure is news maps or GIS, I believe Mulcahy and K. C. Clarke overemphasize the effectiveness of isolines. If someone is unfamiliar with the concept of isolines, it would be much harder for isolines to convey distortion. Furthermore, the connected-

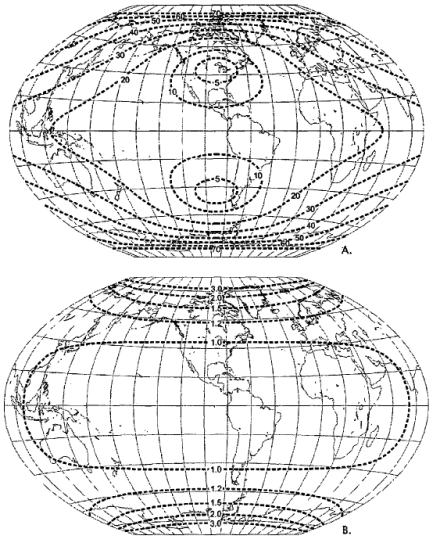


Figure 11: *Isolines showing distortion of the Winkel Tripel projection. Taken from Mulcahy and K. C. Clarke (2001).*

ness of the isolines makes the distortion feel “stepped" in a way that Tissot’s indicatrix, Familiar shapes, etc. do not.

Color

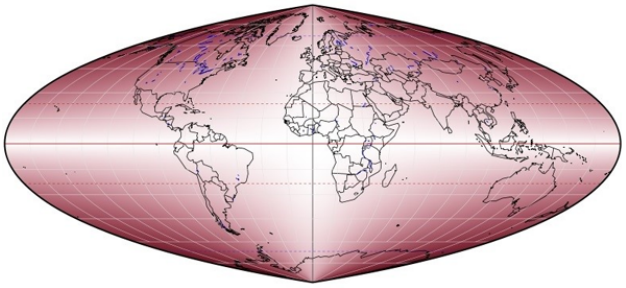


Figure 12: *Color Method where darker colors represent angular distortion. Taken from Cartographic Perspectives.*

Another option for conveying distortion is through the use of color. Color offers an effective method to convey the effects of distortion *continuously*, something missing from many of the other techniques listed here. By mapping different variables (area, shape, etc.) to different color channels, multiple variables can be displayed at the same time (Mulcahy and K. C. Clarke, 2001). In Figure 12, color reflects angular distortion on a map using the quartic authalic pseudocylindrical projection. The method is a fairly straightforward and easily comprehensible one to the average viewer.

Tissot's Indicatrices

Tissot's indicatrix (plural: Tissot's indicatrices) (TI) is perhaps the most widely known and used method to convey distortion. Created by Tissot (1861) in the late 1800s, the method involves projecting circles of infinitesimally small size onto a map; the resulting ellipse (enlarged to be seen) describes the linear, angular, and areal distortion at the center point. TI is not without limitations: it can only distort at certain intervals, the size of the circles may be misleading as to the distortion over that whole area instead of only the point at its center, and it may obscure the underlying data (Mulcahy and K. C. Clarke, 2001). Despite these limitations (some of which could be adjusted by using transparency, outlines, etc.), Tissot's indicatrix is perhaps one of the most intuitive and elegant techniques to understand distortion. It is no surprise then that it has been adapted to raster datasets and is widely used in cartographic textbooks.[6] In symbolizing size distortion with size distortion, shape with shape, etc. the type of distortion is immediately apparent to the map viewer. The natural understanding makes it well-suited for projection novices.

Visual Analysis of the Map Graticule

Visual analysis of the map graticule as a method of projection classification dates back to Robinson (Mulcahy and K. C. Clarke, 2001). Through different rules of graticule appearance (nine according to Robinson), maps can be classified into different types of projections. For example, a map with straight parallels but curved meridians would be pseudocylindrical. Burkalow (1955) also suggests focusing on visual analysis of graticules as a method of teaching. By teaching students to compare graticules on a map to graticules on the globe, they would have a method that they could apply to any map projection with a graticule, familiar or not, and have some sense of the distortion they may be encountering. Mulcahy and K. C. Clarke (2001) note that the graticule is limited in that it "does not directly symbolize scale, area, or angular change as clearly as TI, isolines, color methods, or a perspective surface." This is a fair point, but Mulcahy and K. C. Clarke gloss over the greatest strengths of the graticule, its widespread usage. The other techniques mentioned here focus on

6 The *Grid Squares method* is similar TI but with squares, a modification made originally to allow for adaptation to raster datasets (Mulcahy and K. C. Clarke, 2001). The advantage of using this method over the traditional TI is its applicability to raster, and that it can be used to examine differences in distortion between different projections. The *Checkerboard method* is similar, only here "a data set is developed with alternating colored squares and is then transformed by map projection." (Mulcahy and K. C. Clarke, 2001). As the squares are squashed and expanded, the distortions of the projection are revealed. This method has the same benefits of *familiar shapes* (after all, it is essentially using squares for the familiar shape, moving them closer together, and coloring them), but has the added benefit of helping to reveal changes in the raster data structure (Mulcahy and K. C. Clarke, 2001).

conveying the distortion through a particular technology or an additional symbolization layer. By empowering map readers to leverage an existing and common map attribute, they are far more likely to insight the projection. Not all maps have graticules, certainly, but far more carry graticules than TI. Empowering map readers to understand how the graticule reflects projection (and by extension impart some idea of distortion knowledge) would allow for far greater baseline understanding and map projection literacy. Training in how to read the graticules would be required, but short of adding TI as an appendix to all maps, visual analysis of the map graticule seems a promising and feasible method for increasing broadly increasing FMPL.

Examples of Innovative Implementations

With the invention of D3 (and the d3-geo module specifically) and other libraries, there are unsurprisingly a dizzying array of visualizations that convey distortion. Here we present a selection of a few that seem well suited to conveying distortion to those unfamiliar with map projections. The implementations here use some of the techniques listed above combined with an innovative twist.

Consistent Transition

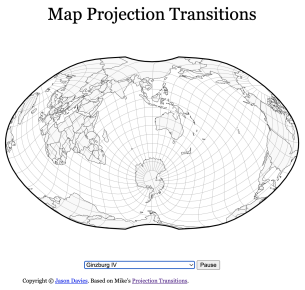


Figure 13: *Jason Davies' Map Projection: Ginzburg IV Centered on Antarctica. Taken from Davies (n.d.).*

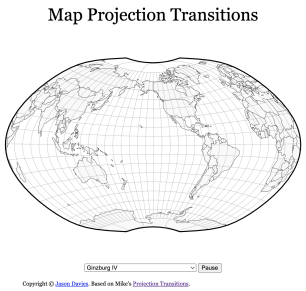


Figure 14: *Jason Davies' Map Projection: Ginzburg IV Centered on Atlantic. Taken from Davies (n.d.).*

Davies (n.d.) provides an inspiring example of how comparisons can be used to help demonstrate projection distortion. Here, no visualization overlay is needed. Instead, smooth transitions occur between both projection aspects and different projections. As the image morphs smoothly between projection aspects, continents are slowly distorted in different ways, and with the selection of different projections, one can compare the various extremities. Aesthetically it is a simple website, its simplicity allowing the user to focus solely on the map. The animation of the map may also contribute to the comprehension of distortion, as multiple studies have pointed out the positive influences of animation on learning (Beşdok et al., 2012). This

example shows how innovative implementations of interactivity and comparison can make projection distortion understandable and interesting.

Bounding Box

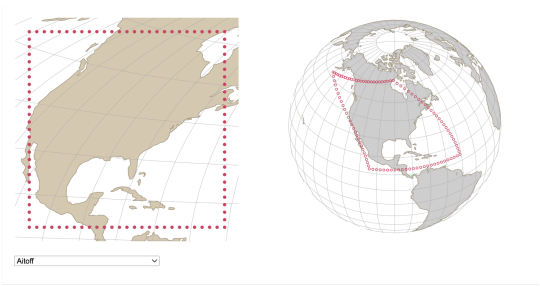


Figure 15: *Screenshot of Aitoff Bounding Box Comparison. Taken from Johnson (2021).*

In this example, Johnson's (2021) *visualizing map distortion* provides another interesting approach. Here, a bounding box square (the outline of which is formed by small circles) shows what a particular projection would look like on the surface of the globe. The user can see how Mercator's shape changes to the poles (it must shrink back together on the globe) while others like Eckert IV change shape entirely. While in many ways it is the familiar shapes' reimagined (the square form of the projection is transformed when put back on the globe), the ability to select between many different projections and have a constant comparison between the projection and the globe is useful. It is limited in its implementation to North America, but it is still an engaging approach. However, conceptually it feels difficult to reason back and forth. This technique encourages exploration and questioning more than insights.

Suggestive Projections

While towards cartographers as opposed to map readers, the *Projection Wizard* tool offers an interesting way to explore distortion by looking regionally. Created by Šavrič, B. Jenny, and H. Jenny (2016), the tool allows users to select different areas of the map they are interested in and which properties they would like to preserve. As different areas or properties are selected, the recommended projection changes. The difference between the extent's appearance in the recommended projection vs. the same area on the base map helps to showcase the distortion at the global scale. While this is a helpful tool for learning and provides the user somewhat of a feel for distortion, thereby not allowing comparison to different base maps, the user cannot get a feel for the difference between global projections.

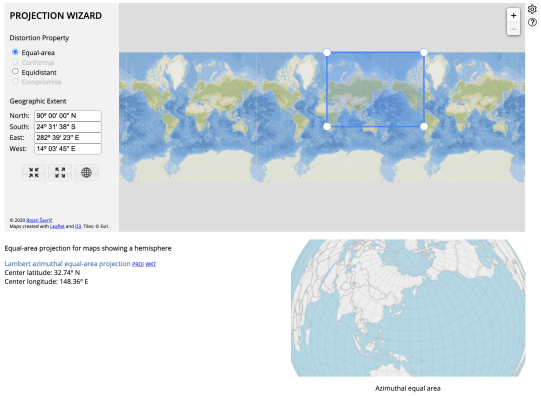


Figure 16: *Screenshot of Projection Wizard Tool. Taken from Šavrič, B. Jenny, and H. Jenny (2016).*

The True Size Of

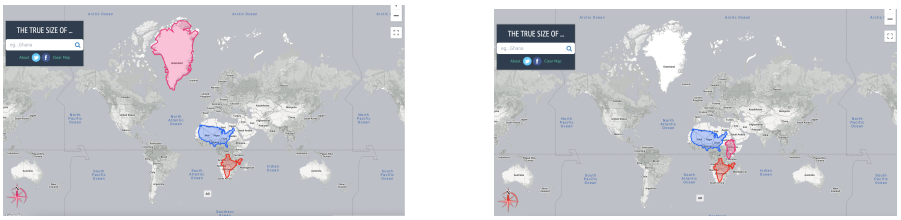


Figure 17: *Screenshots of The True Size of showing Web Mercator's size distortion. Taken from The True Size Of.*

The True Size Of is a uniquely entertaining tool for showing distortion. While at its core it is another implementation of the comparison method, its interface is mesmerizing. First, the user searches and selects a country. The user can then move a colored, semi-transparent version of the country around the map. As this shape moves around the map, its size and shape adjusts to match what the projected shape would be at that point. The user can select multiple countries, moving together countries from the equator and the polar regions to compare their actual sizes (see Figure 17 for the classic comparison of Greenland and Africa). This demonstrates how some countries' size or shape are vastly distorted by projections, and conversely how countries near the equator would be distorted if they were located closer to the poles.

