Faculdade de Design, Tecnologia e Comunicação
Universidade Europeia

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Projeto apresentado ao IADE – Faculdade de Design, Tecnologia e Comunicação, para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Comunicação e Multimédia realizada sob a orientação científica do Doutor Milton Cappelletti Júnior, Professor Auxiliar da Universidade Europeia.

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Rita e Luís Monteiro
Finalmente!

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Keywords

Data visualization; visual perception; cognition; framework; Instagram; Eurostat.

Abstract

This project helps to close the gap in design-oriented research on the integration of human cognition and neuroscience into data visualization design. It makes the case that generating more useful and easily available data representations depends on matching visualizations with human visual perception and cognitive processes. Two main goals were followed by the research: first, to investigate the degree to which Eurostat's Instagram data visualizations embrace ideas of human visual perception and cognition; second, to propose an original Perceptual-Cognitive Data Visualization Framework. This framework helps designers create cognitively accessible visuals and offers a means of neurologically evaluating their effectiveness — including stylistic risk evaluation. Applying the proposed framework on Eurostat's visualizations revealed its simplicity and efficiency in spotting and fixing problems compromising communicative efficacy. The research ends with underlining the need of human cognitive comprehension for the design of data visualization. Future research should concentrate on verifying the framework by means of professional assessment in several environments, including integration of neuroscientific expertise, and the creation of an interactive version to lower cognitive load for its users.

palavras-chave Visualização de dados; perceção visual; cognição; framework; Instagram; Eurostat.

resumo O interesse humano em perceber como o cérebro humano funciona é antigo, comprovado pelas cirurgias feitas pelos egípcios 1 700 AC ou pelo interesse demonstrado pelos filósofos gregos, como Platão ou Aristóteles na busca pela compreensão do funcionamento do intelecto humano. De qualquer modo, só recentemente é que o nosso conhecimento sobre processos cerebrais e cognição humana sofreu avanços significativos. Desde então, várias áreas de atuação humana aproveitaram este conhecimento para enriquecer e guiar a sua atividade.

Também a visualização de dados é uma prática humana que encontra reflexos na antiguidade – certos autores defendem que as pinturas feitas nas paredes das cavernas pelos nossos ancestrais já eram uma visualização de dados, conforme iremos explorar em maior detalhe ao longo deste trabalho –, mas é com o Iluminismo e, mais tarde, com a Industrialização que a visualização de dados como hoje conhecemos começa a tomar forma. Vários autores defendem que a visualização de dados é uma ferramenta essencial para a aquisição de conhecimento, tirando, através da sua forma, partido de funcionamentos basilares da cognição humana.

Este projeto examina a convergência entre a neurociência, cognição humana e o design de visualizações de dados. Apesar do crescente conhecimento sobre a função cerebral humana e da evidente eficácia comunicativa das visualizações de dados, persiste uma lacuna na investigação orientada para o design que investigue o alinhamento das visualizações de dados com a

perceção visual e os processos cognitivos humanos. A revisão de leitura para este projeto revelou que a maioria da investigação feita sobre visualizações de dados e os processos cognitivos humanos é realizada, maioritariamente, por profissionais nas áreas das neurociências e da psicologia. Este trabalho defende que o conhecimento para a integração de conceitos neurológicos é crucial para desenvolver visualizações de dados mais eficazes e acessíveis.

A investigação visou alcançar dois objetivos: primeiro, examinar o grau em que as atuais visualizações de dados, particularmente as visualizações publicadas pelo Eurostat no Instagram, incorporam princípios da perceção visual e cognição humana; e segundo, introduzir uma framework para auxiliar no desenvolvimento e avaliação de visualizações de dados. Este trabalho incluiu uma extensa revisão da literatura sobre visualização de dados, perceção visual humana e consumo de informação em redes sociais, seguido pela formulação da Perceptual-Cognitive Data Visualization Framework. Esta framework visa auxiliar os designers na produção de visualizações cognitivamente acessíveis e fornece um mecanismo para avaliar neurologicamente a sua eficácia, incluindo uma avaliação de risco para compromissos estilísticos. Pretende-se, com esta dupla função, criar uma ferramenta prática e de utilização simples e de elevada abrangência.

A aplicação da Perceptual-Cognitive Data Visualization Framework às visualizações de dados publicadas pelo Eurostat no seu canal oficial no Instagram demonstrou a sua facilidade de uso e eficácia na identificação de múltiplos problemas que poderão estar a afetar a eficácia comunicativa das mesmas. As diversas recomendações obtidas através da aplicação da framework foram eficazes no auxílio para guiar na resolução dos problemas identificados. A utilização de uma escala de Likert permite, por um lado a criação de avaliações que levem em linha de conta problemas de subjetividade que, invariavelmente, poderão estar associados quando estamos a avaliar trabalhos criativos. Por outro lado, a utilização deste tipo de escala permite obter diferentes níveis de necessidade de revisão gráfica das visualizações de dados a serem avaliadas.

Este projeto conclui sublinhando o imperativo da compreensão cognitiva humana como um elemento fundamental no design de visualização de dados. Esforços futuros deverão concentrar-se na validação da Perceptual-Cognitive Data Visualization Framework através da avaliação da mesma realizada por profissionais na área da visualização de dados e da infografia, examinando-a em vários contextos e plataformas, contribuindo assim para a percepção detalhada, não só da real eficácia da framework proposta neste projeto, mas da sua aplicação em outros meios de publicação e distribuição de visualizações de dados que não apenas a rede social Instagram, uma vez que, na sua maioria, as recomendações apresentadas na Perceptual-Cognitive Data Visualization Framework poderão ser aplicadas de forma mais abrangente. Outro passo importante como futuro esforço será a integração da experiência científica de neurocientistas para um melhoramento contínuo da framework. A criação de uma versão interativa da framework é aconselhada para aliviar a carga cognitiva para os designers e avaliadores que a utilizem. Este último ponto é bastante importante uma vez que a framework proposta neste trabalho conta com dezoito recomendações e desaseis justificações para essas recomendações. Uma versão interativa da Perceptual-Cognitive Data Visualization Framework permitirá uma utilização mais simplificada, onde os utilizadores, sejam eles designers ou avaliadores, poderão aceder a cada uma das recomendações passo-a-passo e aceder às respetivas justificações apenas quando necessário, através de um sistema de informação acedida através de um ‘pop-up’, por exemplo.

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1. Introduction

1.1 Background

Human interest over the functioning of the brain has persisted for millennia, evidenced by the Egyptians conducting cranial surgeries in attempts to remedy brain injuries and mental problems, as early as 1700 BCE. Greek philosophers, such as Plato and Aristotle, explored the pursuit of comprehending human intellect. Over the ages, scholars and scientists have expanded their knowledge of the nervous system; nevertheless, significant advancements in the understanding of brain processes and human cognition occurred in the latter half of the 20th century.

According to Robinson (2015, p.3), “for the past three decades (...) researchers were piling up evidence for the bodily basis of mind and meaning. Diverse disciplines such as biology, psychology, cognitive neuroscience, and phenomenology steadily yielded evidence of the extent to which mental properties depend on the functioning of the human nervous system. They collectively converged on this fact: all human endeavors depend upon our brains functioning as organic members of our bodies, which are in turn actively engaged with the ecological, architectural, social, and cultural environments in which we dwell”. Nonetheless, this knowledge remains insignificant for most of us, as Dehaene (2009, p.58) asserts “in the twenty-first century, the average person still has a better idea of how a car works than of the inner functioning of his own brain — a curious and shocking state of affairs”.

The substantial potential of data visualization as a tool for comprehending complex data is unequivocal. According to Chun (2023, p.112) "(...) the advantage of a combined text and graphics goes beyond simple memory recall, with a large number of studies showing a boost in deep comprehension (...)”, and Li (2020, p. 42) elucidating that “when quantitative data is presented in a graphical form, the users are asked to use their visual perception to make judgements about the visual form, to compare relative sizes, locations, orientations, colors, densities, textures of the elements of the visualization”. The issue is that, according to psychologist and neuroscientist Stephen Kosslyn, a leading authority in data visualization and human cognition, “many charts and graphs do not convey information effectively” (Kosslyn, 1989, p.185). Kosslyn (2006, p. 4) asserts that numerous data visualizations are constructed in a manner that, rather than facilitating viewers' comprehension of graphically represented data, impedes cognitive processing.

