

Framework for Understanding Elements of Map Trust

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Abstract: Trust in maps is essential for the use of maps, but the factors that lead to a more or less trusted map have been understudied and are poorly understood. To understand the problem space of trust in maps, a framework previously used for understanding visualization trust has been adapted specifically for maps and a comprehensive review of 32 relevant map and visualization trust papers was undertaken to identify design choices which have been theorized to effect trust and to conceptualize the current understanding and research gaps in map trust. Within this framework, we identify the most likely antecedents to lead to the creation of trust, while also acknowledging the existence of a behavioural dimension and the role of heuristics in processing and trusting a map, both ongoing questions about the construction of trust in maps. We also outline future research opportunities to make true strides in understanding how design choices affect trust in maps. This paper stands as a foundational stone on the road to understanding trust in maps and developing practical guidelines for cartographers to design with trust in mind.

Keywords: trust, map trust, foundations of trust, cartographic design, ethics

1. Introduction

Trust is a critical dimension of how individuals read, interact with, and ultimately make decisions based on maps and data visualizations. There is a longstanding and growing body of trust-based literature in the fields of Information Visualization, Visual Analytics, and Human Computer Interaction (Mayr et al., 2019; Elhamdadi et al., 2022), yet maps are not the focus of most of this research. Despite the more recent interest from the cartographic research community in studying trust in maps (Prestby 2023), neither a common nor congruent understanding of what trust is and how to measure it has been widely adopted. Advancing this understanding is important, particularly given the critical role maps play in communicating information about science, politics, economics, etc., in a post-truth and post-pandemic world (Kent 2017). Moreover, maps can rapidly spread online via social media without the cartographer's consent, knowledge, or additional context, sometimes in misleading ways (Meyer et al., 2024).

Cartographers possess a great deal of agency in deciding how to design maps. Their design decisions may be well-intentioned and informed by best practices in cartographic design and considerations for map audience. Importantly, each design decision may influence the trustworthiness of the final map product. At the same time, map users possess unique backgrounds, and lived-experiences, cognitive and other biases, as well as varying levels of data and visualization literacy, all of which influence the extent to which they may trust a given map.

The nascent (but growing) field of map trust has had a period of heightened interest during which researchers have begun to attempt to understand the effect of design choices a cartographer could make on the level of trust

experienced by the user. This literature survey seeks to identify, organize, and synthesize what elements, or antecedents, have been theorized to affect the levels of trust experienced by individual map users. In the following sections, we first describe our approach to characterizing antecedents of trust in relevant cartography/visualization literature, then detail two distinct yet interrelated views of that characterization. Next, we reflect on the limitations of the framework and discuss the role of behaviour and heuristics in trust research. Finally, we conclude with a summary of promising directions for future research on map trust.

2. Methods

We conducted a semi-structured review of current literature to distil a comprehensive list of theorized and investigated antecedents of trust. This work developed out of ad hoc attempts to categorize and keep track of antecedents through unstructured exploration of recent map trust and visualization trust (vis trust) research. To formalize the process and ensure coverage of the most recent and relevant articles, we conducted a keyword search for both “Trust” and “Map Trust” on four journals which had commonly published the originally discovered articles, *Cartographic Perspectives*, *Cartography and Geographic Information Science*, *International Journal of Cartography*, and *IEEE Transactions on Visualization and Computer Graphics* via IEEE Xplore. The search results required further pruning to ensure relevance to trust in the sense of dependence, as opposed to other meanings (land trusts, corporate trusts, cryptographic trust, etc.). The papers selected encompass empirical studies of trust in visualizations and maps (9 papers), theory crafting papers in maps and visualization trust (8 papers), review papers of current research (5 papers), and papers where trust is