This web application is one of the most entertaining and interesting to use, and seems to have widespread appeal[7]. However, like many of the other techniques listed here, it fails to implement any thematic data. Furthermore, it only works for the Web Mercator projection.

7 For example the podcast *Easy German* mentioned it in a segment called 'Das ist schön,' where they provide random suggestions of interesting links to explore.

2.4.3 *Strengths of Existing Methods*

Nearly all of the traditional methods described by Mulcahy and K. C. Clarke (2001) are effective in their task to convey distortion. The additional 'novel web-based methods' listed here are similarly effective, and also have the additional benefit of being more engaging[8] than some of the older methods mentioned by Mulcahy and K. C. Clarke (2001). The strength of all these methods is that they effectively, to lesser and greater degrees, effectively convey map projection distortion.

2.4.4 *Limitations of Existing Methods*

Given that many of these techniques are effective at conveying distortion, why is the general public's FMPL knowledge so low? The greatest drawback of the existing techniques lies in the fact that they fail to stimulate interest in the topic or relate it to something meaningful for the map readers. Because of this, it is perhaps not surprising that these methods are "rarely used beyond textbooks and technical documentation" Mulcahy and K. C. Clarke, 2001. These techniques are largely effective at conveying the effects of distortion. A paper by Hsu (1981) notes that even to geographers (who would presumably be more interested in understanding maps than the average person), the literature available on understanding MPD and selecting map projections is "unstimulating and overly mathematical." Some of the modern implementations mentioned here are more stimulating and entertaining to use, even to non-cartographers, but they are still not widely known about and also do not attempt to draw links to thematic maps.

When dealing with thematic maps—the kind of maps featured most prominently in news stories and interactive data visualizations, the kind of maps that often dominate social media—the effects of distortion are often amplified (and even more so if the said map is 3D) (Brainerd and Pang, 2001). And yet distortion is presented in isolation when it should be shown in conjunction with data. Consider the examples presented here; all of them focus on land mass. The idea that distortion should be shown on thematic maps is not new; some have gone so far as to argue that distortion information should be carried alongside maps as confidence layers (Mulcahy and K. C. Clarke, 2001). It is important for the map reader to understand the effects of map projection distortion in thematic maps. If a thematic map has a projection that distorts area and utilizes a visualization technique like choropleth or dot density, this could be used deceptively.

8 For example, the map projection website from Davies (n.d.) and *The True Size Of* draw the viewer in and hold their attention in a way that some of the older methods do not.

To pique people's interest in understanding MPD in thematic maps, it makes sense to create tools to convey and explain distortion that use data, specifically data is relatable and somewhat controversial. And the teaching method must demonstrate how map projections affect the maps and stories the public consumes on an everyday basis.

2.5 HOW COULD ALTERNATIVE METHODS HELP TO ADDRESS THIS PROBLEM

Alternative approaches could very well help to address this problem. The problem is not how to convey distortion; effective techniques exist, they can just be found rarely outside of cartography textbooks. Furthermore, these techniques might not be effective or interesting to the layperson. The challenge lies in how to integrate these techniques into topics that have broader appeal and relevance. Two possible ways are through art and storytelling. Throughout history, art and storytelling have been used to help engage debate and interest in topics. In the next section, we present outline existing research on how these techniques are effective, and how they could be appropriate for this challenge.

How might artistic and storytelling methods help to make distortion interesting, understandable, evocative, and relatable beyond the theoretical level? With a multitude of technical/traditional methods that can effectively convey the effects of MPD but a general public with poor understanding and very little interest, the logical question would be how to make MPD interesting and relevant to people outside the realm of cartography. For the reasons outlined in this section, one possible approach could be through artistic and storytelling approaches.

2.5.1 *Artistic Approach*

Before delving into how an artistic approach might help counteract some of the limitations of traditional methods, we must begin with what an *artistic approach* is. Naturally, this starts with defining art, a challenging—and some would argue futile (Weitz, 2017)—endeavor. In *The Definition of Art*, Adajian (2022) addresses this controversy, writing that whether "art can be defined has also been a matter of controversy. The philosophical usefulness of a definition of art has also been debated." Some have stated adamantly that art cannot be defined, that any theory of it is "logically impossible" (Weitz, 2017). Given that entire papers, and in some senses entire fields of research, have been dedicated to the topic (Dickie, 1969; Weitz, 2017), it would be far beyond the scope of this thesis to offer a full definition. Rather, this paper presents the challenges of defining art and then cobbles

together a *working definition* from existing sources, the core aspects of which align with the goals of this thesis.

Walton (2007)'s paper "Aesthetics–What? Why? and Wherefore?" offers a glimpse into the confusing world of defining art. As he succinctly puts it, "It's that darn concept of art that has made it so hard to understand art—and lots of other things as well." Art is not easily definable (Viégas and Wattenberg, 2007; Walton, 2007). Indeed, some papers that look for definitions choose to gloss over the definition; for example, in a paper on *artistic* visualizations, Viégas and Wattenberg (2007) define artistic visualizations (here applicable as the final project will involve visualizations) as "visualizations of data done by artists with the intent of making art." This definition is tautological (as they recognize), but it is also accurate and works for their purposes.

Among those who say art can be defined, there are many definitions. Adajian, 2022 offers the following agreed-upon aspects of art:

> There is fairly wide agreement that most works of art are made to be appreciated; that a significant amount of art appreciation is aesthetic; that definitions of art that do not illuminate why art is valued, leave important philosophical work undone; that art has vague boundaries: some things are clearly artworks, some are clearly not, and some are on the borderline; that, if natural kinds are timeless, sharply demarcated entities, individuated extensionally, then artworks do not constitute a natural kind; and that list-like definitions, lacking principles that explain why what is on the list is on the list, and how to project the list, are short on explanatory power.

Another definition of art comes from Dickie (1969). In his paper 'Defining Art,' he explores many definitions before outlining his own, primarily through rebukes of other definitions. He summarizes and closes his argument as follows:

> Now what I have been saying may sound like saying, "a work of art is an object of which someone has said, 'I christen this object a work of art."' And I think it is rather like that.

Combining the definitions from Dickie (1969), Viégas and Wattenberg (2007) it does not seem unreasonable to allow for a definition of art that includes the idea that for something to be art, it requires nothing more than being made to be considered art. If we include the slightly more concrete concepts of 'artistic' from Adajian (2022), then the following points seem the most poignant and appropriate for this project: *art must be aesthetic, controversial, meaningful, and meant to be considered as art.*

Benefits of Art

With art 'defined,' we move on to the possible benefits of an artistic approach. In a 2014 article, Marshall and Donahue notes how art can "address significant concepts and prompt viewers to think about them, perhaps for the first time or more deeply than they have before."

Art is also uniquely well suited towards broadening understanding within cartography. Wood and Krygier (2009) write "in place of such professional values as accuracy and precision, art maps assert values of imagination, social justice, dreams, and myths; and in the maps they make hurl these values as critiques of the maps made by professionals and the world professional maps have brought into being."No single projection can do everything, so why attempt to present any one solution as 'correct' to the public? Instead, art offers the possibility to showcase the multiple narratives and versions of reality different projections create. By exploring MPD artistically as opposed to scientific, the map maker rejects "the authority claimed by professional cartography uniquely to portray reality as it is" (Wood and Krygier, 2009).

Art has also been combined with map projections. Cosgrove (2005) lists two prior combinations of art and map projections. In 'Isometric Systems in Isotropic Space—Map Projections' (1974), Agnes Denes projected the world map onto uncommon mathematical shapes such as snail shells, cubes, and doughnuts (Cosgrove, 2005). Taking map projections further outside their traditional realm, Lilla LoCurto and William Outcault mapped the scanned images of their bodies according to various projections, exposing the technical difficulties of mapping curved surfaces in two dimensions (Cosgrove, 2005). Here, art is used as an exploration of the map-projection process and the "representational power of geometry and projection" (Cosgrove, 2005).

While this project uses projections safely within their traditional role of transforming latitudes and longitudes to x and y coordinates on a flat surface, there are similarities to these artistic projects. Similar to how LoCurto and Outcault force the observer "to explore the formal relationships between the globe and the human body" (Cosgrove, 2005), this project aims to encourage the user to consider the relationship between projections, distortion, narrative, and their own preconceived mental global maps.

From Adajian, 2022 we can also identify some of the limitations of an artistic approach to conveying MPD. Unlike conventional approaches that aim to clearly illustrate with no obfuscation or distractions, by some definitions art itself is only "partially comprehensible to cultural outsiders—they are neither opaque nor completely transparent" Adajian (2022). The very aspects of an artistic approach that could help to increase engagement, interest, and relevance (by mak-

ing it controversial, adding some confusion, etc.) could confuse, or bewilder the reader by the nature of the additional information being presented unconventionally.

The impact and integration of art in learning is a burgeoning field. Multiple papers have examined the positive impacts that art can have on learning. For example, Marshall (2014) notes art's "potential for deepening and transforming learning"and its importance as a transdisciplinary pedagogy. In a separate study, Marshall and Donahue (2014) also write how art can "address significant concepts and prompt viewers to think about them, perhaps for the first time or more deeply than they have before." This quote perfectly illustrates the importance of utilizing art to help convey distortion. In an area that to non-cartographers (and some cartographers) may be dull, art is a way to break through and critically question the impact of projection distortion.

2.5.2 *Storytelling Approach*

How could storytelling be used to help increase functional map projection literacy? Research into narrative cartography and story maps is an expanding field. It is no wonder why; Roth (2021) notes that "visual storytelling offers an entry point for hybridization in cartography, uniting technology with praxis" and giving opportunities for transdisciplinary research. Mocnik and Fairbairn (2018) writes that stories are important for making information personal and grabbing a map reader's attention. Furthermore, Caquard and Cartwright (2014) call out the "importance of linking maps with narratives describing critically the cartographic process and context in which maps unfold and come to life." This idea is at the crux of my project. The concepts required for functional map projection literacy are complex and require some explanation, or storytelling. Maps are a less effective medium than text for storytelling (Mocnik and Fairbairn, 2018), so attempting to rely only on maps and visualization methods to convey the nuances of map projections would be a very limited approach. Integrating thematic maps with projection distortion visualization within an explanatory story allows a reader to confront their existing cognitive map of the world and consider ways in which a projection could be affecting how they view the narrative they are consuming. It is one thing to have a theoretical understanding of projection distortion, that projections are like peeling and flattening an orange. It is another to move beyond the peel, into an understanding of how projections impact the maps we see daily.

Storytelling is widely accepted as a pedagogical tool (Witherell and Noddings, 1991). Its ability to "make students experience curiosity, mystery and even wonder" (Kokkotas, Rizaki, and Malamitsa, 2010) helps incite and encourage learning in ways few traditional other

methods do. The benefits of storytelling on learning have been documented across disciplines. Its effectiveness as a teaching method is listed by Kokkotas, Rizaki, and Malamitsa (2010), noting that it helps students by "stimulating their imagination, engendering inspiration, and leading them to a conceptual understanding." Other studies have pointed out the effectiveness of storytelling for adult learning (Rossiter, 2002). Robin (2015) mentions the effectiveness of storytelling and how storytelling can help contribute to 'Twenty-First Century Literacy', and specifically global literacy.

As the concepts necessary for functional map projection literacy require some explanation, it is logical to incorporate storytelling into attempts to broaden understanding. Attempting to convey the complexities through maps and visualization techniques alone would be foolhardy. Storytelling allows for explicit links between real-life data and projections. By clearly indicating the effects of projections within stories, the role of projections and the importance of understanding potential distortion are made explicit.