Instagram, on the other hand, is becoming one of the main channels for people to access information. As per the *Youth Survey 2024*, “when young people are asked which social media and platforms, they use to obtain information on political and social issues, Instagram emerges as the most commonly used one (47%), followed by TikTok (39%) and YouTube (37%). Lower shares obtain information from Facebook (27%) and X (Twitter) (21%). WhatsApp is used for information on political and social issues by 16% of respondents” (Ipsos European Public Affairs, 2025).

Through the confluence of the understanding of human brain functions with the design of data visualizations, specifically for its publication on Instagram, an opportunity arises for the creation of visual information solutions that can be better comprehended by the public.

1.2. Problem Formulation

To investigate the prospects for a multi-disciplinary partnership between data visualization design and neuroscience, distributed on Instagram, we commenced by articulating a succinct inquiry:

> "To what degree can we guide and assess the design of data visualization published on Instagram, according to the principles of human visual perception and cognition?”

To answer this question, we have chosen Eurostats’ Instagram channel to provide us with a sample filed for this study. Eurostat is European’s Union official data and statistics office. Eurostat produces statistics in partnership with European Union Member states national statistic institutes (like the Instituto Nacional de Estatística, in Portugal). This partnership is known as the European Statistical System. Eurostats’ mission is to provide high-quality statistics and data on Europe and, among other goals, to inform European citizens about the European Union. As one of its’ values, Eurostat states that it aims to “drive innovation in official statistics” (Eurostat, n.d.). Considering these factors and the importance of Instagram as a news media channel, we opted to examine Eurostats’ distribution of data visualizations on this social network and assess whether these visualizations were crafted with the latest neuroscience findings in mind, as well as the impact on their communicative effectiveness when human visual perception and cognition findings were considered or disregarded.

1.3. Research Scope

For the development of this project, it is important to set its research scope, providing orientation for the subsequent research. The goal is to create a framework that will guide the design of data visualizations, for publication on Instagram, in conformity with human visual perception and cognitive capacities and for the assessment of previously designed visualization in accordance with the same knowledge.

A framework is defined as a structure designed to facilitate the construction of something. The online Cambridge Dictionary defines framework as "a supporting structure around which something can be built" and "a system of rules, ideas, or beliefs that is used to plan or decide something". A method to establish such a structure involves formulating a system of observations or guiding principles that subsequently governs a process or decision-making, thereby ensuring that the output remains consistent and aligned with the fundamental elements of human visual processing and cognition.

To achieve this, we have established several subjects to be researched:

- Understanding of what data visualization is: data visualization encompasses several terminologies that describe the graphical depiction of data, which has developed as a medium of information throughout human history. A distinct collection of attributes differentiates data visualizations from other forms of information transmission, and its visual elements are varied. Data visualizations serve as a human tool for the acquisition of knowledge. A comprehensive understanding of these diverse themes will enable us to better inform the design of data visualizations.
- The relevance of Instagram as an information distribution channel: evaluating the expansion of this social media platform, the manner in which individuals utilize it for news consumption, and the methods of data visualization being developed and shared on Instagram will guide the creation of visual data representations tailored to the platform's usage and requirements.
- Comprehending human visual perception and cognition: examining the mechanisms of human visual perception and the brain's information processing, along with an analysis of reading and learning, will enhance our comprehension of the cognitive processes engaged in information consumption via data visualizations. This research will build a foundation for formulating a framework with a series of recommendations to guide and assess the design of data visualizations.

- Framework assessment: applying the framework on diverse instances of data visualizations published on Instagram, specifically on Eurostats' channel, will enable us to evaluate its usability and its contributions to the improvement of data visualization design in alignment with the perceptual and cognitive functions of the human brain.

1.4. Rationale

This work posits that the convergence of the expanding understanding of human brain function with other fields of expertise is crucial for fostering creativity and creative solutions across many domains, as articulated by Flory & Ivanova (2019, p. 22), "every day new frontiers are forged as neurobiologists and cognitive scientists look beyond the mere structure-function neuronal correlations of thought, emotion, and behavior. Understanding this growing evidence base through the lens of a mind well-trained in critical, rigorous, and creative thinking heralds immense potential for ground-breaking applications through multi-disciplinary collaboration".

In the realm of design, particularly in data visualization, the primary focus of this work, the aforementioned 'multi-disciplinary collaboration' requires further development. Our inquiry revealed a limited number of designers who have explored human cognition and visual perception, while the majority of research has been conducted by psychologists and neuroscientists.

Alberto Cairo, an academic specializing in data visualization and design, has expressed his interest in this research domain, "if you asked me to choose one mystery that has fascinated me through the years, it would be our brain's ability to create and understand visual representations with different degrees of abstraction: graphics that encode data, concepts, connections, and geographical locations. How is it possible that the brain, a wrinkled chunk of meat and fat squeezed into a cavity too small for its size, can accomplish such challenging tasks?" (Cairo, 2013, p14).

This project's rationale emerged from recognizing the significance of applying contemporary insights into human cognition across various domains, particularly noting the lack of implementation in the design sector, especially in the visual representation of data.

1.5. Document Structure

This document is structured into five chapters, exploring different stages of the research project. It also includes bibliographic entries and appendixes with additional support material.

- Chapter 1 – Introduction: determinates the background for the main subject of this project, outlines the problem formulation and research scope, and the rationale behind it.
- Chapter 2 – Literature review: details the main aspects of the research for this work, such as the understanding of what is a data visualization, the significance of Instagram as a pertinent medium for information dissemination, and an analysis of various elements pertaining to human visual perception and cognition.
- Chapter 3 – Methodology: delineates precedent methodologies relating to data visualization and cognition and proposes the Perceptive-Cognitive Data Visualization Framework along with the justification for its development.
- Chapter 4 – Framework for data visualization: establishes the sample space and analyzes the application of the framework on various data visualizations published on Instagram through a heuristic evaluation of its usefulness and usability. Examines the findings and provides an evaluation of the Perceptive-Cognitive Data Visualization Framework, highlighting its strengths and flaws, as well as the limits of the current research.
- Chapter 5 – Conclusion: resumes the investigation done for this project and based on its limitations, outlines future measures to enhance the research.

2. Literature review

2.1. Visual representation of data

2.1.1. In support of the term 'data visualization'

Upon examining the literature regarding the visual representation of data, one salient observation emerges: there is an absence of a definitive nomenclature for the activity of visual data representation. Terms such as infographics (Ozdal&Ozdamli, 2017, p. 1199), data visualization (Li, 2020, p. 19), data graphics (Tufte, 2011, p. 10), and information graphics (Cairo, 2013, p. 73) appear to be employed by different writers in a seemingly interchangeable manner.

A thorough examination of the literature reveals that these terms are employed to denote the visual representation of data for informational purposes:

> "(...) of all methods for analyzing and communicating statistical information, well-designed data graphics are usually the simplest and at the same time the most powerful” (Tufte, 2011, p.10).
>
> “Locoro, Cabitza, Actis-Grosso and Batini (2017) defined infographics as visualisation tools used with the purpose of informing users in general”. (Ozdal&Ozdamli, 2017, p.1199).
>
> “A broad, umbrella term, information graphics — often contracted as ‘infographics’ — refers to the use of visuals to meaningfully communicate data and complex information” (Chun, 2023, p.110).
>
> “(...) an information graphic is a tool for the designer to communicate with readers, and a tool for readers to analyze what’s being presented to them” (Cairo, 2013, p.73).

Cairo (2013) addresses this issue by asserting that the terms 'infographics' and 'information visualization' exist on a continuum; hence, the author opts to use both terms interchangeably. “In the following pages, I take an unorthodox approach. Infographics and visualization exist on a continuum. (...) every infographic and every visualization has [SIC] a presentation and an exploration component: they present, but they also facilitate the analysis of what they show, to different degrees” (Cairo, 2013, p.14 - 15)

In alignment with Cairos' solution, this study will utilize the term 'data visualization' to denote the visual depiction of data aimed at informing an audience.

The online Cambridge Dictionary defines the term we selected as follows:

“Data visualization - the act of representing information as a picture, diagram or chart”, (Cambridge University Press, n.d.).

