Chapter 5
Cognitive Processes and Traits Related to Graphic Comprehension

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ABSTRACT

The subject of how visualizations and graphics in general can be understood by their viewers draws on theories from many fields of research. Such theories might address the formal structure of the visualization, the style and graphic design skills of the creator, the task driving the viewer's interaction with the visualization, the type of data being represented, or the skills and experiences of viewer. This chapter focuses on this last question and presents a set of interrelated constructs and viewer traits that contribute to (or interfere with) a viewer's ability to analyze a particular data visualization. The review covers spatial thinking skills, cognitive styles, mental models, and cognitive load in its discussion of theoretical constructs related to graphic comprehension. The review also addresses how these cognitive processes vary by age, sex, and disciplinary background–the most common demographic characteristics studied in relation to graphic comprehension. Together, the constructs and traits contribute to a diverse and nuanced understanding of the viewers of data visualizations.

INTRODUCTION

With the rise of big data initiatives in academia, industry, and the public sector, the need for rapid and reliable pattern and trend analysis that can be easily communicated to a broad audience has created a growing demand for data visualization. Data visualization as a practice is thus becoming increasingly global, being conducted by and distributed to increasingly diverse stakeholder groups. Users of visualizations may engage in a variety of tasks related to the visualization, including both low-level tasks like data foraging and high-level tasks like problem-solving and

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composing (Card, Mackinlay, & Shneiderman, 1999), but the success of user interactions with visualizations is dependent on a variety of factors.

Small-scale studies of individual visualizations or common visualization types have established user success at interpreting specific structural devices or artifacts (see work by Fabrikant and colleagues–e.g., [Fabrikant, Montello, Ruocco, & Middleton, 2004]) or selecting appropriate interaction strategies (Molitor, Ballstaedt, & Mandl, 1989), commonly using response rate and accuracy as evaluation metrics (Lam, Bertini, Isenberg, Plaisant, & Carpendale, 2012). These studies, however, are often designed to evaluate a specific graphic or a limited set of visualization properties. With the rise of visual analytics and the broadening of the audiences for visualizations, a detailed examination of the interaction between an individual's skills and success at a full complement of visualization interpretation tasks is crucial to the development of appropriate and successful data visualizations and visual analytics systems.

This chapter will synthesize theoretical work that focuses on the viewer and the cognitive processes and traits that have been found to be relevant to the comprehension and interpretation of visualizations or, more broadly, graphics. We focus on the user/viewer of data visualizations and visual analytic systems to the exclusion of the visualizations and systems themselves; this focus allows us to identify research outside of the fields of data visualization and visual analytics that nonetheless have bearing on the interpretation process.

THEORIES OF COGNITION RELATED TO GRAPHIC COMPREHENSION

Graphic comprehension is at its heart a process of sense making. Low-level perceptual processes interact with higher-level attentional, associative, and interpretational processes to influence what people see and understand. The following section omits the cognitive processes with broader applicability and focuses instead on a series of specific constructs developed and tested to explain some component of graphic comprehension. Research on spatial thinking skills helps to categorize independent sets of skills necessary for different types of graphic comprehension tasks, from mental rotation of objects to maintaining vivid imagery. Mental models research applies across those spatial skills to describe how individuals interacting with an expectable external system gain experience and expertise, which they use to guide future interactions. Finally, cognitive load theory addresses the context surrounding the visualization system, building of the individual's experiences to predict what sorts of modes of communication are likely to be helpful or confusing.

Categories of Spatial Thinking Skills

A major theoretical area related to graphic comprehension is that of spatial thinking. Research within the field of spatial thinking forms a foundation upon which graphic perception can be structured. The visual encodings and reference systems used by graphics and diagrams to represent data in a manner that can be interpreted depends heavily on the skills developed during interactions with the visible world around us. Spatial thinking as a construct incorporates many other, related concepts, including spatial literacy, spatial intelligence, mental maps, and so forth. Research on spatial thinking describes the general types of spatial reasoning competencies people can acquire as they develop (e.g., spatial perception, mental rotation) and provides a broader framework within which more specified theories of graphic perception can be placed.

Spatial thinking, though foundational to a variety of interpretive tasks, is not an undifferentiated pool of tasks and abilities. Linn and Petersen (1985) conducted a meta-analysis of spatial ability research and identified the following three categories of spatial ability: spatial perception, mental