2.6 CONCLUSION

Research on map projections is consistent in its assertion of the importance of map projection understanding to non-cartographers. From everyday living to history to map literacy to geoliteracy, functional map projection literacy is important. It is unfortunate then, that literature also points to low levels of map projection literacy, map literacy, and geoliteracy across the globe. This is particularly concerning when viewed through the lens of our click-driven, viral, inflammatory social-media culture; having a partial understanding of map projections is not enough. It may allow for better decisions as to the trustworthiness of a few specific map projections, but it does little to encourage trust in cartography as a whole. Surprisingly little research has explored efforts to increase map projection literacy more broadly. Numerous technical methods exist that adequately convey the effects of projection distortion (familiar shapes, isolines, TI, etc.), but these methods are rarely used outside of cartography and geography textbooks. While little literature exists on the integration of map projections into artistic and storytelling approaches, there is substantial literature on the benefits of both for learning more broadly.

Part II

PROJECT CREATION AND EVALUATION

3

PROCESS

*Now what I have been saying may sound like saying, "a work of art is an object of which someone has said, 'I christen this object a work of art'." And I think it is rather like that. —**George Dickie***

In a MSc. thesis, it may seem unusual to have a *process* section, let alone a whole chapter. Given the time that was involved in the ideation of the final product, however, excluding such a chapter would leave an incomplete picture of the work involved. Despite its simplistic nature, the creative process behind *The Projection Flipbook* was steeped in creative, artistic, and iterative processes. Through the literature review, I realized that there were certain elements I wanted to emphasize in the project that my initial plan would not accomplish. Through much sketching, exploring[1], daydreaming, and refining I came to my final idea of *The Projection Flipbook (TPF)*.

Figure 18: *Inspiration in many forms. The Pinakothek der Moderne where an artwork using the Mercator projection stands next to a piece from Joseph Beuys.*

This chapter focuses on the decisions and processes that led to *TPF*. This includes the process of pursuing multiple alternative ideas before honing in on and refining *TPF* as the idea I wanted to pursue. The technical process of creation is contained in Chapter 4, where the tools and techniques used are outlined and figures of the project are presented.

3.1 CONCEPTUALIZATION

Reviewing the existing literature was highly influential on the final form of this project. As mentioned in Chapter 1, this thesis was orig-

1 I sought out inspiration in many places, from everyday objects to museum visits. Some trips, like that shown in Figure 18 were surprisingly topical.

inally meant to have a very different focus. With an original title of "Distorted Reality Visualizing the Difference Between Perceived Distortion and Reality," the plan was to explore if there were differences between the distortion visualized by Tissot's Indicatrix and the perceived distortion, examining if Steven's Power Law held regarding map projections. After conducting the initial stages of my literature review, however, I quickly found that such an approach wouldn't be feasible and that exploring more artistic methods of conveying distortion held more interest.

3.1.1 *Sketching and Ideation Phase*

Following the realization that a shift from my initial plan would be required, my thesis advisor encouraged me to widely explore the possibilities. During this phase, the goal was not to be constrained by what seemed possible, but rather to explore. Inspiration came from everyday objects surrounding me, tram trips taken for the exclusive purpose of clearing my head, and museum trips for inspiration (see Figure 18. I focused on specific feelings that I wanted to convey: *confusion, uncertainty, bewilderment, hesitation, puzzlement, mystification, strangeness, unfamiliarity, nuance, interest, 'huh?', really, come-again, opening, perplexity*. By confusing even readers who already had some knowledge of projections, the idea was to provide a 'reset' of what they already knew and to encourage new feelings about projections and projection distortion.

3.1.2 *Refining and Elimination Phase*

Following my initial ideation process, I began narrowing down my options and exploring certain possibilities more in-depth. They are included here as documentation of the creative process, as well as suggestions of possible alternative methods to be addressed at another time or for a different purpose. For each idea that I considered exploring more deeply, I ultimately considered each based on three key criteria:

1. Whether the idea presented enough artistic and creative opportunities for experimentation.
2. Whether the idea would be feasible given the limited time frame and my programming capabilities.
3. Whether the idea could incorporate the key takeaways from the literature review, namely to allow for exploration of nuance (specifically through the incorporation of thematic data) and usage of existing distortion visualization techniques.

These criteria were not weighed equally but contributed to a holistic evaluation. For example, while I wanted the project to be artistically interesting, I also felt that understandability was more important. Similarly, even if an idea was promising in its artistic and educational elements, if I knew it would be far beyond my skills to implement I was forced to discard it. Below is a selection of the project ideas that I considered, along with my considerations and deliberations on pursuing more deeply.

Transitional Developable Surface

Figure 19: *Sketch of 'Transitional Developable Surface' from Ideation Process.*

The principal idea behind the *Transitional Developable Surface* would be a mini film or interactive app that you could filter between different projections. Here the concentration would have been on an animation that would slowly have morphed and shown the process of the globe to map. The animation would have started with the earth rising over the horizon and light shining through from its center, blocked only by the land masses of the continents (see Figure 19). The earth would then be wrapped in a developable surface, and the beginning of the explanations of map projections would begin. As time progressed, the user would be presented with explanations of maps projections through developable surfaces. Explanations of types of distortion would accompany transitions between different surfaces.

Ultimately I discard this approach for two reasons. First, I lacked the technical skills; 3D modeling software and/or animation software would have been required. Second, this form would not lend itself easily to incorporating distortion visualization techniques. Given that I wanted it to be a beautiful spinning light object, the overlay of any sort of projection would have sullied the effect.

Projection Selection Exploration Tool

Loosely based on the color picker tool, the idea behind the *Projection Selection Explorer* would be that as the user dragged a marker

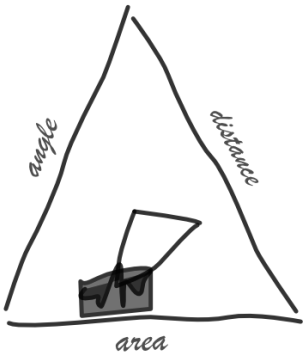


Figure 20: *Sketch of 'Triangle Selector' from Ideation Process.*

around the center of a triangle, different projections would be suggested. Each side of the triangle would be a different type of distortion. In the exact middle of the triangle, where there would be no distortion, no projection would be suggested. Ultimately this seemed unfeasible both from a programming perspective, and also perhaps more interesting to people who are already familiar with projections and are looking for a tool to help them select one.

Puzzle Projections

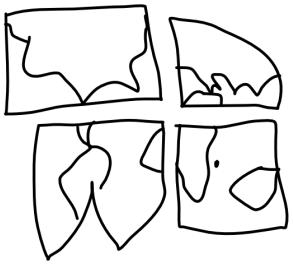


Figure 21: *Sketch of 'Puzzle Projections' from Ideation Process.*

Puzzle Projections was an idea I considered early. I ultimately decided that it would be too mismatched to implement; attempting to align all the different pieces in a way that would still be comprehensible would be quite challenging, as would attempting to cut out the "puzzle." This idea did somewhat come back in the form of *The Projection Flipbook*, however.

One Liners

Inspired by the one-line drawings that are increasingly popular on social media sites such as Instagram, I was intrigued by the idea of drawing the earth in such a manner. Artists with single-line drawings attract hundreds of thousands of followers, views, and responses; perhaps the appeal of one-line drawings could also bring more attention

Figure 22: *Sketch of 'One Liners' from Ideation Process.*

to map projections. In this approach, I would have created one-line drawings of various map projections with matching captions. The analysis would have involved posting the one-line projections to Instagram and measuring the responses. While I was initially quite excited about this idea, ultimately I rejected it as it did not allow for integration of thematic data; drawing by hand it would have been very difficult to include the multiple thematic datasets in any significant way, particularly not if the 'one-line' aspect was to be observed.

Subtractive Tissot's Indicatrices

(a) *Mercator* (b) *Polyconic* (c) *Peirce Quincuncial*

Figure 23: *Sketch of Three Different 'Subtractive Tissot's Indicatrices.'*

After listening to a *Hidden Brain* podcast on the power of subtraction and creation through simplification (Vedantem, 2010), one idea that I experimented with was the idea of showing Tissot's indicatrices subtractively by matching the color of the TI to the background (see Figure 23). As map readers are chiefly concerned with distortion where there is data, typically on land, by having the indicatrices in the same color as the background image, only the effect on land is shown. To avoid the problem of unclear landmass definitions, continents are outlined.

Reversible Image Projections

Instead of taking familiar shapes and superimposing them upon maps, why not take familiar images and use reversible projections to show

what they would look like as a globe? This was the idea behind *Reversible Image Projections*. By taking the x and y coordinates of the pixel values, you could subsequently reverse-encode what that image would like as a map. For example. what size would Mona Lisa's forehead be on the globe if we assumed that the actual Mona Lisa was a projected version (and how would the initial globe look different based upon Mercator, Winkel III, etc.). While I believed that the reverse image projections would be fascinating, I concluded that it would be difficult to translate the concepts necessary for FMPL through this approach, and it offered no possibility to incorporate real-world data.

Wanted Ads: Anthropomorphism of Projections

Figure 24: *Sketch of 'Wanted Ad' from Ideation Process.*

In popular culture, projections are often demonized (Mercator) or glorified (Gall-Peters) (Sorkin and Redford, 2011). Wanting to push this idea further, I considered exaggerating and extending this idea through some sort of anthropomorphism. Anthropomorphism, giving human characteristics to a non-human object or creature, would be realized by casting projections as criminals of sorts, with 'Wanted ads' (Figure 24) listing their supposed 'crimes of distortion.' The idea would be to force the user to consider and learn in a fun way.

While I enjoyed the playfulness of this idea and thought it could lend itself well to many different interpretations—for example, styling the ads depending on when and where the projections were created—and would also be relatively clear to implement, I was unsure if the satire of the ads would come across. Furthermore, the incorporation of multiple datasets with the poster format also seemed questionable.

	AESTHETICS	FEASIBILITY	LIT. REVIEW
Transitional Developable Surface	✓	-	-
One Liners	✓	-	-
Puzzle Projections	✓	-	-
Triangle Selector	✓	-	-
Wanted Ads: Anthropomorphism	✓	✓	-
Subtractive TI	-	✓	✓

Table 4: *Weighing the Benefits of Various Ideas*

3.1.3 *Summarization of Alternative Ideas*

Each of the considered ideas—those listed here and the many not included—had positives and negatives. As shown in Table 4, each rejected ideas failed to fit at least one of the three major criteria for this project[2]. The idea that I felt ultimately came the closest to fitting the three criteria was *The Projection Flipbook*.

3.2 SELECTING THE PROJECTION FLIPBOOK

3.2.1 *Initial Projection Flipbook Idea*

Figure 25: *Initial Sketch of 'Flipbook' from Ideation Process.*

2 *Lit. Review* meaning alignment with the findings of the Literature Review, e.g. showing thematic data.

The original inspiration for *The Projection Flipbook* occurred at the Children's Museum Schönbrunn Palace in Vienna, Austria. Watching the interactions of the children and parents, I was struck by the wide-ranging appeal of the flipbook they had on display. Yes, they are typically meant for children, but the playfulness of a flipbook is endearing and attractive. As I was drawn to the idea of a flipbook I considered how it could be adapted to map projections.