We have also ascertained the definition of the term 'infographic':

“Infographic - a picture or diagram or a group of pictures or diagrams showing or explaining information”, Cambridge University Press, n.d.)

It is evident that, according to the online Cambridge Dictionary, the terms 'data visualization' and 'infographic' can be utilized interchangeably. For this study, we have opted to utilize the American spelling of the term 'visualization' rather than the British spelling (visualisation).

2.1.2. The evolution of data visualization

The visual depiction of data has existed nearly as long as humanity itself. Ozdal and Ozdamli (2017, p.1198) state that "(...) pictures drawn on the walls of the caves adopted different visualisation [SIC] methods of people for centuries in terms of education, health, artistic activities as well as for communication and the presentation of knowledge in other areas”.

Li (2020, p.17) states that “the term “data visualization” has a long history dated back the 2nd century AD. At the ancient society, drawings and other visual representations were used to investigate the world and also to record the historical events”.

Nonetheless, data visualization, as previously defined and central to this study, is a contemporary innovation, according to Tufte (2011, p.10). The author details the history of data visualization in his book *The Visual Display of Quantitative Information*, showcasing instances of work produced prior to the standardization of systematic visual data representation. Tufte (2011, p.10) posits that the impetus for the current emergence of data visualization may be “(...) perhaps because of the diversity of skills required - the visual-artistic, empirical-statistical, and mathematical”.

Diverse writers provide insights into the history of data visualization and the pioneers of the profession as we recognize it today. Alyahya and Bhat (2024, p. 3) identify two significant contributions to the development of data visualization: “James Joseph Sylvester is credited with coining the term 'graph'. In 1626, Christopher Scheine published the first infographic in the scientific journal Rose [SIC] Ursina sive Sun, illustrating the logical relationships between mathematical qualities and chemical bonding in chemistry”.

Tufte (2011, p.10) provides historical insights on some prominent data visualization formats: “it was not until 1750-1800 that statistical graphics length and area to show quantity, time-series, scatterplots, and multivariate displays were invented(...)”.

Recently, “Peter Sullivan made significant contributions to the development of infographics by introducing the term infographic in the 1980s and 1990s. The term gained popularity through The Sunday Times publication, which expressed a preference for graphics”, as per Alyahya and Bhat (2024, p. 4).

One cannot discuss the history of data visualization without acknowledging the invention and widespread adoption of the personal computer. As stated by Li (2020, p.17), “(...) the development of computer software has advanced the application of data visualization, allowing users to manipulate a substantial amount of data for exploration and analysis in an easier and more affordable way”.

The history of data visualization clearly illustrates that the primary objective of this innovation has been to create visual representations of data that enhance human comprehension of the world and its concepts and products. Fu and Stasko (2023, p.6) state that “data visualization is often touted for its value in amplifying human cognition, such as expanding working memory, enhancing pattern recognition, and making information manipulable”, while Cairo (2013, p.18) mentions that “graphics, charts, and maps aren’t just tools to be seen, but to be read and scrutinized. The first goal of an infographic is not to be beautiful just for the sake of eye appeal, but, above all, to be understandable first, and beautiful after that; or to be beautiful thanks to its exquisite functionality”.

2.1.3. Taxonomy of data visualization

This work has previously indicated that a distinct taxonomy or collection of criteria differentiates data visualization from other media. Dunlap and Lowenthal (2016, p. 55) state that “effective infographics rely primarily on visual elements and structure, as opposed to text, to convey content/messages. An infographic’s visual elements are not decorative in nature but used instead to deliver content vital to the representation and interpretation of the instructional message/narrative”. Consequently, we may ascertain that data visualization possesses, as one of its primary attributes, visual features and organization.

Moreover, Chun (2023, p.112) asserts that fundamentally, data visualizations can be characterized as an amalgamation of text and graphics. Chun (2023, p. 113) subsequently asserts that “the interplay between text and graphics occurs in the same space, distinguishing the infographic form from a simple news photo and its accompanying caption. While a photo and its caption operate together, we would not reasonably consider the coupling as an infographic, as the image and text are not intermixed”.

Various scholars have conducted distinct analyses of the area to more precisely delineate the primary aspects of data visualizations: “infographics have been frequently used in recent years with the purpose of the visual presentation of information. It is a visualisation [SIC] method which aims at presenting any content with a visual composition, combining such elements as shapes, symbols, graphics, photographs, illustrations, and texts for the target audience” (Ozdal&Ozdamli, 2017, p.1197). Tufte (2011, p.10) asserts that when examining the visual depiction primarily of statistical data, “data graphics visually display measured quantities by means of the combined use of points, lines, a coordinate system, numbers, symbols, words, shading, and color”.

At this juncture in establishing a taxonomy for data visualization, it is evident that this medium predominantly employs other recognized media. In this context, Ozdal and Ozdamli (2017, p.1199) assert that “it is known that the elements used in the design of infographics are actually not completely new. Several elements used in the design of an infographic, such as pictures, shapes, symbols, graphics, and text, are used individually or in combination with the purpose of transferring information”.

The literature review indicates another significant attribute of data visualization. “(...) the common characteristics of traditional data visualization including readability, recognizability and meaning. These characteristics are based on data communication for comprehension and knowledge acquisition. (...) Data visualization may has [SIC] more characteristics, such as graphical design, color and interactivity, but the essential and common characteristics focus on readability, recognizability and meaning” (Li, 2020, p.41).

In data visualization, "readability, recognizability, and meaning" are closely associated with "the interplay between text and graphics," as noted by Chun (2023, p. 113). The significance of this dynamic as a fundamental property of data visualization is elucidated by Hill and Hollan (1991), as referenced by Chun (2023, p.112): “pointing, for example, is a deictic mechanism that directs our audience’s visual attention to what’s important or relevant in the conversation. Hill and Hollan (1991) argue that effective visualizations also incorporate a graphical form of deixis. Explanatory text and labels along with arrows, brackets, and pointers that are layered on top of an image are the visualization counterparts of linguistic deixis".

In conclusion, a taxonomy for data visualization can be established through the application of recognized graphic elements within a defined structure, intended to convey meaning to the visually represented data. This approach employs editorial and design techniques that serve as a deictic mechanism to focus attention on pertinent information, ensuring that the utilized elements are primarily functional rather than decorative, thereby facilitating the audience's comprehension of the presented information.

2.1.4. The fundamental components of data visualization

Having established a taxonomy for data visualization, we may advance our comprehension of the various components that constitute the "(...) shapes, symbols, graphics (...)" stated before by Ozdal and Ozdamli (2017, p.1197) or the "(...) points, lines, a coordinate system, numbers, symbols, words, shading, and color", as noted by Tufte (2011, p. 10) and several authors previously referenced in this work.

Dunlap & Lowenthal (2016, p.44) assert the significance of elements utilized in data visualizations: "infographics commonly include charts, maps, diagrams, and illustrations to quickly tell a story, show relationships, and reveal structure(...)".

Alyahya and Bhat (2024, p. 1) state that "information graphics or infographics are visual representations of data using graphic elements, such as pie charts, bar graphs, line graphs, and histograms" and Li (2020, p. 22) asserts that "(...) the common forms of data visualization refer to trees, scatter plots, charts, tables, diagrams, and graphs. Selecting forms for data visualization is dependent on the type of data".

Li (2020, p.23) provides a comprehensive table enumerating the general and unique kinds of data visualization:

Common forms	Specific forms
Tables; Charts; Trees; Maps; Scatterplots; Diagrams; Graphs; Simulations; Waveforms; Volume	Area Chart; Bar char; Bullet graph; Box-and-whisker Plots; Bubble Cloud; Cartogram; Circle View; Dot Distribution Map; Gantt Chart; Heat Map; Highlight Table; Histogram; Matrix; Network; Polar Area; Radial Tree; Streamgraph; Text Tables; Timeline; Treemap; Wedge Stack Graph; Word Cloud

Table 1 - The forms of data visualization (Li, 2020, p.23)

This comprehensive table of (mostly) all the different forms of data visualization, added with the previously shared contribution by Ozdal and Ozdamli (2017, p.1199) referring "(...) pictures, shapes, symbols, graphics, and text (...)", provides us with a clear understanding of the various elements and forms that can be used to make a data visualization.