approached tangentially (10 papers), often coming out of findings and theorized in discussion or future work sections. As repeated antecedents emerged, it became useful to apply concepts of cognitive and affective trust to model the two-sided construction of trust as adapted for visualizations by Elhamdadi et al. (2023). This framework, presented as a matrix in Figure 1 and as a Sankey diagram in Figure 2, was chosen because of its recent development and application in the visualization realm, the similarities between visualizations and maps, and the recognition of this framework in map trust publications (Prestby 2024; Ly Toong Yi 2024). Each item within this framework is either pulled from trust literature in cartography or a related field where trust is cited or theorized. Of the 32 papers analysed, the 21 which directly addressed maps are bolded in the matrix. Elements are sometimes explored in composite within some papers and individually in others. This is denoted by indenting subordinate elements below their composite element.

3. Discussion

This section characterizes an array of map and visualization antecedents identified in the literature, drawing upon two distinct yet complementary visualizations to establish a comprehensive framework for understanding elements of map trust.

3.1 Trust Antecedent Matrix

Figure 1 reflects the current trust antecedent matrix, showing identified and theorized properties and conditions that can affect the creation of trust in a map. In this framework, trust is recognized to be comprised of both the physical characteristics of the map itself as well as the unique understandings, abilities, cultural affiliations, expectations, and conceptions of the individual viewing the map.

3.1.1 Trust dimensions

The framework distinguishes between cognitive and affective factors, where cognitive factors are processed logically, and affective factors are processed by map users viscerally. Separating the cognitive from the affective dimensions enables researchers to parse out and better understand how different physiological responses and biases or prior knowledge of the individual sway trust measurements. These measured changes are real and should be expected when asking individuals to rate or rank their trust; however, these differences cannot be only attributed to design choices. Rather, they are intrinsic to the individual reader. These two categories of trust comprise the two rows of the framework.

3.1.2 Design dimensions

The columns of the matrix framework extend beyond those proposed by Elhamdadi et al. (2023) to include additional dimensions that are tailored toward design considerations for how trust can be built or eroded specifically in maps, particularly the *textual* and *experiential* dimensions. The intent is to prompt thought about both what these

dimensions have in common and the inherent differences between how they function on, within, and around a map to change the user's perception of the map.

The *data dimension* refers to the data presented on the map itself and was an original category in the Elhamdadi et al. (2023) framework. Differences here could be seen between similar data collected with two different resolutions, data generalization, similar data with different levels of accuracy, or a raster and vector representation of the same phenomenon. This dimension includes trust in data collection practices, basic data model, as well as data dimensionality, accuracy, ethical collection, prior understandings and attitudes of the topic. Existing work on trust within maps and other relevant spheres points most strongly to potential effects of data coverage (Prestby 2024) currency (Flanagin and Metzger, 2008), accuracy (Xiong et al., 2019), and sourcing (Trapsilawati et al., 2019).

The *visual dimension* encompasses pieces of the map which are primarily processed as they are seen. Here, research has and should continue to investigate differences in trust between the same data encoded with different visual variables, differences depending on the inclusion or exclusion of a basemap or additional contextual datasets, or differences in trust with different levels of visual complexity in the map. The visual dimension includes the aesthetics of the map itself, symbolization choices, design elements, placement of marginalia, and geometry simplification, among other factors. This dimension is the one that cartographers most directly control and likely most often consider in map design. Current research points most strongly towards the aesthetics of the design (Kelton et al., 2007; Peck et al., 2019), use of colour (Griffin 2020), and the encoding of uncertainty (Gustafson and Rice, 2020) as factors most likely to affect trust.

The *textual dimension* accounts for typographic choices, as well as the content of the written or other additional material on the map. Looking at the same map with and without a title or with a different font choice could influence how the map is perceived and the trust the map inspires within individuals. This category also includes typeface, font size, text colour, amount of text, labelling choices, and the actual meaning of the verbiage on the map. In the matrix, most work has pointed to the content of narrative text (Skarlatidou et al., 2008; Kim et al., 2021; Pingel et al., 2025), as well as the effect of having that text present on the map (DiBiase 2025) as most likely to build or erode trust.