By cutting across different lines of latitude, the earth can be divided into the top, middle, and bottom of a flipbook. While the exact edges of the continents do not line up as they would in a traditional flipbook (e.g., with the head connecting to the neck), each section of the flipbook starts at the latitude where the next one begins.

As I mulled this idea around in my head, I was increasingly excited with the idea of showing multiple versions of a map all at once. In his article on ethics of map design, Monmonier (1991) argues that single-map solutions "foster a highly selective, authored view perhaps reflecting consciously manipulative or ill-conceived design decisions." He notes that even if a map maker is conscientious, any *single* map is susceptible to many pitfalls, and calls instead to present the reader with a series of dynamic maps (Monmonier, 1991). *The Projection Flipbook* is, in a sense, a series of maps; it contains multiple map projections within one map, and then transitions between the different configurations of that map. It also offers the possibility of exploring different series of projections and visualization techniques for a single dataset.

While this approach does have limitations, namely that it only works for projections with similar developable surfaces, it fulfills the three requirements listed in Table 4. *TPF* has enough design possibilities to be rendered artistically and it is within my coding capabilities. The last requirement, alignment with literature review, is the most challenging to meet, but by making certain decisions *TPF* can address some of the challenges of achieving FMPL. The individual components of *The Projection Flipbook* which help to address these challenges are outlined in the subsections below.

3.2.1.1 *Integration of Thematic Data*

This project allowed for the integration of thematic data. Because it is constructed programmatically, different data sets and visualization methods could be specified. By showing interesting, controversial data sets and how their visualization is affected by projections and thematic data symbolization techniques MPD is more relatable and the importance of FMPL is more clear.

3.2.1.2 *Satirical Exploration of Nuance*

By coupling *TPF* with titles that poke fun at the clickbait titles so often used in explanations of map projections, the reader is prompted to question and break down the dichotomous good vs. bad, true vs. false view. By presenting extreme and clearly erroneous views, the reader is forced to consider what they are looking at. Becker and Bode (2018) find that satire is an effective method of communication. One of the goals of this project is to address the dichotomous view of projections. By overemphasizing how *perfect* each of the *TPF* maps is when it is confusing and not perfect, the hope is to point out how preposterous it would be to assume there is one *perfect* map projection.

3.2.1.3 *Stacking Multiple Projections*

Stacking allows for more than two distortions to be compared at once and helps to point out that every projection is but one of many possibilities. Intzidou et al. (2021) write that by teaching through exploration and comparison, knowledge will come naturally.

Having more than just two options helps to break down the idea that one is right and the other is wrong. Having all the sections at a global scale—as opposed to one local and one global as in some projection comparison tools—helps to demonstrate that all projections must distort somehow. As Schultz, Kerski, and Patterson (2008) write, "flaws in spatial data conversion or projection can be insightful and reinforce projection systems to students. In fact, data sets with known spatial errors can be used as a challenge to understand and explain why errors in the data are visually identifiable." While the data here will use accurate data, the selection of projections will range from expected to highly unsuitable, particularly in combination with the symbolization techniques used for the thematic data (for example, combining a projection that distorts area with a dot density visualization). By juxtaposing how differently various projections portray the data, the importance of considering which projections are paired with which visualization technique is emphasized.

4

METHODS

Creation of *The Projection Flipbook* can be broken into three main areas: data collection and cleaning, technical aspects of the flipbook itself, and crafting the website project as a whole.

Art is a method.
*—**Picasso***

4.1 DATA

4.1.1 *Data Requirements*

This project had no predetermined dataset, but rather a set of criteria that data needed to meet. Given the goals of making MPD more relevant and engaging to a wide audience, the key data requirement was that the topics be controversial and widely interesting to a broad audience. If people do not find the topic being shown important, then they are unlikely to find how projection shapes the view of this topic important either. Beyond this, data needed to be available globally, to show different distortions in different areas of the globe. Finally, data needed to be accessible at the country level; if the data was too granular, the computational requirements for animation would be too great. I ultimately selected two datasets that met these criteria, information on reproductive (abortion) rights and COVID-19. Information on the datasets used can be seen in Table 6.

Nothing and I mean nothing, is interesting unless it is PERSONAL.
*—**Billy Baldwin***

4.1.2 *Data Pipeline*

The data pipeline for this project was relatively simple. I retrieved the COVID-19 data as an Excel spreadsheet. In the case of the reproductive rights data, I created the Excel Spreadsheet from the information contained in the PDF. Within Excel, for each dataset, I created a crosswalk sheet that contained the original country name from the dataset on the left paired with the ISO country name on the right. I then used VLOOKUP() function to pull the correct ISO 3 Digit Code for each country. I then applied the TEXT() function to ensure that the 3 digit codes were kept as three digits (e.g., *042* would stay as *042* and not be converted to *42*). For each dataset (the COVID-19 data contained both deaths and cases), I created another sheet and recoded the ISO-alpha-3 code as 'id' and the relevant value as 'value.'

The country outline data from Natural Earth was largely left untouched, with one exception. For reasons relating to how D3 draws

DATASET	SOURCE	DESCRIPTION
Thematic Data		
Reproductive [Abortion] Rights	Center for Reproductive Rights	This dataset contains information on access to abortion. Data is nominative, with rankings from I to V (V being the most comprehensive access). This dataset is used for *choropleth* mapping. Note that since this data was initially collected (February 23, 2021) many countries have changed their reproductive rights policies.
COVID-19 Case and Deaths Data	World Health Organization	This dataset contained both raw and per 100,000 figures for COVID-19 cases and deaths. This dataset is used for *choropleth* and *dot density* mapping. Data last updated August 1, 2022.
Additional		
Country Outlines	Natural Earth, processed by D3	TopoJSON versions of Natural Earth country outlines at 110m, TopoJSONified by D3.
ISO Codes	ISO 3166	The ISO three-digit numeric code (numeric-3) was used to join the natural earth data to the thematic data within the project

Table 6: *Data Sources*

Figure 26: *Clipping Problems Caused by Fiji Polygons.*

polygons and how TopoJSON encodes polygons when the dataset was clipped, the country of Fiji caused issues and created a polygon running across the entire map (see Figure 26). After trying to resolve the issue by modifying the arcs within the TopoJSON file, I eventually was forced to simply remove the Fiji features altogether.

4.2 CREATING THE PROJECTION FLIPBOOK

This section outlines the process of creating *The Projection Flipbook*. A selection of tutorials and code sources are listed throughout the technical implementation sections. For a full list, please see Appendix C.

4.2.1 *D3 Implementation*

Data-Driven-Documents, or D3 as it is more commonly referred to, "is a novel representation-transparent approach to visualization for the web" (Michael Bostock, Ogievetsky, and Heer, 2011). In 2018, the team behind D3 launched Observable, "a collaborative data canvas built for and powered by community where everyone can come together to make sense of the world with data" (Mike Bostock and Meckfessel, 2022). Observable's open-source and MIT-licensed notebooks and many other tutorials were critical in the creation of this project. I relied heavily on many tutorials, specifically the World map (with Canvas) tutorial, and Tweening examples to learn how to create the base map. Additionally, I consulted multiple tutorials to learn how to use HTML5 Canvas with D3. SVG is the standard way to use D3, and when I originally started creating *TPF*, I planned to use SVG as there is far more documentation and tutorials available. However, when I realized how computationally expensive drawing the dot density graph would be, Canvas became the only option. Creating the project with Canvas was much more challenging as many 'workarounds' had to be found[1].

1 For example, built-in D3 functions such as .transition() don't work in Canvas. I instead had to use tweening and interpolation which was more challenging.

4.2.2 *Dividing the Earth*

To divide the earth into three sections, my original idea was to clip the natural earth dataset using Python (see Appendix A) and then use the resulting geoJSON files for the three different sections of the flipbook. This attempt ultimately failed, however, as the Python method used to clip the polygons to the designated latitudes automatically took the shortest path to complete a clipped polygon. This resulted in polygons that instead of being clipped directly along a given latitude were cut off at the nearest great circle (see Figure 27).

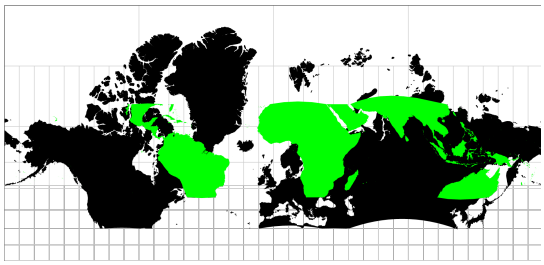


Figure 27: *Clipping Problems Caused by Python Pre-Clipping.*

I instead had to utilize the d3-geo.projection.pre-clip() functionality. There is surprisingly little documentation and few examples of this function, but the d3.geoClipPolygon notebook was helpful. I created the function clipProjectionByLat() which takes an unclipped projection and clips it to a given minimum and maximum latitude.

4.2.2.1 *Thematic Visualization Techniques*

Choropleth Here choropleth is used both for abortion data and COVID-19 density data. In both cases, an ordinal greyscale is used. I consulted the Choropleth, World notebook for guidance as to how to implement.

Dot Density Andrew Woodrufs's open source 'Dot Density Map of Boston' was enormously helpful in determining how to create the dot density map. I utilized his technique of creating an invisible dummy canvas function positioned exactly on top of the real canvas (a technique also listed on FreeCodeCamp. Features are drawn on the invisible canvas and assigned a specific color based on their id. Pixels are then thrown at the visible canvas within a rectangular bounding box of the relevant feature on the invisible canvas. If a pixel is within the actual polygon on the invisible canvas (not just within the rectangular area), tested by the color on the invisible canvas then it is added. Figure 28 shows how the process works by coloring the pixels that are outside the bounds of bounds red; in the actual flipbook, these red pixels are not drawn.

Figure 28: *Testing the Dot Density Visualization.*

Animation and Timing

The animation and timing of *TPF* proved to be a challenge. In traditional D3 implementations with SVG, transitions are built-in and are simple to implement. When using canvas, however, one must either create interpolation and tweening functions or use a workaround to bring D3's .transition() capabilities to Canvas. I explored both options but ultimately went with the custom interpolation method as it allowed for greater flexibility.

I consulted Mike Bostock's 'Orthographic to Equirectangular' notebook to figure out how to create the interpolation between different sections. The 'interpolateProjection()' function returns values between two projections. When combined with tweening, it returns a smooth transition between the given projections. I utilized this interpolateProjection() function directly in my code, modifying the surrounding code to work outside of the Observable environment and with clipped projections.

4.2.3 *Projections Included*

When deciding how to create *TPF* one limitation was that I could only use projections that could be aligned, limiting my options to cylindrical, pseudo-cylindrical, and compromise projections. While I initially planned to exclude the Mercator projection to avoid the typical 'Mercator is bad' discourse, I ultimately decided that given its prevalence it should be included, but without calling particular attention to it. Additionally, the implementation of certain raw projections in D3 is such that it is not possible to interpolate between them. Due to this, I was forced to exclude a few more projections that I would otherwise have included, such as the Gall-Peters[2]. The pages of *TPF* purposefully use combinations of projections that distort different aspects, for example combining an equal-area projection with a conformal one.

2 The included projections are (alphabetically): Baker, Collignon, Eckert, Equirectangular (Plate Carée), Mercator, Miller, Mollweide, Sinusoidal, Robinson

4.2.4 *Distortion Visualization Technique*

Following the review of the current methods for conveying distortion, I selected Tissot's indicatrices. The method is intuitive and easy for novices to understand. By utilizing only the outlines of the indicatrices, I was able to add them as a layer to the map without obscuring the thematic data layers underneath. For ease of creation and computation, true Tissot's indicatrices are not used. Instead, javascript is used to constructs small circles of the same radius spaced at equal meridians and parallels across the globe, giving the illusion of the indicatrices.