2.1.5. Data visualization as a mechanism for knowledge acquisition

As previously stated in this work, data visualizations are essentially instruments for the acquisition and comprehension of information. Dunlap & Lowenthal (2016, p.43) advocate for the effectiveness of these communication tools: "because of their wide acceptance and use as a device for delivering complicated content to a wide audience, infographics have considerable potential as a way of efficiently, precisely, and clearly delivering abstract, complex, and dense instructional content (...)".

The literature review reveals multiple writers who have examined the effectiveness of data visualization as an educational aid. We assert that this type of research aligns well with the objectives of our ongoing investigation.

Alyahya and Bhat (2024, p. 5) elucidate that “infographics play a crucial role in data visualization for educational purposes by simplifying complex information, increasing engagement, enhancing memory retention, encouraging critical thinking, promoting data literacy, supporting differentiated instruction, emphasizing key takeaways, improving communication, and stimulating creativity”. Emphasizing the significance of data visualization as a knowledge tool, Ozdal and Ozdamli (2017, p. 1199) assert that “as an extremely useful medium in the transfer of knowledge, infographics contribute to the presentation of information presented in complex and long texts by simplifying the data in a more easily comprehendible size”.

Dunlap & Lowenthal (2016, p.42) enhance our comprehension of the effectiveness of data visualization as instruments for knowledge acquisition by asserting that “people learn and remember more efficiently and effectively through the use of text and visuals than through text alone. Infographics are one way of presenting complex and dense informational content in a way that supports cognitive processing, learning, and future recognition and recollection”.

In their literature study, researchers Ozdal and Ozdamli (2017, p.1199) synthesized a collection of papers and experiments regarding the impact of data visualization as a learning tool. For instance, the authors convey that “Lankow, Ritchie and Crooks (2012) stated that (...) infographics are effective in the understanding and learning processes of intense and sometimes complex information (...) Lankow, Ritchie and Crooks (2012) said that infographics (...) are essential tools for learning and teaching processes with the comprehensive graphic and design elements that they provide. Dur (2014) and Li, Carberry, Fang, McCoy and Peterson (2014) claimed that infographics (...) could be essential tools in persuading, guiding and mobilizing people”.

In conclusion, numerous studies have demonstrated that data visualization is an effective instrument for knowledge acquisition in educational settings. We understand that the same might be asserted regarding its efficacy as a effective mode of communication. Alberto Cairo (2013, p.24) asserting that “the first and main goal of any graphic and visualization is to be a tool for your eyes and brain to perceive what lies beyond their natural reach” seems to be defending just that.

2.2. Instagram as an information distribution channel

2.2.1. General usage of Instagram

The *Digital 2025: Global Overview Report* (Datareportal, 2025) indicates that, by 2025, there will be over five billion Internet users. Most of these users has a social media presence, "(...) equating to 63.9 percent of all the people on Earth." (Datareportal, 2025).

The primary motivations for utilizing social media, as indicated in the same report, are: "Keeping in touch with friends and Family - 50,8%; Filling spare time - 39,0%; Reading news stories - 34,5%; Finding content - 30,5%" (Datareportal, 2025).

According to Datareportal (2025), the most utilized social media worldwide are:

Facebook (monthly active users) - 3.070 million users

YouTube (potential ad reach, measured in monthly active accounts) - 2.530 million users

Instagram (monthly active users) - 2.000 million users

WhatsApp (monthly active users) - 2.000 million users

TikTok (potential ad reach, measured in monthly active accounts) - 1.590 million users

Nonetheless, a significant proportion of users (16.6%) indicate that Instagram is their preferred social media platform (% of active social media users aged 16+ who identify each choice as their 'favorite' social media platform), (Datareportal, 2025).

According to Meta's planning tools, as of January 2025, 47% of Instagram users were female, while the remainder were male (Datareportal, 2025). The average age of Instagram users in January 2025 ranged from 25 to 34 years old (Datareportal, 2025).

In Europe, 64.8% of the population has Internet connectivity, with over 269 million individuals using Instagram, as reported by Hutchinson (2024).

As per the *Media & News Survey 2023*, in Europe "49% of respondents use social media for communication purposes to send direct messages to friends and family and 47% reply they use these media for information purposes to follow the news and current events (...)", (Ipsos European Public Affairs, 2023).

In Portugal, according to the *Digital News Report Portugal 2025*, 51% of the population uses Instagram (Cardoso et al., 2025, p134).

2.2.2. Utilizing Instagram for the consumption of news content

Given its extensive utilization, it is unsurprising that numerous individuals are employing social media platforms to remain informed. According to Ipsos European Public Affairs (2023), news consumption in Europe is as follows:

> (...) 71% of respondents reply that TV was one of their most used media to access news in the past seven days. TV is the most commonly used media channel in most Member States. TV is followed (at a distance) by online press and/or news platforms (42%), social media platforms (e.g. Facebook, Instagram, etc.) with 37% and radio with 37%. The written press (e.g. newspapers, weekly or monthly magazine, etc.) is mentioned by 21% of respondents and video platforms (e.g. YouTube, etc.) by 19%.

Concerning the frequency of news consumption, Ipsos European Public Affairs (2023) assesses that "44% of respondents reply that they follow the news on a daily basis and 26% actively search for news several times a day". This research also indicates that "in all but one Member State the largest share of respondents follows the news on a daily basis (between 29% in Hungary and 54% in Portugal). In Germany, the largest share of respondents actively searches news several times a day (39% vs 31% who follow the news daily). In all Member States, a minority of respondents either try to avoid some news topics or actively avoid all news (between 3% and 15%)", (Ipsos European Public Affairs, 2023).

The *Youth Survey 2024* report indicates that "in 11 Member States, Instagram is young people's most popular social media or platform for obtaining information on political and social issues. Instagram is selected by more than half of respondents in Italy (59%), Portugal (56%), Czechia (53%), Slovakia (53%), Greece (52%) and Spain (51%). The lowest shares are found in Malta (26%), Lithuania (27%) and Bulgaria (28%)", (Ipsos European Public Affairs, 2025).

In Portugal, 21% of the population uses Instagram to access information (Cardoso et al., 2025, p134). In the younger generation (18-24 years), 27% use Instagram as their primary source of news (Cardoso et al., 2025, p117).

2.2.3. Utilizing Instagram for the dissemination of data visualizations

To assess Instagram as a platform for posting and consuming data visualization, it is essential to first comprehend the semiotics of this social media medium. Cara (2018, p. 334) states "in the combination of Instagram's functionalities and the portability of smartphones we see the digital image reaching an apex of ubiquity, acquiring distinctive characteristics in terms of production, ease of manipulation as well as its relevant role in edition, dissemination, consumption and storage of images".

The flexible semiotic environment of Instagram has allowed content creators to experiment with various media designed for publication on the network. Initially, as Shahin (2021, p. 2) asserts "data visualizations and Instagram are unlikely, but complementary, media". This author additionally asserts that "in the already multimodal environment of Instagram — a platform that, like the DV [data visualization], is grounded in visuality and 'aesthetic visual communication' (Manovich, 2017, p. 41) — the interactive and communicative capacities of DVs become all the more prominent", (Shahin, 2021, p. 2).

To comprehend the functionality of Instagram as a publishing platform for data visualization and how its features influence the production and presentation of data visualizations, Shahin (2021, p.7) examines the Instagram infographics created by Mona Chalabi:

> Consider one post in which Chalabi compares the percentage of American police officers who received a conviction for killing someone, a charge but no conviction, or no charges at all (Chalabi, 2020, May 30). The extent of the first two is immediately visible as 0.3% and 1.0%, respectively, but the user must swipe a staggering nine times through the post's images to get to the end of the visualization. There, they finally see that 98.7% of killings by police officers 'resulted in no charges whatsoever.' The effect of the post is sobering, and it is precisely that sobering quality which is its epistemic resource.

Shahin (2021, p. 8) elucidates that the swiping feature of Instagram posts is essential to the message conveyed in Chalabi's data visualization, because:

> (...) the post is interactive, explicitly telling the user to 'keep swiping' to reveal the full extent of the DV's data. But interactivity, here, is not simply about technical input from the user, nor is it a mere means to the end of getting to the data in that final image. Instead, the swiping communicates a phenomenology of data.