The *experiential dimension* accounts for the effects of framing, media choice, and interactivity. An individual map may be understood and trusted differently when displayed alone as opposed to within a series or atlas. This category includes map distribution (Fish and Quines Kreitzberg, 2023) and placement within larger works; features which place the user on the map or ask the user to connect personally with the map (Sui and Goodchild, 2011);

	Data	Visual	Textual	Experiential
Cognitive	Data Coverage ^{AGHQWYB} Data Clarity ^{KQ} Data Currency ^{AGILW} Collection Practices ^{IL} Sample Size ^{KO} Uncertainty ^{GILM} Accuracy ^{AGKNQYdfe} Metadata ^{ACKTW}	Models of Representation Basemap ^W Locator Maps ^W Legend ^W North Arrow & Scale Bar ^W Visual Encoding Symbolization ^Z Clarity ^{HQW} Uncertainty ^{GIMQT} Complexity ^{PHQ}	Marginalia ^a Accompanying - Visualizations ^{GHLX} Photos/Illustrations ^B Logos ^{WB} Narrative or Explanatory - Text ^{DBKLOX} Disclosures Websites/QR Codes ^W Objectivity ^{PGJY}	Medium ⁶ Print ^T Digital ^{ADIR} Physical Properties ^T Interaction ^{GIN} Interface design ^{DT} Panning ^B Zooming ^B Additional Layer/Basemap ^B Multiscalar Representation ^{BZ} Add Supplemental Data ^{RE} Egocentrism ^{HI} View angles GPS/IP location on map ^I Other locators ^E Context ^{LE} Map discovery ^{LKVdP} Additional/removed - images ^{DEKTP} Additional/removed map - elements ^{LKTP}
Affective	Data subject ^{OQ} Data source ^{CHQdfe} Crowdsourcing ^{ACTL} Automated collection ^{FIL} Authoritative - sources ^{BHKTW} Transparency ^{ACFKWY} Presence of metadata ^{CKW}	Familiarity ^{GW} Cultural Expectations ^{FUa} Color Connotations ^{ILTX} Coherent Style ^{GW} Map Aesthetic ^T Visually pleasing ^{PHQWY} Scientific look ^{BOY} Authoritative look ^{BLQWXY} Predictability ^{BDGY}	Coherent Style ^{BGX} Visual Arousal ^{BH} Expressed Values Emotional appeal ^{GW} Competence ^{BDKS} Integrity ^{BDKSY} Benevolence ^{BDSYB}	Virality ^{LV} Anchoring & Priming Effects ^{HUM} Familiarity ^{FHUK} Perceived Risk ^F Passage of Time ^{GI} Ease of Use ^P Technology Savvy ^{FFGIK}
Sources:	A. Bishr and Kuhn, 2007 B. Kelton et al., 2007 C. Flanagan and Metzger, 2008 D. Skarlatidou et al., 2008 E. Sui and Goodchild, 2011 F. Hoff and Bashir, 2015 G. Mayr et al., 2019 H. Peck et al., 2019	I. Trapsilawati et al., 2019 J. van der Bles et al., 2019 K. Xiong et al., 2019 L. Griffin 2020 M. Gustafson and Rice, 2020 N. Nelson 2020 O. Kim et al., 2021 P. Zhang et al., 2021 Q. Elhamdadi et al., 2023	R. Fish and Quines Kreitzberg, 2023 S. McKay et al., 2023 T. Prestby 2023 U. Gartner et al., 2024 V. Liu et al., 2024 W. Ly Toong Yi 2024 X. Meyer et al., 2024 Y. Prestby 2024	Z. Adams et al., 2025 a. Buckley and Case, 2025 β. Case et al., 2025 γ. DiBiase 2025 δ. Griffin and Robinson, 2025 ε. Pingel 2025 ζ. Prestby 2025

Figure 1. Trust Antecedent Matrix. Citations are listed in the matrix in chronological order; map-based works are bolded.