4.3 CRAFTING THE WEBSITE

Code was written using Visual Studio Code and development with my local server was run via http-server. Aesthetic and design decisions regarding scrollytelling, colors, typeface, and storytelling approach are listed below.

4.3.1 *Scrollytelling*

The scrollama tutorial from Jonathon Soma served as both my introduction to scrollytelling and the basis for my scrollytelling implementation. The original tutorial provides a base template to show how the various scrollytelling triggers work for overlay, side-by-side and other types of scrollytelling. Following the tutorial and templates gave me a base for combining and creating my own scrollytelling experience.

4.3.2 *Colors*

Blue has no dimensions, it is beyond dimensions, whereas the other colours are not.
—Yves Klein

The original selection of colors was based on three core tenants. First, I wanted it to be bright and stick out, to grab attention. Originally inspired by a poster display at the Pinakothek der Moderne in München, I experimented with orange and blue. I was drawn to and decided to stick with orange and blue for multiple reasons. First, orange and blue are accessible. Second, I appreciate the vintage 60s aesthetic. Third, the orange was a tongue-in-cheek reference to the fact that map projections are nearly always explained as "peeling an orange." Once I decided on blue and orange, I used the web color generator coolors.io to create the initial color scheme.

However, as development progressed further and I honed the feeling that I wanted the site to have, I felt that the blue and orange color contrast was *too* bright. Given the millennial color trends and preferences—muted neutrals and shades of white—the blue and orange felt out of place. I shifted to a muted neutral palette composed of greys, blues, and light pinks, but this appeared too restrained. Af-

ter experimenting with different options, I ultimately decided on a middle ground between the boldness of the original color palette and millennial-restrained-mutedness, a mixture of blueish-greys, whites, and fiery red. The evolution of the color palette can be seen in Figure 29.

Figure 29: *Progression of Color Palette from Original to Final.*

4.3.3 *Typeface*

I originally opted for a classic typeface, Georgia. Given the bright feel of the colors, I wanted to ground the reader through the font choice. Using one that is familiar and serif also helped to give the piece a feel similar to a newspaper. Georgia, while traditional, has a distinctly modern edge and is also highly readable.

After I switched to the more neutral color scheme, however, Georgia looked flat. I opted to go with a slightly bolder and crisper typeface from Christian Thalmann, Cormorant Garamond. This typeface holds more tension than Georgia which matched the slight confusion I wanted to create with the flipbook.

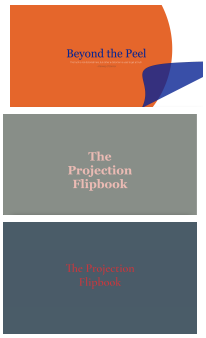


Figure 31: *Progression of Landing Page Design. From Top to Bottom: Original with Bold Sixties Colors and Georgia Typeface, Second with Muted Tones and Georgia Typeface, Final with Stronger Colors and Cormorant Garamond Typeface.*

4.3.4 *Approach to Storytelling*

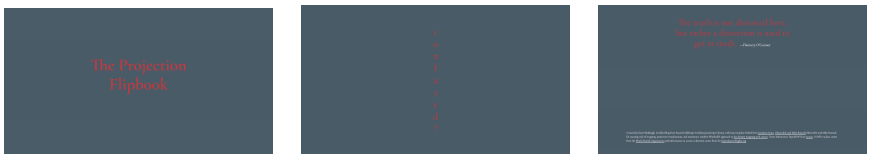
Storytelling offers an exciting opportunity for learning (Kokkotas, Rizaki, and Malamitsa, 2010). As Mocnik and Fairbairn (2018) write, maps themselves are not the best method for telling stories. The *mixture* of text and maps can jointly provide a better explanation of MPD than a map alone. The *TPF* website is composed of three parts, one of which is the actual *TPF* map section. The overall construction of the website is loosely based on the narrative arc, as shown in Section 4.3.4.

STAGE SETTING The 'characters' are introduced and the scene is set through the quotes. The quotes included (e.g. 'Maps Have Been Lying To You Your Entire Life') hint at the debate that surrounds projections.

CLIMAX The uncomfortableness and confusion of the contrast between *The Projection Flipbook* and the satirical [3] narrative titles on the right are purposeful. This lacks explanation and obfuscates any explanation on purpose.

3 Research has shown satire to be an effective technique for learning (Becker and Bode, 2018).

RESOLUTION The final portion of the website offers an explanation of *The Projection Flipbook*and map projections as a whole. This explanation focuses on addressing the key aspects of FMPL and clears the confusion that may have been in the reader's mind from the *TPF* section.



(a) *Intro* (b) *Confusion Midway* (c) *Ending*

Figure 32: *Three Main Breakpoints of The Projection Flipbook.*

The initial opaqueness of the story is purposeful. Through the quotes, the reader is set up with a view of maps that is then directly conflicted by the [unexplained satirical] titles in the *TPF* section. Scrolling through the *TPF* section, the reader is left in a state of confusion for a longer period, perhaps forcing them to confront what they already think, or don't think, of projections. Once they have had this opportunity for confusion, the *TPF* section and projection distortions are explained.

The storytelling in this project takes the form of scrollytelling. Scrollytelling "uses long, narrative types of text (e.g., report, feature) to tell complex stories," (Seyser and Zeiller, 2018) typically by allowing the user to *scroll* through the story. Unlike traditional pagination, scrollytelling allows for an uninterrupted flow of information. Scrolltelling is particularly well suited to complex topics and mixed media formats, like the mixture used in the *TPF* project (Seyser and Zeiller, 2018).

4.4 FINAL PROJECT

The final project can be found at middaugh.github.io/projection-flipbook. It is composed of an introduction screen, quotes, *The Projection Flipbook*, an explanation, and a credits section. All code and datasets utilized in the project are publicly available on github.

Within *TPF* itself, different versions of the same data are shown on different pages with different titles, as shown in Figure 34. In Figure 34, different projection combinations showing abortion rights data were coupled with titles that all claimed to be showing the reality of abortion rights. The impact of the projections on the proportion of the map shaded one color or another is apparent.

Each page of *TPF* transforms between each of the different projections in each section of *TPF*. This animated transition can be seen in Figure 33. On each page, the sections move and shrink as they

(a) *Beginning*

(b) *End*

Figure 33: *Different Animation Stages of Mercator-Equirectangular-Baker Projection Combination in The Projection Flipbook.*

transition between projections, with the thematic data flashing across the screen between transitions.

(a) *Baker-Eckert-Mercator*

(b) *Miller-Ecker-Mollweide*

(c) *Robinson-Mercator-Sinusoidal*

Figure 34: *Three Different Pages on Abortion in The Projection Flipbook.*

5

RESULTS

*Art is a lie that makes us realize the truth. —**Pablo Picasso***

What could an artistic, thematic, and storytelling based approach to conveying distortion look like? What possible insights could be gleaned from the creation of such a project and how might one evaluate said project? Chapter 3 and Chapter 4 elaborate on the former question. The latter question forms the basis of this chapter and Chapter 6. In this chapter the evaluation process is described and the results are presented.

5.1 EVALUATION PROCEDURE

Scientifically evaluating art seems a futile challenge. As Muller et al. (2015) write in their paper on art-science, "quantitative methods (visitor numbers, citations, etc.) do not provide the data needed to determine the value and benefit of aesthetic engagement; conventional quality evaluations are insufficient because they do not assess value beyond their disciplinary value structures." With this in mind, a quantitative evaluation is not attempted here. Instead, focus is placed on a limited qualitative evaluation with the goal of understanding peoples thoughts and impressions, feelings, thoughts, and experience of *The Projection Flipbook (TPF)*.

Five non-cartographers were recruited and asked to provide their feedback on *TPF*. Participants were told ahead of time that they would be scrolling through a website and asked to pause at various points along the way to answer questions. Over the course of one week, participants were individually interviewed via a Google Meet call, where they were given a link to the *TPF* website and instructed to share their screen, with the knowledge that the meeting would be recorded. At this point the meeting was recorded and the participants were asked the pre-assessment questions. Once these questions were answered, participants began scrolling through the website, some speaking their thoughts aloud and others scrolling silently. If participants asked questions I would provide affirmative answers, but not if they asked for an overall explanation. When they had completed *TPF* section and had reached the 'confused?' section, I told them to stop scrollying and I asked them the mid-assessment questions. After the questions were answered I instructed them to continue scrolling and reading through the rest of the website. After they had finished reading through the website I asked them the final post-assessment questions and stopped recording. In the case of some participants, after the video stopped recording they offered additional information

[unprompted]. In these cases, a summary of the participants notes were added at the end of the transcribed recording. The list of assessment questions can be found in Section 5.1.1. See Appendix B for transcriptions and summaries of individual participant responses.

5.1.1 *Assessment Questions*

Pre-Assessment

1. How would you summarize your knowledge of Map Projections?

Mid-Assessment, Before Reading the Text

2. Do you think there is a relation between the titles on the right and the maps shown in *The Projection Flipbook* at left? *If so, what is the relation?*

3. How does *The Projection Flipbook* mesh with your current understanding of global maps and map projections?

Post Assessment

4. How did the explanation relate to *The Projection Flipbook*?

5. What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.

6. How would you summarize your current knowledge of Map Projections now vs. before you explored *The Projection Flipbook*?

5.2 COLLECTED RESPONSES BY QUESTION

QUESTION	RESPONSES
How would you summarize your knowledge of Map Projections?	- Almost Zero. - Better than average–knows what they are and is familiar with them from The West wing. - Doesn't know too much about maps but is aware of the Greenland / Mercator effect. - Very minimal, experience limited to google maps. - Slightly above average; has a conception that there are different map projections and thinks about it.

Do you think there is a relation between the titles on the right and the maps shown in *The Projection Flipbook* at left?	- *Summary: No: II, Yes: III* - Didn't think there was a relation between the titles and the map - Thought yes because it mentioned projection names on the right and then some statistic - Thought yes, but noted that this might not be normal for Americans.
How does *The Projection Flipbook* mesh with your current understanding of global maps and map projections?	- Found it to be very similar to expectations, also found them similar to each other. Recognized the differences in them being round or flat. - Saw the changes of the different maps being rounded or not. - Knew before that Greenland was always shown too big on mercator, noticed on some of the projection flipbook pages with other names things seemed to be shown more realistically in size compared to other countries. - Thought it seemed similar but different; a little skewed. Used to seeing a singular view of it. - Liked seeing a dynamic / moving view.
How did the explanation relate to *The Projection Flipbook*?	- *Summary: Explanation of what to look for as indications of types of distortion: II* - *Summary: noted the idea that it explained that it isn't necessarily that a map is lying: II* - Said it refers back and explains how the information begging given "maybe wasn't a great picture. Or could have been. Or could not have been" - Showed that the different maps "weren't necessarily lies or intentionally wrong" - Made you aware of the grid as a tool. - Explained Tissot's indicatrices. - Explanation covered what you say in the flipbook. Covered how there were different kinds of distortion.