The literature review reveals that the utilization of Instagram for data visualization dissemination is primarily being explored due to its potential as an instrument for activism, as demonstrated by Shahin's analysis of Chalabi's posts.

Kaviani and Salehi (2021, p.79:3) examined data visualizations and U.S. ethnic movements on Instagram, asserting that “in 2020, activists from across the world supported the Black Lives Matter movement by sharing Instagram posts in the form of an infographic (...) Propelled by the Black Lives Matter movement’s posts, ethnic movement activists across the platform began to utilize infographics in their virtual organizing, resulting in the dispersion of an unprecedented number of viral activism-oriented infographics.”, including that “Instagram infographic activism amplifies information dissemination for largescale education, necessitates the resolution of internal disputes for movement credibility, and leverages on-the-ground resourced efforts that drive forth transformative change”, (Kaviani&Salehi, 2021, p.79:3).

The research for this paper has revealed a paucity of academic inquiry into Instagram as a medium for the publication and dissemination of data visualizations. A cursory examination of prominent news media outlets on Instagram reveals several instances of data visualizations on the social media site. We believe that additional research on the topic is necessary, as an increasing number of viewers are obtaining their news from Instagram, corroborated by Kaviani and Salehi (2021, p. 79:22) stating that “(...) while only 36.99% of posted images were infographics, 50.44% of likes and 54.19% of comments belonged to infographics from 2014 through 2020”, demonstrating the efficacy of this social media platform for presenting data visualizations as a crucial instrument for information distribution.

2.3. Human visual perception and cognition

2.3.1. Comprehending human visual perception

In examining literature for this study and exploring human sight and cognition, we must initially comprehend the mechanisms of human vision and perception. Masland (2020, p.66) asserts that “to truly understand vision, you have to understand more than just how our eyes work. You also must understand how our brains make sense of the outside world”. The processing of visual information through numerous pathways is perception, which is a complex process, as noted by Pinker (2009, p.37): “what does the eye do? The eye is an organ of information processing, firmly connected to — anatomically speaking, a part of — the brain. And all those delicate optics and intricate circuits in the retina do not dump information into a yawning empty orifice or span some Cartesian chasm from a physical to a mental realm. The receiver of this richly structured message must be every bit as well engineered as the sender”.

Kosslyn (2006, p.9177) emphasizes the intricacy of this network of circuits: “the mind is not a camera. We are not simply passive receptors; we actively organize and make sense of the world, and when we do so we are at the mercy of the wiring of our eyes and brains”, additionally asserting that “when you look around, it seems that you see everything at roughly one level of sharpness, just as would a camera with one lens. But in fact our visual system operates as if it has a number of distinct ‘input channels’. These operate like a set of different lenses, each of which is adjusted to register a different level of detail. Some channels are sensitive only to relatively large changes in a pattern, whereas others are tuned to fine details” (Kosslyn, 2006, p.10049).

The varying levels of complexity in our visual system's operation are warranted by enhanced brain performance, as elucidated by Kosslyn (2006, p.10051): “why doesn’t it just use the single ‘best’ level? The answer is that there isn’t one. Which channels are optimal depends on the task at hand. For counting hairs, the best level of acuity would be the highest; for counting cows, the best would be a lower one, which allows us to ignore extraneous detail”.

It is essential for us to deepen our comprehension of visual perception as the aggregate of visual data acquired by the eyes and the cognitive processing of that data. Kosslyn, Thompson, and Ganis (2006, p. 1725) elucidate that “visual processing can be divided into two general types, ‘sensory’ and ‘perceptual’. Sensory visual processing is driven primarily (if not purely) by sensory input, whereas perceptual processing makes use of stored information.”, and Dehaene (2021, p.722) further elucidates that “(...) every image that appears on our retina is ambiguous — whenever we see a plate, for instance, the image is compatible with an infinite number of ellipses. If we see the plate as round, even though the raw sense data picture it as an oval, it is because our brain supplies additional data: it has learned that the round shape is the most likely interpretation”.

Kosslyn (2006, p.10486) provides additional explanation into the process of interpreting visual patterns and constructing an understanding of the universe: “our eyes and minds attempt to interpret visual patterns as signifying three-dimensional objects whenever possible. Specifically, the mind operates as if it unconsciously assumes that shapes have regular, closed contours composed of parallel and perpendicular sides, that objects have the same shading and markings all along their surfaces, and that the world is made of cohesive surfaces rather than clouds composed of tiny drops or shards. Thus, we often will organize lines on a page (or screen) as if they signified the presence of three-dimensional objects". These processes provide an initial insight into the Gestalt Principles. Finally, concerning the sense of color, this author conveys that "we see warmer colors (e.g., red) as 'closer' to us than cooler colors (e.g., blue) (...)" (Kosslyn, 2006, p.10487).

Prior to examining the operations of the visual system in further detail, we must first clarify the concept of attention. Kosslyn, Thompson, and Ganis (2006, p. 1034) elucidate that "(...) in vision, we typically shift attention by making rapid saccades, which produce the phenomenology of one point of view being replaced by another". These rapid eye movements (saccades) facilitate swift shifts in attention, as noted by Kosslyn & Koenig (1995, p. 1039): "whenever there is a relatively large change in one region of the visual field, it reflexively moves the eyes to that location. (...) Because images outside the high-resolution central region of the retina are difficult to see, we must be able to bring attention to objects not currently being attended (otherwise we would only see what we already have been seeing)".

This ocular motion is essential because "(...) your vision has a far higher pixel density in the central region than in the periphery. The pixels that matter in this case are the retinal ganglion cells, those last cells in the retina closest to the brain, whose axons form the optic nerve" (Masland, 2020, p.418), with Dehaene (2009, p.232) adding that "even within the fovea, visual information is not represented with the same precision at all points. In the retina (...) the number of cells allocated to a given portion of the visual scene decreases progressively as one move away from the center of gaze. This causes a gradual loss of visual precision. Visual accuracy is optimal at the center and smoothly decreases toward the periphery(...) our eye sensor accurately perceives only the precise point where our gaze happens to land. The surroundings are lost in an increasingly hazy blurriness".

Masland (2020, p.539) explains the importance of vision detecting edges as "(...) edges embody a central principle that controls many, many aspects of vision. The pixels of the natural world are far from random. The natural visual world occurs in structures — lines, angles, curves, surfaces. What that means is that the occurrence of certain pixels is influenced by what's around them", including that "(...) the most important things in the visual stimulus are objects, and objects are defined by their edges. Tell the brain about the orientation of edges — and nothing else — and it can make a very good guess what the object is like." (Masland, 2020, p.1359).

The author elaborates that “lines and edges are important because they are a dominant information-carrying part of the natural scene. This is because of the inescapable fact that our world is made up of objects, and their edges delineate their boundaries; they separate the object from everything else. Often the edges are straight — for example, the trunks of trees. Sometimes they are slightly curved — for example, the edge of a stone. (...) edges are a big part of the input that the visual system receives as it is becoming wired” (Masland, 2020, p.2312), reaching the conclusion that “in a normal brain, things tend to be seen as wholes rather than assemblies of parts. But the world does not intrinsically tell us what is an object; it only shows us an array of pixels, and the brain has to figure out what is an object.” (Masland, 2020, p.1711).

An additional significant aspect of human visual perception is the presence of regularities in the visual environment. Masland (2020, p.1801) elucidated this significant attribute by stating: “regularities in the world skew the brain’s interpretation of inputs in favor of those regularities”, persisting in the addition of that “(...) your perception does not really need to evaluate every pixel in a scene. It can use the regularities of the scene to predict what neighboring pixels contain, and insofar as the brain knows those regularities ahead of time (because it has created cell assemblies representing them), it can save itself work. This is a huge general principle in the design of biological sensory systems” (Masland, 2020, p.1876).

According to Masland (2020, p.2247), visual information prediction systems driven by constructed cell assemblies may introduce distortions in visual inputs, “visual systems are not neutral, bias-free recorders of their inputs. At every level, their responses are distorted to match the regularities of the natural environment. In some cases, this match is embedded in the genetic code, but in many it is accomplished by nerve net learning. This goes all the way from basic regularities such as sensitivity to edges and lines to complex perceptions such as faces”.