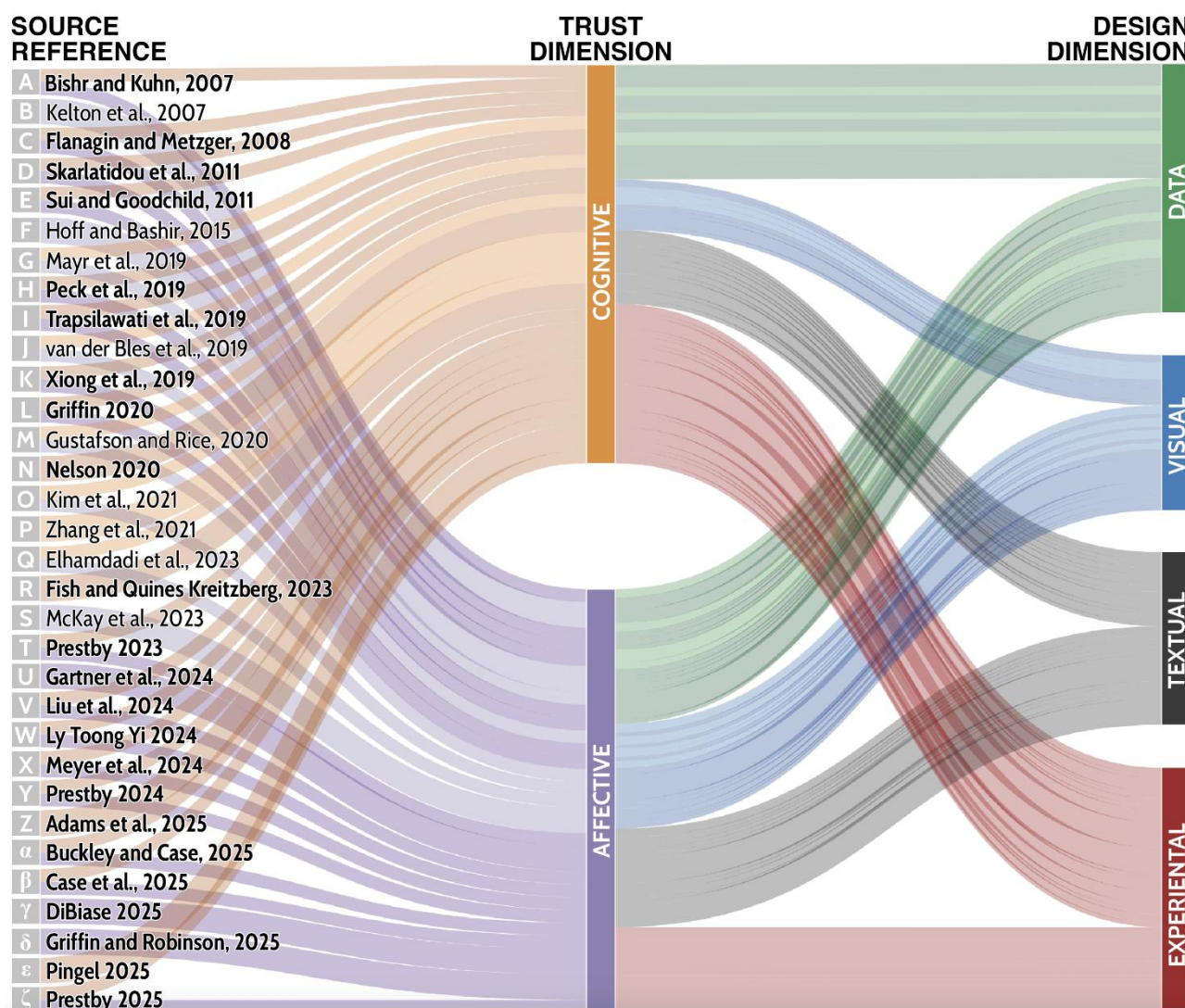


Figure 2. Trust Antecedent Sankey Diagram.

material properties of the print or format (Buckley and Case, 2025); basemap or layer toggles (Zhang et al., 2021; Prestby 2025), and the reader's technological savvy (Hoff and Bashir, 2015).