What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.	- *Summary: Liked the quotes: III* - *Summary: Wanted side-by-side as well: II* - *Summary: Liked the design: II* - *Summary: Found the color contrast difficult to see: II* - Would have preferred that the explanation and the maps were mixed together - Thought that you were supposed to discover what's being taught as you go through - Was confused about the circles and the statistics - Would have preferred to focus on just one data set. - Would have liked to have also been able to see multiple maps at the same time side-by-side with the circles. - Liked that there were different data examples. - Found the explanation understandable.
How would you summarize your current knowledge of Map Projections now vs. before you explored *The Projection Flipbook*?	- *Summary: Understanding after was better: IIIII* - *Summary: Liked learning about the specific names: II* - The Tissot's indicatrices were new and interesting. - Found it interesting how "how or why something may or may not have been distorted" - Found the COVID/ dot density interesting – "it totally changes the information that you're getting from the map and I hadn't realized that." - Has a better understanding of what to look for in a map [in terms of identifying distortion]. - Better understanding of how you might be able to use maps one way or another.

Table 8: *Participant Responses to Qualitative Survey*

Following the interview process, all recordings were transcribed and evaluated. For each question, the key notes from each participant are listed in Table 8. When participants had similar responses, results are combined with the number of responses shown and any additional comments listed separately. For a complete listing of all participant responses, please see Appendix B.

Noteworthy Quotes

Beyond the sentiments summarized above, multiple participants had quotes that spoke directly to their experience with *TPF*. These quotes capture unique views of *TPF* and reflect some of the challenges and positives.

- When describing what the explanation conveyed one participant noted that the explanation focused on how the map "maybe wasn't a great picture. Or could have been. Or could not have been."
- On the format of the project as a whole, one participant said "I felt like I was getting a story but it's a story where you don't really get what's going on until the very end."
- When asked about how *TPF* meshed with current understanding, one participant stated the following. "I mean obviously it seems a little skewed. I'm just kind of used to that singular view of it. So I guess it's similar but different. I mean I know there's this kind of idea out that that statistics even are used, you can kind of wield statistics like a weapon where you can kind of choose what key facts you want and that might not tell the whole story. And it's interesting to think about maps in the same way."
- On the topic of the form of *TPF*, one participant said that it "places additional attention on how the projection type itself alters our perceptions of what the data is. Just the fact that it moves in in of itself calls attention to that.
- On the meaning behind *TPF* and the explanation, one participant was very thorough. "...just because it isn't 100 percent the mirror image copy of something doesn't make it inherently a bad representation of it. I think it's asking viewers to reexamine the current claims of 'we're presenting something in this way but it doesn't actually mean it's an accurate presentation.' I think it makes people recognize there isn't . . . just because we're reexamining things doesn't mean the old one is inherently attempting to present things in a disingenuous manner."

5.2.1 *Specific Criticisms*

While all participants felt that they came out with a better understanding of map projections, participants also offered some helpful critique and suggestions for future iterations.

- Colors. While multiple participants remarked that they liked the design of the website, two participants found the color con-

trast between the red and blue/gray background to be difficult to see.

- More explanation / integrating pages throughout the explanation. Participants noted wanting to go back and check *TPF* to compare the projections with the guidance provided in the explanation.
- Simpler. Some participants thought that the project as a whole could have assumed a lower level of understanding, or first provided an explanation before introducing *TPF*.
- Implementation of scrollytelling. For all of the participants, the implementation of the scrollytelling was somewhat confusing; having the text be greyed out before it came into focus caused people to try to read the text beforehand.
- More 'clues' in the *TPF* section. Some participants requested that the legend would have been included for the choropleth mapping. One participant said they would have liked to see the projection name alongside that particular section of the map.

6 DISCUSSION

Art is not there simply to be understood. ... It is more the sense of an indication or suggestion.
—***Joseph Beuys***

In Chapter 5 the evaluation process is outlined and the results are presented. This chapter concentrates on possible insights that can be gleaned from said results. The results are summarized and interpreted. A review of limitations is also presented, as well as possibilities for future work and research in this area.

6.1 SUMMARIZATION AND INTERPRETATION OF RESULTS

The primary goals of the qualitative evaluation were to get holistic feedback on users' experience with *The Projection Flipbook (TPF)* and their understanding of map projections as a result. Based on the pre-assessment questions, participants had a wide-ranging experience and knowledge of map projections. Responses ranged from zero knowledge to partial familiarity (awareness of them and familiar with some aspects of area distortion). The responses to this question generally aligned the research presented in the literature review (see Chapter 2). On the whole, knowledge of map projections was lower than would be desired, although perhaps slightly above average levels indicated by the research.

The mid-assessment questions, those that were asked to the participants when they had viewed the *TPF* section but not yet read the explanation, offer an interesting view into how people interpreted *TPF* on its own. When asked if there was a relationship between the map on the left and the titles on the right, participants were split in their responses. Interestingly, there did not appear to be a relationship between existing knowledge of map projections and whether participants thought the titles related. Of the two participants who thought that there was no relationship, one had 'almost zero' knowledge of map projections while the other self-described as 'better than average.' It could be that their response was due mostly to reluctance to assume a relationship without explicit proof; both participants who said that there was not a relationship also requested a legend for the choropleth and density maps.

Responses to the question regarding how *TPF* meshed with current world views give insight into what the participants noticed. In general, participants noted a feeling of familiarity mixed with strangeness at the same time. As one participant said, the flipbook seemed 'similar but different' to the maps they were used to. Here there did appear to be a correlation between previous knowledge and comfortability with *TPF*. Generally, those that self-described as having very little knowl-

edge of projections knew that something was different or skewed but couldn't necessarily identify what it was. Participants who were aware of the concept of map projections called out specific changes or noticed the change in size discrepancy of certain countries. One of the participants who self-described as having a better-than-average understanding, liked the animated aspect of the projections, calling out how it "places additional attention on how the projection type itself alters our perceptions of what the data is. Just the fact that it moves in-in-of-itself calls attention to that." Responses to this question indicate how having a slightly greater base knowledge allowed a user to get more out of *TPF* and it caused them to question already-held beliefs. This also offers support for restructuring; priming the audience with a small explanation first, then presenting the artistic interpretation of projections may be more effective.

Participants' responses to the post-explanation questions offer an interesting look into how *TPF* affected their understanding of projections and what they thought of this approach. Responses to the first question—how the explanation related—show that through the explanation all of the participants understood what *TPF* was showing. Each of the different participants called out a different takeaway, for example how to use the grid or what Tissot's indicatrices were. Multiple participants specifically called out how they understood that different maps "weren't necessarily lies or intentionally wrong." This understanding is promising given the important aspect of projection literacy that distortion does not necessarily equal deception.

Responses to the question about what the participants liked and disliked resulted in the greatest range of responses, some of which were conflicting. While multiple people commented that they liked the design, multiple others also found the blue and red contrast hard to read. In general, the storytelling aspect was popular, with multiple people calling out the quotes as something they enjoyed. Participants liked the movement aspect of *TPF* and found it interesting, but some were also confused or wished that in addition to the animated *TPF* there were also stationary, side-by-side comparisons of the different projections presented. The majority of participants appreciated the connection to real-life data, but one participant also noted that they might have understood the relationship better if only one dataset had been focused on. There were two areas, however, that had consistent responses. First, while the scrollytelling was intuitive for the younger audience members, it caused some confusion for older participants. This could, however, be more related to the specific implementation here— having the text be partially transparent before coming into focus confused people. Second, a key theme that emerged was that participants would have preferred greater interweaving between the flipbook with the text explanation.

When asked to summarize their current knowledge of map projections now vs. beforehand, all participants indicated that their understanding was better post-flipbook. Participants who were slightly more familiar with map projections appreciated the inclusion of Tissot's indicatrices. From this, it is clear that participants understood the impact of map projections on thematic data and perception of stories, one of the key aspects of FMPL.

One of the key takeaways seems to be that it is difficult to find a balance between artistic and scientific forms of presentation. For some participants, the artistic side may have been overdone, as the confusion they experienced (by lack of additional legends, etc. in the *TPF* section) hindered their ability to draw links between the titles and the maps until the explanation. More user testing would have to be done to fix some of the confusing and less accessible aspects of the website, and the website could be improved through a better interspersion of the explanation text with the flipbook, or additional images of the flipbook included in the explanation. On the whole, however, the results of this qualitative analysis are positive and suggest that alternative approaches such as artistic and storytelling methods can help increase non-cartographers FMPL levels. Perhaps this is best summed up through one participant's takeaway: "I think it makes people recognize there isn't . . . just because we're reexamining things doesn't mean the old one is inherently attempting to present things in a disingenuous manner." This understanding is exactly the type of FMPL that is trying to be achieved with *TPF*.

6.2 FUTURE WORK

Results from this qualitative analysis indicate that alternative methods for increasing map projection literacy is an area ripe for exploration and research. Here, artistic and storytelling methods are meshed with traditional projection visualization techniques, and non-cartographers are open and excited about the mixed form of explanation. Many other alternative methods could be explored and implemented. Gamification, for example, might be highly effective toward engagement and deeper exploration.

Future work for *The Projection Flipbook* itself could involve implementing some of the feedback from the users and conducting more user testing. *TPF* could also be transformed into a more interactive tool, one where the user could select the different projections, data, and visualization types to see how the different projections compared. Or a different approach would be to have multiple 'pages' next to each other all at once (similar to Figure 34). User testing could also be run to find the optimal time to show the thematic data between each projection constellation transition.

6.3 LIMITATIONS

As with any research, this thesis has its limitations. Said limitations can be broken into three primary areas. Limitations of *The Projection Flipbook* itself (form and technical implementation), limitations regarding the evaluation, and limitations regarding an artistic approach itself. The second points are both tied to the time limitations of a master's thesis. With additional time some of these limitations could be avoided or addressed more elegantly, while some such as the possible projection combination constellations are intrinsic to the form of the project.

6.3.1 *Limitations Regarding The Projection Flipbook*

The Projection Flipbook has some unavoidable limitations due to its form. One of the key limitations is that only certain types of projections can be combined at one time. For example, equirectangular can be combined with rectangular, but not polar or conic projections. Furthermore, some of the more 'unique' projection types cannot be combined at all; for example, how could one reasonably combine a Peirce Quincuncial projection with a Waterman Butterfly projection? While more extreme versions of the flipbook could mix more dissimilar projections or even have different points or shift the center away from 0 degrees longitude, this version has only the simplest constellation.

Another limitation is the necessary computing power. Ideally, thematic data would have remained visible to the viewer throughout the interpolation between the projections. However, this proved a challenge. The computational requirements of interpolating between two different projections (redrawing hundreds of polygons) are taxing. An attempt to include the dot density data—drawing the dots alone is computationally taxing as thousands of points have to be thrown at the canvas and 'tested' before being drawn—slowed down the animation to an intolerable amount. A more skilled programmer could have found a more elegant solution, but given the time constraints and my abilities I opted to interpolate between projections, show a flash of the thematic data at that point, and then continue to the next interpolation before showing letting the flipbook 'rest' with the thematic data shown.

6.3.2 *Limitations Regarding Evaluation*

An evaluation limitation of this project is the limited testing size. Five participants were recruited and interviewed. With such a small group surveyed, it is harder to detect trends and find insights. Additionally, it would have been ideal to do multiple rounds of evaluation and feedback. In this way, the aesthetics and usability could have been

considered first, and then in later iterations, the impacts of the artistic format and *TPF* on FMPL could have been analyzed.