With an enhanced comprehension of human visual perception, we can now examine pertinent literature to elucidate how human cognition transforms the visual information obtained by the retina and the visual cortex into actionable insights for our existence and survival.

2.3.2. Cognition and information processing in the human brain

Our research indicates that it is crucial to comprehend how the human brain obtains and interprets visual information, remembering that “(...) for ninety-nine percent of human existence, people lived as foragers in small nomadic bands. Our brains are adapted to that long-vanished way of life, not to brand-new agricultural and industrial civilizations" (Pinker, 2009, p.42). Subsequently, we will discover that the capacity of the brain to develop new cognitive instruments (such as writing and reading) that utilize the functions of this 'forager' brain is what renders us a flourishing species. Similar to an early axe composed of a sharp stone for cutting wood and a handle designed to fit comfortably in a human hand, numerous cognitive instruments have been developed by humans to align effectively with the human brain. We assert that data visualization is such an instrument.

Initially, let us explore the relationship between the brain and information. According to Eagleman (2011, p.114) "brains are in the business of gathering information and steering behavior appropriately". Pinker (2009, p.65) further reveals that: "information itself is nothing special; it is found wherever causes leave effects. What is special is information processing". The processing of information is paramount. Pinker (2009, p.62) states "(...) the mind is a system of organs of computation designed by natural selection to solve the problems faced by our evolutionary ancestors in their foraging way of life", Dehaene (2021, p. 3615) asserts that "curiosity is a fundamental drive of the organism: a propulsive force that pushes us to act, just like hunger, thirst, the need for security, or the desire to reproduce(...) In an unstable universe populated by predators, curiosity can make all the difference between life and death (...) Curiosity is the determination that pushes animals out of their comfort zones in order to acquire knowledge. In an uncertain world, the value of information is high and must ultimately be paid in Darwin's own currency: survival".

Kosslyn and Koenig (1995, p. 931) elucidate how people process pertinent information: "we do not look around randomly when we seek additional information. Rather, stored information is used to make a guess about what we are seeing, and this guess then guides further encoding", and Dehaene (2021, p.725) elaborates on how the stored knowledge is utilized to infer fresh information: "behind the scenes, our sensory areas ceaselessly compute with probabilities, and only the most likely model makes it into our consciousness. It is the brain's projections that ultimately give meaning to the flow of data that reaches us from our senses".

Masland (2020, p.1886) expands on the concept of a personal world model by asserting that "(...) all perception is biased by things you have seen before. I mean here not just that you expect to see certain things in certain contexts — the way you expect to see your cousins on

Thanksgiving — but that at an unconscious, basic level, even the simplest elements of sensation are created, just as much as they are literally recorded, by your eye, ear, skin, or nose".

Dehaene (2021, p. 618) asserts that "(...) in a fraction of a second, our brain can recognize a face or a word, put it in context, understand it, and even integrate it into a small sentence... The limitation, however, is that the process remains strictly bottom-up, without any real capacity for reflection. Only in the subsequent stages, which are much slower, more conscious, and more reflective, does our brain manage to deploy all its abilities of reasoning, inference, and flexibility". These facets of cerebral function correspond with Kahneman's (2011, p.358) systems: "System 1 operates automatically and quickly, with little or no effort and no sense of voluntary control. System 2 allocates attention to the effortful mental activities that demand it, including complex computations. The operations of System 2 are often associated with the subjective experience of agency, choice, and concentration".

In further examining how the human brain formulates an understanding of the universe through information processing and probabilistic computation, Dehaene (2021, p. 708) states that "you may not be aware of it, but your brain has acquired thousands of internal models of the outside world(...) We all have in our brains, for example, a mental map of our neighborhood and our home — all we have to do is close our eyes and envision them with our thoughts. Obviously, none of us were born with this mental map — we had to acquire it through learning.", and Eagleman (2011, p. 1388) summarizes that "instead of reality being passively recorded by the brain, it is actively constructed by it".

A pertinent function of the brain for this task is imagery, akin to the aforementioned depiction of the mental map of our neighborhood. We assert that the utilization of mental imagery is pertinent to our project, and we contend that data visualization serves as a tool that facilitates these image-based cognitive processes. Kosslyn and Koenig (1995, p. 2058) elucidate the significance of this role: "(...) imagery can be used in four ways: to access information in memory, help one reason, learn new skills, and aid comprehension of verbal descriptions".

Kosslyn, Thompson, and Ganis (2006, p. 946) assert that imagery is significant as it enables individuals to generate "mental simulations are imagined scenarios that mimic what one would expect to happen in the corresponding actual situation", furthermore "(...) imagery is useful in large part because it can lead to the unexpected. Imagery allows one to anticipate the consequences of ‘trying something out’ before actually doing it” (Kosslyn&Thompson&Ganis, 2006, p.1007).

Pylyshyn (2002, p. 178) asserts the connection between imagery and the human visual system: “it not only suggests that the visual system is involved in imagery and that it examines a pictorial display, but it appears to attribute to the ‘mind's eye’ many of the properties of our own eyes”. Kosslyn, Thompson, and Ganis (2006, p. 543) assert that “(...) visual mental imagery draws on very much the same neural system as visual perception”.

Kosslyn, Thompson, and Ganis (2006, p.649) elucidate the process of accessing and recovering information from our brain imagery: “(...) consider the fact that we can regard a painting in two ways. On the one hand, we can attend to its content, admire its composition, and reflect on the painter's mood and message. On the other hand, we can attend to the painting itself as an object, noting the texture of the canvas, the way the frame encroaches on the borders of the tableau, and so on. And we argue that the same is true for imagery: we can ask about the contents of a depiction as well as the properties of the depiction itself”.

Eagleman (2011, p. 471) provides an example illustrating the connection between attention, the manipulation of information in imagery, and the incorporation of new information into it: “your internal model has some general idea that you’re in a coffee shop, that there are people to your left, a wall to your right, and that there are several items on the table. When your partner asks, ‘How many lumps of sugar are left?’ your attentional systems interrogate the details of the bowl, assimilating new data into your internal model. Even though the sugar bowl has been in your visual field the entire time, there was no real detail there for your brain. It needed to do extra work to fill in the finer points of the picture”.

Kosslyn, Thompson, and Ganis (2006, p. 1828) elucidate the mechanisms by which imagery is generated in the human brain: “(...) image generation begins by a process of first looking up a description of a spatial layout in long-term associative memory. If a spatial image is all that is required by the task, stored information is unpacked to create an object map (...) The object map specifies the relative locations of objects, or parts of a single object, but does not indicate depictive properties of shape”, adding that “if a depictive image of a multipart shape is required for a task (for example, a bicycle, with all of its individual parts), an object map is created at the outset” (Kosslyn&Thompson&Ganis, 2006, p.1844).

Extracting information from imagery is analogous to directing our visual attention on a specific detail within our visual field: “if one has visualized object properties, and hence an image representation is formed in the visual buffer, one inspects the imaged pattern by shifting the attention window over it to encode properties (e.g., as would occur if one were asked what shape are a cat's ears and so visualized a cat's head and examined the shape of its ears)" (Kosslyn&Thompson&Ganis, 2006, p.1850). Kosslyn, Thompson, and Ganis (2006, p. 1857) additionally assert that "image inspection is in fact a key part of image generation and vice versa. It is often the act of trying to inspect an imaged object that leads one to generate images of specific parts and properties (...)".

Ultimately, concerning the human ability to acquire and digest knowledge, Dehaene (2021, p.1330) states that "such is the new vision of the brain: an immense generative model, massively structured and capable of producing myriad hypothetical rules and structures — but which gradually restricts itself to those that fit with reality", and Eagleman (2011, p. 1198) asserts that "one of the most impressive features of brains — and especially human brains — is the flexibility to learn almost any kind of task that comes its way".

We will next examine the capacity to learn, as it is a pertinent topic for this work; we contend that the primary objective of data visualization is to facilitate viewers acquiring new information.

2.3.3. The mechanisms by which human brains learn

Dehaene (2021, p.548) discusses a distinctive capability inherent to humans: "if I had to sum up, in one word, the singular talents of our species, I would answer with 'learning'. We are not simply Homo Sapiens, but Homo Docens — the species that teaches itself".