3.2 Trust Antecedent Sankey Diagram

The Sankey diagram, Figure 2, provides a visual representation of the matrix, depicting how each paper is coded to each antecedent via the type of trust used to process that antecedent. This shows the relative impact of individual papers, the way papers contribute across the four data dimensions and the two trust dimensions, and where the bulk of current research points, as well as identifying critical gaps in the literature.

Interestingly, the diagram shows approximately similar proportions of cognitive antecedents to affective antecedents across each of the four design dimensions, with visual showing the largest deviation for a ratio of about 1:2. This could be because there truly are approximately the same proportion for each data dimension, or it could be due to how little we currently

know about how trust is built in maps. If almost all antecedents are simply theorized, which is the case, it is not unlikely that researchers will be able to think of potential cognitive and affective antecedents in similar proportions across each dimension. It is also of note that each of the four dimensions is similar in size, with the largest being only about twice the size of the smallest. This could be due to the same phenomenon.

The diagram also shows that while some papers theorize about trust narrowly and have only one or two contributions, more comprehensive papers, i.e. ones with a large number of theorized antecedents, typically contribute both cognitive and affective antecedents. This could show how related the two ways of processing can often be done on the same or very similar antecedent, like noting both the effect of data source and data coverage. The difficulty in splitting antecedents into two distinct ways of thinking could have caused antecedents the author did not divide to be placed on opposite trust dimensions. Conversely, the relationship could also be explained by the self-evidence of the different processing used when

evaluating an antecedent. It could, in fact, be so obvious that some elements would appeal to reason while others would appeal to something more primal that authors often are able to include both within the same paper.

It is interesting to note the change in the types of papers being analysed, from seldom dealing with maps in the early 2000s to almost entirely map related papers in the 2020s. This can be seen easily in the Sankey diagram as references are increasingly bolded further down the axis. This shift indicates the growth in the research of trust in maps. Many of the most recent articles come from a special edition of *Cartographic Perspectives* focused specifically on ethics, though many authors choose to address trust as part of their works. The inclusion of trust indicates a new understanding of trust as a distinct part of cartographic ethics, as seen in Buckley and Case (2025), bolstering the necessity of understanding trust in maps.

3.3 Internal structures

Within each diagram, there is further internal structure (i.e., composite and constituent antecedents) designed to more fully explain and categorize relationships between documented antecedents. References in both diagrams are listed first chronologically and then alphabetically within each year. Bolded references reflect works that are fully focused on cartography or use a map as part of their data or process.

3.3.1 Composite and constituent antecedents

The matrix (Figure 1) has an internal structure where some antecedents are indented below others. This is designed to denote composite antecedents and their constituent elements, where applicable. In the review process, papers often pointed at slightly different antecedents which were specific to the research but in context were analogous to other previously proposed antecedents, such as a “Scientific-look,” proposed in Elhamedi et al. (2023), to the map being similar to an “Authoritative-look” proposed in other papers, including Ly Toong Yi (2024). In these cases, the similar antecedents were combined in the matrix as both would come from manipulation of similar design elements. Specifically in the example case, “Scientific-look” was listed with “Authoritative-look” and “Visually Pleasing” under the “Map Aesthetic” composite antecedent, which had been previously proposed as an antecedent by was posed in another research paper, Prestby (2023). It is likely that each constituent antecedent is related to its fellow constituents and a future version of this matrix may combine them further or break them into independent antecedents.