6.3.3 *Limitations Regarding Artistic Approaches*

Regarding an artistic approach, one limitation is that by some definitions art is never fully transparent (Adajian, 2022). In honoring this, an artistic approach to conveying map distortion may not be as easily understandable as a traditional explanation, at least at first. For example, to keep *TPF* open to interpretation by the reader I opted to exclude a legend from the choropleth and dot-density maps, hoping that by doing so the reader might be forced to notice the relative size differences of the countries and that impact on the overall impression. This confused some readers. By nature of leaving some aspects open for interpretation, artistic approaches do immediately make clear to the user what they are seeing. By extension, the reader has to work harder to contemplate what they could be seeing and/or be comfortable with temporary befuddlement, which could dissuade some readers. While this limitation could be mitigated through careful user testing and strategic opaqueness, it is still one of the possible downsides of an artistic approach.

7 CONCLUSION

Functional map projection literacy (FMPL) is the awareness that all maps distort, that they must (Monmonier, 2018; John Parr Snyder, 1987), that some projections are better suited than others (but all have their strengths and weaknesses (Burkalow, 1955)), that there can be no perfect projection (Battersby, 2021; Monmonier, 2018) and that a projection is not inherently good or bad, but that it depends on context and content. While there has been an increase in awareness of map projections in recent years, FMPL is still low (Battersby, 2021). This is concerning, as map projection literacy is important in many areas, from everyday activities to skills necessary in the workplace to general geoliteracy levels and awareness of one's role as a global citizen (Edelson, 2014). An increase in FMPL would help to improve two critical factors, the ability to make decisions about an individual map projection's appropriateness, and trust in the cartographic process. It would empower map readers—and amateur map makers—to make decisions and think critically about the reliability of individual maps. Furthermore, it would equip them with an understanding of the map-making process. Increasing the general public's FMPL is greatly important.

Given the importance of map projection literacy to the public, surprisingly limited research exists that focuses on how to increase the general levels of map projection literacy. Research has typically focused on traditional techniques of conveying distortion, or measuring the public's current levels of map projection knowledge. There are many effective techniques to convey distortion (Mulcahy and K. C. Clarke, 2001), however, these techniques often fail to capture the interest of map readers. Novel web-based techniques (Davies, n.d.; Johnson, 2021) are more exciting to use, but even these techniques do not address the underlying and critical relationship between the distortion and thematic data.

This thesis offers an attempt at exploring new possibilities for map projection literacy education. It focuses on how to couple existing distortion visualization techniques with art and storytelling techniques to make map projections interesting, relatable, and understandable to those outside the cartographic realm. A website combining art and storytelling was created, with the goal of conveying the three critical aspects of functional map projection literacy listed above. The key piece of the website is *The Projection Flipbook (TPF)*, a unique artistic piece. By dividing the earth into three horizontal sections, *TPF* combines three different map projections into one. On each 'page' of

TPF, the sections rotate between projections, growing and shrinking in size, and the thematic data flashing briefly onto the screen. When all projections configurations had been rotated through, the thematic data and Tissot's indicatrices are overlaid on top.

Each aspect of the website and *TPF* were carefully considered. Data used in *TPF* (COVID-19 and abortion) was selected for its controversial and global aspects. The website's form follows an abstract version of the narrative arc. First, the setting is established with clickbait title quotes. Second, confusion and conflict are created by the coupling of each page of *TPF* with a satirical title describing the mixture of projections while claiming accuracy and absoluteness in contrast to the quotes at the beginning of the website. Finally, the resolution is presented through an explanatory text that focuses on explaining the critical aspects of FMPL.

Following the creation of the website, a qualitative analysis of the website was conducted. Five participants were recruited and interviewed before, during, and after scrolling through *TPF* website. Users found the website as a whole helpful but were confused about certain aspects. Users liked how the scene was set with the quotes and how the explanation tied things full circle. Users also enjoyed the animation and the incorporation and explanation of thematic data. Future iterations of the website could involve more integration between the explanation and *TPF* itself. Additionally, more user testing would be required to explore if adding a legend to *TPF* would help users. Overall the feedback from users showed that the incorporation of art and storytelling into explanations of map projections is promising.

The question of how to make map projections relatable, understandable, and interesting to non-cartographers is an area ripe for exploration and research. Through the combination of artistic, storytelling, and classical distortion visualization techniques this thesis offers one possible approach. More research should be conducted to explore other ways these techniques could be utilized, as well as to explore others. Through the continued exploration of new approaches there are great possibilities for increasing functional map projection literacy levels.

Part III

APPENDIX

A

ORIGINAL PYTHON SCRIPT FOR CLIPPING

The original plan was to use a python script to clip the earth into three separate sections, and then use the resulting clipped geoJSON files in D3. This is the original script; clipping worked, but when mapping the resulting geoJSON I found that it clipped along the the shortest possible path, resulting in incomplete clipping along the latitudes.

```
import geopandas as gpd
from shapely.geometry import Polygon
import matplotlib.pyplot as plt
import json

# Modify for directory
input_dir = './data/ne_10m_land/'
output_dir = './data/clean/'
fname = 'ne_10m_land.shp'
land = gpd.read_file(input_dir + fname)

def clip_by_lat(min_lat, max_lat):
    clip_polygon = Polygon([(-180, min_lat), (-180, max_lat), (180, max_lat), (180, min_la
    return clip_polygon

# Create a custom polygon
polygon = clip_by_lat(-60, 30)
lower_poly_gdf = gpd.GeoDataFrame([1], geometry=[clip_by_lat(-90, 0)], crs=world.crs)
upper_poly_gdf = gpd.GeoDataFrame([1], geometry=[clip_by_lat(0, 90)], crs=world.crs)

# Testing with dividing in two
clipped_lower = gpd.clip(land, lower_poly_gdf)
clipped_upper = gpd.clip(land,upper_poly_gdf)

# Test Visualization
capitals = gpd.read_file(gpd.datasets.get_path("naturalearth_cities"))
world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres"))

# Create a subset of the world data that is just the South American continent
south_america = world[world["continent"] == "South America"]

fig, (ax1, ax2) = plt.subplots(2, 1, figsize=(12, 8))
world.plot(ax=ax1)
poly_gdf.boundary.plot(ax=ax1, color="red")
clipped.plot(ax=ax1, color="yellow")
```

```
south_america.boundary.plot(ax=ax2, color="green")
capitals.plot(ax=ax2, color="purple")
ax1.set_title("All Unclipped World Data", fontsize=20)
ax2.set_title("All Unclipped Capital Data", fontsize=20)
ax1.set_axis_off()
ax2.set_axis_off()
plt.show()
```

B

INTERVIEWS

The following five interviews were conducted with participants over Google Meet. Responses to questions were transcribed, with additional comments made during or after reading included as well.

Pre-Assessment

1. *How would you summarize your knowledge of Map Projections?*

   Um, almost zero. Like I know what a map is I'm not sure if I know what a map projection is.

   Would you care to elaborate?

   No.

Mid-Assessment, Before Reading the Text

2. *Do you think there is a relation between the titles on the right and the maps shown in The Projection Flipbook at left? If so, what is the relation?*

   Not really, it's the world I get that. And I know its supposed to be showing some sort of statistics but it's hard to tell what. I don't get why the map changes sizes and then becomes colored and I don't know what color correlates to what on the issue at the right.

3. *How does The Projection Flipbook mesh with your current understanding of global maps and map projections?*

   Um, I know what the world looks like. I can see that it changes quite a bit and is flat looking or round looking in terms of the different continents etc.

Post Assessment

4. *How did the explanation relate to The Projection Flipbook?*

   It showed that the different maps that I saw weren't necessarily lies or intentionally wrong they're just done differently and to be aware of the grid. The grid behind to see what areas are made larger or smaller in proportion to what they're trying to tell you about.

5. *What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.*

   Um, I thought it was interesting. I felt that you're supposed to discover what's being taught as you go through it which made the beginning slightly more confusing. Like I felt in the beginning that I just didn't get why I kept seeing different pictures of the world spread over different sized shapes. Those white lines—why does it keep showing me that?—and then I got to

those big round circles and then the dark and light portions underneath I was confused as to was to this actually what the covid statistics are. Or is this actually what the abortion statistics are. And why did I see the distorted map without those things first. It was interesting in that I felt like I was getting a story but it's a story where you don't really get what's going on until the very end?

6. *How would you summarize your current knowledge of Map Projections now vs. before you explored The Projection Flipbook?*

   A lot better. Oddly enough I found the COIVD one very interesting because I've been looking at COVID maps a lot and the fact that depending on depending on how big the country is displayed on the map changes the density of the dots is very apropros because it totally changes the information that you're getting from the map and I hadn't realized that.

7. **Comments While Reading**

   Laughed during the quotes from the different article titles and said "Oh, even google maps!" Noted how it often gets flat and then round and then it gets circles on it. Was confused about the lack of legend. When reading about how the change in area distortion could affect the way the dot density looks said "that's bad!" Said that it seems like the globe would be more accurate.

8. **Additional Comments**

Pre-Assessment

1. *How would you summarize your knowledge of Map Projections?*

   Of map projections? I would summarize it as better than average? Better than average. And only because of that one episode on the West Wing.

   Would you care to elaborate?

   I'm assuming that you're talking about traditional maps. And so I'm comfortable with legends and scales and topography, notations and zoom in zoom out. I'm pretty comfortable navigating maps. You know, I'm from the generation of go to AAA and get the flip map. A giant map and breaking it into little 3x8 pieces when you flip the page you've got to figure out where were you and where you are now.

Mid-Assessment, Before Reading the Text

2. *Do you think there is a relation between the titles on the right and the maps shown in The Projection Flipbook at left? If so, what is the relation?*

   No.

3. *How does The Projection Flipbook mesh with your current understanding of global maps and map projections?*

   Well they seem very similar to one another and they also seem very similar to what I was expecting. The names of the maps changed, the textbook on the right changed, but really what I was seeing the only difference was is rounded or is it flat. And I guess dots vs shading.

Post Assessment

4. *How did the explanation relate to The Projection Flipbook?*

   How did it relate? Well, it just refers back and tells one all the ways that the information I was just being given maybe wasn't a great picture. Or could have been. Or could not have been.

5. *What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.*

   I love the quotes at the beginning because that kind of sets you up for what you're about to head into. I understand why all the maps were together and then all the explanations were together,

but for me it was a little difficult to read the explanation because I really want to scroll back up and refer again. But because we're being recorded I didn't.

6. *How would you summarize your current knowledge of Map Projections now vs. before you explored The Projection Flipbook?*

   I would honestly say I was 100 percent aware of map distortions and how they are regularly... I mean, I have a book how to lie with numbers, so I fully understand that charts and graphs have inherent bias. But what I really liked about this was adding the circles in the background. I'd never seen that before as a presentation options and I thought that was very interesting. ... and I liked because you use very specific names for they types of maps you were looking at which was cool. And you went into detail about how or why something may or may not have been distorted.

7. **Comments While Reading**

   Laughed while reading the quotes about maps lying to you. When getting to the flipbook section, participant asked, "is this about taking the globe and making it flat?" Said "that's really cool how the bubbles kind of show you what's been flattened." Noted observation of population density with dot density as well. Also confused about the lack of legend. Laughed about 'outlandish maps' section of the explanation. Found the dot density explanation section interesting. Liked the last sentence and said it really made things clear.

8. **Additional Comments**

Pre-Assessment

1. *How would you summarize your knowledge of Map Projections?*

   Um, almost zero. Like I know what a map is I'm not sure if I know what a map projection is.

   Would you care to elaborate?

   No.

Mid-Assessment, Before Reading the Text

2. *Do you think there is a relation between the titles on the right and the maps shown in The Projection Flipbook at left? If so, what is the relation?*

   Not really, it's the world I get that. And I know its supposed to be showing some sort of statistics but it's hard to tell what. I don't get why the map changes sizes and then becomes colored and I don't know what color correlates to what on the issue at the right.