Dehaene (2021, p.649) succinctly characterizes learning as "(...) to learn is to progressively form (...) an internal model of the outside world". This idea of an internal picture of the external world is also connected to our comprehension of human cognition and information processing. Eagleman (2011, p. 1388) provides a summary that "instead of reality being passively recorded by the brain, it is actively constructed by it", to which we may append that "according to an emerging theory, the reason that our brain is still superior to machines is that it acts as a statistician. By constantly attending to probabilities and uncertainties, it optimizes its ability to learn" (Dehaene, 2021, p.633).

We have previously articulated our belief that data visualization is a human-created instrument designed to use our cognitive capacity for deriving insights from visual data representations. To elucidate this concept, Dehaene (2021, p.2572) states that "I have formulated the neuronal recycling hypothesis. The idea is simple: while synaptic plasticity makes the brain malleable (...) our brain circuits remain subject to strong anatomical constraints, inherited from our evolution. Therefore, each new cultural object we invent, such as the alphabet or Arabic numerals, must find its 'neuronal niche' in the brain: a set of circuits whose initial function is sufficiently similar to its new cultural role, but also flexible enough to be converted to this new use". Changizi, (2011, p.5) calls this hypothesis "(...) nature-harnessing: mimicking nature so as to harness evolutionarily ancient brain mechanisms for a new purpose", and subsequently suggests that "language and music, on the one hand, and the human brain, on the other, are designed to fit one another." (Changizi, 2011, p.2), adding that "cultural evolution could, over comparatively short periods of time, fit language and music into the shapes our grooved (non-blank slate) brains are able to learn. It is not so much that our brains learn language and music, but rather that culture learned how to package language and music so that they fit right into our brains. Culture learned how to harness us" (Changizi, 2011, p.22).

Various authors elucidate this concept, including Kosslyn and Koenig (1995, p. 2801), who claim that "the lines and angles we use in writing neatly correspond to sets of nonaccidental properties.", as asserted by Changizi (2011, p.20) "(...) writing looks like three-dimensional scenes with opaque objects. Writing looks like nature, but as before, nature of a very general kind (...)" and Kosslyn and Koenig (1995, p. 2720) indicating that "reading apparently is a relatively late cultural invention, which followed speaking and cave painting by many generations. Thus, reading is an example of opportunistic processing at its best. Presumably, processing subsystems that were used to subserve other functions — such as object identification — were then available for this role".

Although a more detailed examination of human reading will occur later in this work, it is currently essential to explore certain facets of human reading abilities to enhance our understanding of the aforementioned concept of 'nature-harnessing'. Dehaene (2021, p. 2772) elucidates that "when we learn to read, a subset of our visual regions becomes specialized in recognizing strings of letters and sends them to spoken language areas. As a result, in any good reader, written words end up being processed exactly as spoken words: literacy creates a new visual gateway to our language circuits", adding that "the acquisition of literacy involves the emergence of a region of the visual cortex (...) This region concentrates our learned knowledge of letter strings, to such an extent that it can be considered as our brain's 'letter box.’ It is this brain area, for instance, that allows us to recognize a word regardless of its size, position, font, or cAsE, whether UPPERCASE or lowercase” (Dehaene, 2021, p.2777).

Dehaene (2021, p.675) reveals four fundamental mechanisms that influence human learning: “the first is attention: a set of neural circuits that select, amplify, and propagate the signals that we view as relevant (...) My second pillar is active engagement: a passive organism learns almost nothing, because learning requires an active generation of hypotheses, with motivation and curiosity. The third pillar, and the flip side to active engagement, is error feedback: whenever we are surprised because the world violates our expectations, error signals spread throughout our brain. They correct our mental models, eliminate inappropriate hypotheses, and stabilize the most accurate ones. Finally, the fourth pillar is consolidation: over time, our brain compiles what it has acquired and transfers it into long-term memory, thus freeing neural resources for further learning”.

A distinct form of feedback, called ‘shared attention', is exclusive to humans. Dehaene (2021, p.1243) provides a comprehensive explanation of the functionality of this feature: “(...) in general, the speaker pays attention to what he or she is talking about (...) All the child has to do to infer what his mother is talking about is follow her gaze or the direction of her finger: this is called ‘shared attention’ and it is a fundamental principle of language learning”. We consider the characteristic of 'shared attention' to be relevant for data visualizations, as will be demonstrated subsequently.

A further significant facet of learning is memory. Dehaene (2021, p.2035) elucidates the mechanisms of memory: “when I see, let’s say, Donald Trump in the Oval Office, some neurons respond to his face (...) others to his voice (...) others to the layout of his office (...) and so on and so forth. Single neurons may provide some information, but the overall memory is always encoded by several interconnected groups of neurons”, adding that “once a synaptic memory is formed, the neurons can now rest: when they stop firing, the memory remains dormant, unconscious but inscribed in the very anatomy of my neuronal circuits. In the future, thanks to those connections, an external clue (say, a photo of the presidential office) may suffice to produce a cascade of neuronal activity in the original circuit. This cascade will restore a pattern of neural discharges similar to the moment the memory was made (...)”, with (Dehaene, 2021, p.2047), concluding that memory is not localized to a singular region of the human brain, but rather is spread “(...) in most, if not all, brain circuits, because each of them is capable of changing its synapses in response to a frequent pattern of neural activity" (Dehaene, 2021, p.2052).

The crucial process in learning involves transferring new information from short-term memory to long-term memory, as articulated by Dehaene (2021, p.2070): "memories do not seem to stay in the hippocampus forever. At night, the brain plays them back and moves them to a new location within the cortex. There, they are transformed into permanent knowledge: our brain extracts the information present in the experiences we lived through, generalizes it, and integrates it into our vast library of knowledge of the world".

According to Dehaene (2021, p.2970), attention is a critical mechanism for learning. The author characterizes attention as "in cognitive science, 'attention' refers to all the mechanisms by which the brain selects information, amplifies it, channels it, and deepens its processing", adding that "(...) a pyramid of attention mechanisms, organized like a gigantic filter, carries out a selective triage. At each stage, our brain decides how much importance it should attribute to such and such input and allocates resources only to the information it considers most essential" (Dehaene, 2021, p.2977.

In Dehaene's work, when counseling educators regarding the significance of attention, the author states: "teachers must carefully choose what they want children to attend to, because only the items that lie at the focus of attention are represented in the brain with sufficient strength to be efficiently learned" (Dehaene, 2021, p.3157). In this project, we assert that one can simply substitute the terms 'teacher' with 'designer' and 'children' with 'viewers' in the aforementioned sentence to derive significant guidance for the creation of data visualizations.

At this juncture of our literature review, we have acquired knowledge on 'shared attention' and its significance for learning. As we examine the topic of attention, we can further explore the concept. Dehaene (2021, p.3323) defends that "(...) attention in humans exhibits a unique feature that further accelerates learning: social attention sharing. In Homo Sapiens, more than in any other primate, attention and learning depend on social signals: I attend where you attend, and I learn from what you teach me". We previously asserted that the notion of 'shared attention' is crucial for data visualization. When a designer incorporates 'attention-aiding symbols' into a visualization to direct viewers' focus toward significant data, the designer effectively leverages the viewers' inherent capacity for 'shared attention'.

In the concluding phase of this literature analysis concerning learning and human cognition, several facets of human learning capacity might be perceived as a 'guide' for the creation of enhanced data visualizations. For example, Dehaene (2021, p.3585) asserts: "(...) experiments show that all of us have an easier time remembering a picture than a spoken word, and that our memory is even better when the information is conveyed by both modalities — an audiovisual experience. (...) For all we know, all humans share the same learning algorithm". Kosslyn and Koenig (1995, p. 2463) recommend that "retaining a mental image requires effort, and a limited amount of information can be held in an image for a limited amount of time. This is important because most imagery reasoning tasks cannot be carried out instantly; one needs time to complete them", with Kosslyn (2006, p.13108) adding that "people have a limited capacity to retain and to process information and will not understand a message if too much information must be retained or processed".

After examining pertinent literature on human learning capabilities, we will now explore the cognitive processes involved in reading. Reading is not merely a crucial component of textual information retrieval from data visualizations by observers; comprehending the mechanisms employed by the human brain during reading can yield significant insights applicable to other facets of data visualization.