Similarly, some composite elements did not appear in the literature explicitly (e.g., “Disclosures,” “Expressed Values,” and “Visual Encoding”) and have been conceptualized as a way to categorize similar constituent elements that are discussed in literature to better understand and organize the facets of trust being theorized. While these composite antecedents were not explicitly found in any of the reviewed papers, the concepts are

broadly used across the cartography and visualization research communities, thus are useful and relevant for grouping antecedents that build or erode trust. For an example from the *textual dimension*, while an appeal to emotion is not the same as an expressed benevolence, the idea of using text on the map to explicitly speak to the reader as a way to convey trustworthiness of a map is a clear throughline between the two. The antecedents, “Benevolence” observed in McKay et al. (2023) and “Emotional Appeal” from Mayr et al. (2019), have been listed together under “Expressed Values”, despite “Expressed Values” never appearing in any of the reviewed papers.

3.3.2 Repetitive antecedents

A close inspection of the matrix and Sankey diagram will show that there are some antecedents which are listed more than once on the two diagrams and more where a very similar concept is listed in two different places. These repeated antecedents are included intentionally.

Across different types of trust, they represent the reality that some antecedents could be processed either way. For instance, “Authoritative Sources” and “Logos” are both listed, despite the fact that the value of a logo is representing a source or author, especially authoritative ones. In this case, while the two antecedents point to the same concept, the two signs of that concept perceived by the user are processed in different ways. This difference is what prompts the matrix to list the antecedents separately.

Across the same type of trust, the repetition represents that the antecedent can be evaluated across multiple design dimensions. “Uncertainty,” for example, appears in both the data and visual columns. The double listing refers to the effect of uncertainty in the data on trust as well as the effect of the visualization of uncertainty via the map.

4. Limitations & Future Opportunities

4.1 Behavioural trust

In some scholarship that seeks to breakdown and understand trust, a third category has emerged: behavioural trust. Behavioural trust has been conceptualized as the unique understandings and tolerances of an individual (Case 2025). This has been a way to account for factors like risk tolerance and personal preferences. Importantly, this conceptualization is seen as separate from either affective or cognitive trusts.

The framework presented in this research clearly does not use the concept of behavioural trust as a separate mode of trust. This is in line with the original Elhamedi et al. (2023) framework which this work builds upon and has been used in other map and visualization studies (Prestby 2024; Ly Toong Yi 2024). This framework does, however, capture many antecedents that could be categorized as behavioural, including “Familiarity,” “Predictability,” “Expressed Values,” and “Accuracy.”

The separation of behavioural trust as a unique category of trust has not been adopted as widely as the dichotomous view in map and visualization trust. The phenomenon it is describing is demonstrably true. We, as humans, all

possess differences that affect how we make decisions, including deciding to trust or not.

Unlike the other two categories, behavioural trust describes less how the antecedents are processed mentally and more how they are often determined practically. In trust literature that does separate out a behavioural trust dimension, it has been noted that elements of behavioural trust can be either cognitive or affective (Case 2025). Factors of behavioural trust are often decided by heuristics, which are related and covered in more detail in the next subsection. The fact that behaviours themselves are considered separate from either cognitive or affective processing means that the behaviours must be determined without absorbing all information available within the map. Making a decision which ignores some of the available information is the hallmark of heuristic decision making (Gigerenzer and Gaissmaier, 2011). While proposed behavioural antecedents are often processed heuristically, they are not only processed heuristically, and they are not the only antecedents which can be processed via a heuristic. Behavioural factors are important for informing trust; however, they do not conclusively stand as a distinct trust building process. For these reasons, we have not included a separate behavioural trust row in the matrix or the Sankey diagram, though we have accounted for potential behavioural trust elements within both cognitive and affective trust categories.