3. *How does The Projection Flipbook mesh with your current understanding of global maps and map projections?*

   Um, I know what the world looks like. I can see that it changes quite a bit and is flat looking or round looking in terms of the different continents etc.

Post Assessment

4. *How did the explanation relate to The Projection Flipbook?*

   It showed that the different maps that I saw weren't necessarily lies or intentionally wrong they're just done differently and to be aware of the grid. The grid behind to see what areas are made larger or smaller in proportion to what they're trying to tell you about.

5. *What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.*

   Um, I thought it was interesting. I felt that you're supposed to discover what's being taught as you go through it which made the beginning slightly more confusing. Like I felt in the beginning that I just didn't get why I kept seeing different pictures of the world spread over different sized shapes. Those white lines—why does it keep showing me that?—and then I got to

those big round circles and then the dark and light portions underneath I was confused as to was to this actually what the covid statistics are. Or is this actually what the abortion statistics are. And why did I see the distorted map without those things first. It was interesting in that I felt like I was getting a story but it's a story where you don't really get what's going on until the very end?

6. *How would you summarize your current knowledge of Map Projections now vs. before you explored The Projection Flipbook?*

   A lot better. Oddly enough I found the COIVD one very interesting because I've been looking at COVID maps a lot and the fact that depending on depending on how big the country is displayed on the map changes the density of the dots is very apropros because it totally changes the information that you're getting from the map and I hadn't realized that.

7. **Comments While Reading**

   Laughed during the quotes from the different article titles and said "Oh, even google maps!" Noted how it often gets flat and then round and then it gets circles on it. Was confused about the lack of legend. When reading about how the change in area distortion could affect the way the dot density looks said "that's bad!" Said that it seems like the globe would be more accurate.

8. **Additional Comments**

Pre-Assessment

1. *How would you summarize your knowledge of Map Projections?*

   I'm a lawyer I'm not a cartographer. I don't know much about maps.

   Would you care to elaborate?

   I would care. Well, I'm interested in maps and I know world maps and I know that there's different projections of maps. Ones that show Greenland in a huge scale and some small scale. Some are called Mercator. But I think that's where my knowledge stops.

Mid-Assessment, Before Reading the Text

2. *Do you think there is a relation between the titles on the right and the maps shown in The Projection Flipbook at left? If so, what is the relation?*

   Is there a relation? Well, I guess there was the name of the projection at right and some statistic what it is on the right. And then it showed basically the world map on the left. Yes, there was a relation.

3. *How does The Projection Flipbook mesh with your current understanding of global maps and map projections?*

   Well, as I said the big thing for me is always that Greenland on the Mercator projection is always shown as too big. And then towards the lower parts there was something called Mollweide or so and there it was shown more realistically as compared to Spain or Congo. All the ones that are closer to the equator.

Post Assessment

4. *How did the explanation relate to The Projection Flipbook?*

   Well, it made it more clear that there are these indicatrices, the indicatrix thing with those circles which probably for most readers wasn't what they would know in advance. I think that's a very specific cartographical knowledge and that was explained. And it was explained that every maps lies. Or not lies, but has to use some form of distortion because there is not perfect form of map projection.

5. *What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.*

Well no it's good to see different kinds of projections whatever they're called, Mollweide Mercator and so on. It's a good design. It's good that they are just all beneath each other. I wonder if it would be good to use just one single example. Because this way it could also confuse the reader because the reader will look at the contents too, the Covid or whatever it is the reproductive rights the contents but its mostly about the projection so I wonder if it shouldn't focus on one topic. That's just one idea.

6. *How would you summarize your current knowledge of Map Projections now vs. before you explored The Projection Flipbook?*

   I'm enlightened. I know more are about map projections now. And their different names. I think for me that's the main content of this flipbook that there's these different kinds of projections and what their titles are and I think that's cool. So I know more.

7. **Comments While Reading**

   "So there's different circles and I guess the circles show in this case that Greenland and Canada and Russia are too big. And Spain is too small. And Congo. Is that correct?"

8. **Additional Comments**

   Following the interview subject noted that they were confused that each map was actually composed of separate map projections combined into one. Participant suggested added the names of the individual map projections next to the sections themselves.

Pre-Assessment

1. *How would you summarize your knowledge of Map Projections?*

   Very minimal.

   Would you care to elaborate?

   Yea, I guess to be honest I never really thought about it that much. Obviously the experience I have is probably limited to google maps.

   Mid-Assessment, Before Reading the Text

2. *Do you think there is a relation between the titles on the right and the maps shown in The Projection Flipbook at left? If so, what is the relation?*

   Yes, yes I do because it mentions what type it is on the right and then you can see it, kind of a different I don't want to distortion but, you can tell there's differences between the maps and the right text seems to reflect why it's different.

3. *How does The Projection Flipbook mesh with your current understanding of global maps and map projections?*

   Uh. I mean obviously it seems a little skewed. I'm just kind of used to that singular view of it. So I guess its similar but different.

   Post Assessment

4. *How did the explanation relate to The Projection Flipbook?*

   Yea, I think it was a good explanation. Yeah no. I think that the explanation kind of covers basically what you're seeing. Yea, when I asked earlier what the dots are. It was shown in the explanation. Sorry, can you repeat the questions? Yea, it clearly explained what each map, basically the different distortions of the same map we were looking at, the explanation showed why they were distorted and I think the part about what to look for in order to notice such distortion going forward was particularly helpful.

5. *What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.*

Yea, so one thing I think that I would do would be. I don't know if it's even possible, but if you could put some of the maps side-by-side rather than having to scroll up and down that might. For instance, let's just say the COVID maps with the I'm not going to pronounce this right, but the circles the indicatracies, so you can kind of see, visualize the different circle sizes side by side. But otherwise I liked that there was different examples and I thought that it was accessible as far as each explanation was chunked into a nice paragraph. And so I think that really helped to separate the different main points. Yeah no, I think that overall it's pretty easy to understand and scroll through.

6. *How would you summarize your current knowledge of Map Projections now vs. before you explored The Projection Flipbook?*

   Much better. Yeah no, its actually really interesting to think about. I definitely, when you're, I mean I know there's this kind of idea out that that statistics even are used, you can kind of wield statistics like a weapon where you can kind of choose what key facts you want and that might not tell the whole story. And it's interesting to think about maps in the same way. Like I said, I definitely liked the little section on, in terms of what to look for as far as look to see how the lines are. You know with this type of map look for this, with this type of map lok for how wide the lines are. I think that will actually help to get a better understanding of maps going forward.

Pre-Assessment

1. *How would you summarize your knowledge of Map Projections?*

   I'd say it's decent probably slightly above average.

   Would you care to elaborate?

   I think the fact that there's even a personal conception that there's different map projections is a little beyond what most folks... I don't think that most folks think about it at all. I do to some extent. But it's not like I've got a favorite one that I'm going to trot out at house parties or what have you but I do think about it a little.

Mid-Assessment, Before Reading the Text

2. *Do you think there is a relation between the titles on the right and the maps shown in The Projection Flipbook at left? If so, what is the relation?*

   What I think of the relation between the titles and the projections themselves? I think that again there's.... From an American perspective there's not going to be all that big of difference. Like asking an American to identify a Mercator vs Robinson projection when they can't even identify China on a map is going to be tricky. Um, that said, I think there is an ongoing discourse that's reframing how we look at visual presentations and media presentations of any kind. And the reexamination of what kind of map projection we're using in a global health context is changing because we're looking at it all differently. So I think it's very much of the moment to start examining why do we use Mercator. Why do we use that and not something else. From a more global south perspective it makes sense.

3. *How does The Projection Flipbook mesh with your current understanding of global maps and map projections?*

   Um, I think that it's nice to see something that's dynamic. I don't normally get a chance to see something that moves. Seeing as it warps between the different types is useful. I think it also again places additional attention on how the projection type itself alters our perceptions of what the data is. Just the fact that it moves in -in of itself calls attention to that.

Post Assessment

4. *How did the explanation relate to The Projection Flipbook?*

I think that it emphasizes that like, it's the causation correlation thing all over again. If something. It's not assuming some sinister mode. Nothing we can put out is perfect. Any visual representation of anything is only as close to the reality as you can draw it or present it. But just because it isn't 100 percent the mirror image copy of something doesn't make it inherently a bad representation of it. I think it's asking viewers to reexamine the current claims of 'we're presenting something in this way but it doesn't actually mean it's an accurate presentation.' I think it makes people recognize there isn't.... just because we're reexamining things doesn't mean the old one is inherently attempting to present things in a disingenuous manner.

5. *What are your thoughts on this form of presentation? Were there things that you liked or disliked, things that were confusing or clear, etc.*

   Um, I think for me, and it could just be my screen or my own personal rods and cones of my eyeballs. I couldn't almost see the red at all. The blue was very visual but it was almost like I was color blind for that particular contrast. I liked having the quotes at the beginning. I think it gets at this current wave of 'everything you know has been lying to you and there's bad motives behind everything.' I think that's good. I think it would have been useful to pair some of the different projections side by side and not just vertical. But that could be beyond the parameters of accessible programming on that front. But yea, I like it. I like geography, I like maps, it was interesting for sure.

6. *How would you summarize your current knowledge of Map Projections now vs. before you explored The Projection Flipbook?*

   I'd say it's greater. I would add that maybe again, assuming a lower level of baseline knowledge for whomever accesses this might be useful. Like in addition to just presenting all of them in the beginning. A kind of legend showing the different kinds or a refresher course 'this is what this projection is and this is what this projection is' that's static and not moving would reinforce the different kinds of projections in any supposed bias inherent to those. It would be easy to see if you had some kind of static picture at the beginning.

7. **Comments While Reading**

8. **Additional Comments**

C

CODE RESOURCES

In the course of creating *The Projection Flipbook*, many tutorials and open source repositories were utilized. Table 10 summarizes what was used. For full code comments identifying sources, please see the scripts in projection flipbook respository on github.

CODE RESOURCE	USE IN PROJECT
World Map with Canvas	This example was essential to get a basic understanding of how to use Canvas with geoJSON. Code wasn't used directly, but the method of how to setup and process the data was.
Choropleth, World	This code demonstrated how to use the Choropleth method from D3. This project didn't require everything offered in that method so I created my own code, but it was useful to see how the color values were mapped to the data values and implemented with canvas.
Spherical Clipping	This notebook was helpful to understand how the d3.geoprojection.preclip() function worked.
Andrew Woodruff's Dot Density	Andrew Woodruff's code was extremely useful in figuring out how to create the dot density map. His approach to using two canvases and testing whether dots were within bounds based off of colors was implemented directly in the dot-density.js file. The *function testpixelcolor()* was used directly, and the code in the for loop starting on around line 74 was only very slightly modified.

Jason Soma's Implementation of Russel Goldberg's Scrollama Library	Jason Soma's Video Tutorial and Implementation of Russel Goldberg's Scrollama Library was extremely helpful. The barebones HTML template for *TPF* website is from the tutorial, which was then heavily modified and expanded. The JavaScript (index.js, section labelled 'scrollama') and CSS (css/06-scrolly.css) for the scrollama sections are kept fairly 'vanilla,' with customizations for specific scrolling behaviour and content.
Orthographic to Equirectangular	This example was essential to the transitions between projections. The interpolateProjection() function is used directly in base-flipbook-functions.js.

Table 10: *Summary of Code Resources and Usage*

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