4.2 Heuristics

Heuristics are shortcuts all humans use inherently to simplify decisions. They are created by ignoring part of the available information in order to make decisions faster and with less effort than fully comprehending (Gigerenzer and Gaissmaier, 2011). This allows us to quickly make decisions, especially larger ones, without having to explicitly consider the large number of factors that could reasonably affect or be affected by that decision. These heuristics can be based upon many factors, individual experiences, and predilections. Heuristics work much like a map; by abstracting and reducing all of the information available, people are able to more efficiently make decisions which are very often, but not always, accurate. The use of heuristics means that it is unlikely that every antecedent of trust will be evaluated fully or logically when a map is viewed. In map trust, we are largely looking at one-shot trust, where past experience with the map itself is unlikely, meaning there is unlikely to be an obvious reason for a user to deviate from reliance on common heuristics. This phenomenon has begun to be explored in part by Ly Toong Yi (2024), looking at Truth-Default Theory, which outlines a specific heuristic to, by default, assume things are true rather than false or even neutral.

There are ways to break heuristic thinking; however, this should be done with caution. The existence of heuristics is a human reality and, in that way, not a flaw rather a complication in understanding the impact a specific antecedent has on trust. This complicates any future attempts to measure the effects of changing an antecedent on the resulting trust. Intentionally breaking heuristics may

initially seem like a way to avoid this pitfall but could cause inaccurate measurements. Further investigations should take care to pay attention to the effect of heuristic thinking when measuring trust. There is evidence that scrutinization beyond the norm causes the user to rethink their heuristic, and thus trust built via scrutinization is of the cognitive variety (Case 2025). For instance, an expert cartographer will interrogate a map more than the average person, and because of this interrogation, will either find a decision they disagree with or will find the map adequate. Whatever their conclusion is, the resulting trust is more cognitively derived than if it had been done by heuristic thinking. By attempting to force individuals to break heuristics, researchers will artificially increase the proportion of trust and distrust that is cognitive due to the experimental design rather than due to changes in antecedents.

Heuristic factors are not intentionally separated in the created framework. Many of the theorized antecedents could be processed heuristically by a variety of map users and not necessarily in the same way. Some of the most likely to be heuristically understood include data subject, familiarity, cultural expectations, and the presence of marginalia and map elements, like logos, photos, scalebars, or a north arrow.

5. Conclusions

The expanded Elhamedi et al. (2023) framework serves as a productive starting point for guiding and synthesizing studies into how trust functions in maps. While useful for cartographic researchers and actionable for professional cartographers, this framework is not an exhaustive list of all elements which could affect trust. For example, the framework fails to account for map literacy or nuanced personal preferences. There will be topics, geographies, and data that are difficult to map and are inherently polarizing.

This study provides a comprehensive albeit incomplete checklist of antecedents that will need to be investigated, understood, or eliminated to advance understanding of map trust and equip cartographers with tools for designing more trustworthy maps. The literature review and proposed framework distil focused opportunities for empirical research needed to unlock new insights into map trust. For example, from each dimension, further research into data source, use of particular aesthetics, the effect of the values expressed in the text, and the effect of context around the map would be solid steps into understanding what design choices can build or remove trust.

Uncertainty in particular is an interesting case, where disclosing or showing uncertainty is intended to better explain the limitations of the data and build good faith with the reader. If the disclosure or display of uncertainty is found to decrease the trust users feel, this could undercut one of the two reasons to disclose uncertainty. Depending on the use of the map, this could be counter to its intent, in which case the issue could be purely an ethical one. Similarly, disclosures, metadata, and data accuracy are

used for similar purposes and may have similar, potentially counterintuitive, effects on trust.

Future additions and refinement of the matrix as well as expansion of the knowledge about each dimension of trust are needed to understand how trust is built or destroyed in maps. The investigation of a behavioural trust dimension is vital to better defining the map trust space. Understanding what separates and defines the potentially three types of trust is important to be able to take comprehensive steps to design for how individuals actually process and trust a map. This will also require understanding which antecedents are most likely to be overwritten by a heuristic, which are more likely to be intentionally processed, and what could cause a reader to switch between processing modes.

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