2.3.4. The process by which humans read

To comprehend how the human brain processes reading, we must revisit the notion of cultural innovations that utilize pre-existing neural circuits designed for different functions. What Changizi, (2011, p.5) refers to "nature-harnessing". Dehaene (2009, p.146) states that "(...) human brain architecture obeys strong genetic constraints, but some circuits have evolved to tolerate a fringe of variability (...) Within an otherwise well-structured brain, visual plasticity gave the ancient scribes the opportunity to invent reading", concluding that "if the brain did not evolve for reading, the opposite must be true: writing systems must have evolved within our brain's constraints" (Dehaene, 2009, p.169).

Dehaene (2009, p.2132) asserts that "perhaps the most striking feature of the inferior temporal neurons is that many of their preferred shapes closely resemble our letters, symbols, or elementary Chinese characters (...)", adding that "(...) shapes that resemble Western letters, such as T, F, Y, or O, were adopted by inferior temporal neurons because they collectively formed an optimal code, invariant to image transformations, and whose combinations could represent an infinity of objects" (Dehaene, 2009, p.2176), and concluding that "we did not invent most of our letter shapes: they lay dormant in our brains for millions of years, and were merely rediscovered when our species invented writing and the alphabet” (Dehaene, 2009, p.2181).

Another aspect of the human visual system is the retina's capacity to focus solely on a certain region of our visual field. In connection with this feature of reading, Dehaene (2009, p.201) asserts: “only the center of the retina, called the fovea, has a fine enough resolution to allow for the recognition of small print” adding that “the fovea, which occupies about 15 degrees of the visual field, is the only part of the retina that is genuinely useful for reading” (Dehaene, 2009, p.224), thereby necessitating that “our gaze must therefore move around the page constantly. Whenever our eyes stop, we only recognize one or two words. Each of them is then split up into myriad fragments by retinal neurons (...)” (Dehaene, 2009, p.202). Upon the recognition of each word by our cognitive systems, the processing of its meaning must occur: “two major parallel processing routes eventually come into play: the phonological route, which converts letters into speech sounds, and the lexical route, which gives access to a mental dictionary of word meanings” (Dehaene, 2009, p.205).

Reading is a process of extracting visual information, and in conjunction with certain cognitive attributes previously discussed — such as the capacity for our brains to execute repeated tasks with minimal effort — we can enhance our comprehension of the mechanisms underlying the visual recognition of written words. Dehaene (2009, p.292) clarifies that “reading is nothing but the word-by-word mental restitution of a text through a series of snapshots”, stating that “(...) global word shape does not play any role in reading” (Dehaene, 2009, p.353), mostly because “our brain compiles statistics: it determines which letters are most frequent, where they appear most often, and in which associations they occur” (Dehaene, 2021, p.4174). Kosslyn and Koenig (1995, p. 2929) assert that “(...) associative memory contains a representation of the letters of a word and their spatial relations”.

Upon reading and recognizing a word, the human brain must extract its meaning. According to Dehaene (2009, p.582) “a written text is not a high-fidelity recording. Its goal is not to reproduce speech as we pronounce it, but rather to code it at a level abstract enough to allow the reader to quickly retrieve its meaning”. Similar to other processes of mental imagery manipulation previously studied, word recognition during reading is closely associated with the comparison of a word to the reader's repository of visual representations, referred to as the lexicon. According to Dehaene (2009, p.725), “(...) in total, each of our lexicons probably contains between 50,000 and 100,000 entries. (...) Any reader easily retrieves a single meaning out of at least 50,000 candidate words, in the space of a few tenths of a second, based on nothing more than a few strokes of light on the retina", adding that "in adult expert readers, the time to read a word is essentially independent of its length. As long as the word does not have more than six or seven letters, its recognition takes an approximately constant amount of time" (Dehaene, 2009, p.797).

Notably, Dehaene (2009, p.935) informs us that "(...) reading digits relies on anatomical pathways partially distinct from those used for reading letters and words" and that "(...) even in normal readers, reading is always a bit slower and more error-prone when words appear on the left side of fixation rather than on the right" (Dehaene, 2009, p.1382).

Having studied pertinent research regarding various aspects of visual acquisition and information processing, we must now examine the relevant literature on human cognition and data visualization.

2.3.5. Cognitive processes and data visualization

In this concluding section of the literature review for the current study, we examine scholarly publications on human cognition and data visualization. Flory and Ivanova (2019, p. 29) assert that "compelling developments in the structural functional correlation of the human brain are resulting in an incremental intersection of neuroscience with other disciplines — an intersection that can enrich both disciplines and enable targeted user experience and learning", adding that "understanding drivers of human behavior, emotion, affect, choice, and decision is essential to the design process and in itself is a component of an empathetic mindset. All of these considerations for the designer have their foundation in the function and processes of the brain. Applications and insights based on neuroscience theory and research can help with design choices" (Flory&Ivanova, 2019, p.29). Arbib (2015, p.75) states that "(...) hope to encourage further thinking about how the design process can be illuminated more and more by future research in neuroscience".

We believe that practicing designers can gain numerous valuable insights into the workings of the human brain through this 'research in neuroscience'. Significant insights regarding data visualization and human cognition have been discovered, and we will now commence our examination of this topic.

Let us begin by examining general facts on data visualization, its applications, and objectives. Harrison et al. (2017, p. 148) commence by elucidating that "(...) when a person sees a new image, they want to understand that image as quickly as possible. To do this, the observer directs their attention first to the locations in the image that will provide the most information (i.e. give the best understanding of the information)". To integrate this comprehensive understanding with data visualization, we reference Zhao and Gaschler (2022, p.2), who assert: "while there is a multitude of graph types(...) some formats (...) have been in use since the early days of statistical graphing(...)".

Harrison et al. (2017, p. 149) claim that "statistical graphs (SG) are visual representations used to represent high-order relations into different facets of data sets of a variety of types through the use of symbolic systems. SGs present data as different types of images to take advantage of the advanced pattern detection capabilities of the human visual system and to allow an easy and consistent interpretation of information". We affirm that the same citation can be applied by substituting 'statistical graphs'— a specific category of data visualizations— with the more encompassing phrase 'data visualization', as previously argued in this work.

Kosslyn's (2006, p.7430) observes that "many graphs are designed without consideration of principles of human visual perception and cognition", while not neglecting that "our visual systems allow us to read proportional relations off simple graphs as easily as we see differences in the heights of people, colors of apples, or tilts of pictures mishung on the wall. We are visual creatures and are good at noting relative differences in sizes, lengths, orientations, and some other visually perceptible properties. Graphs can also allow us to appreciate the quantitative relations among multiple elements and thus can provide us with precise information" (Kosslyn, 2006, p.7865).

Zhao and Gaschler (2022, p.2) provide a concise overview of the various cognitive phases associated with processing information via data visualization:

> First, pattern recognition methods are used to decipher the visual information in the graph (...) Second, abstract concepts of the visual information are mentally constructed in the capacity-limited working memory (...) Third, conceptual relations are retrieved from long-term memory (...) Fourth, the desired information is located and provided if it is contained in the activated mental representation. Otherwise, interrogation processes and inferential processes are prompted to add entries or adapt existing entries to the conceptual message (Pinker, 1990).

Peebles and Ali (2015, p.4) further elucidate that “when a pattern is identified, a chain of subsequent productions is triggered which obtains further information from the graph and declarative memory until an interpretation is produced. This process continues until all patterns have been identified and interpreted appropriately, and an accurate mental model of the state of affairs depicted in the graph has been generated”.

Harrison et al (2017, p.150) observe that “there are many choices to be made when creating a graph, from the type of graph to use, the style of the text, the placement of text in the graph, as well as the types of graphical cues to use. Each of these choices can have an impact on the memorability of the graph and how easy it is to understand the primary and secondary meanings (if any) contained within the graph. In general, a graph with the simplest layout and the fewest number of variables and extraneous clutter is the easiest to understand, while a graph that is visually striking or has natural objects is more memorable”.

Harrison et al. (2017, p. 150) assert that “research into the memorability of graphs, by Borkin et al., has shown that the most memorable items in a graph are identified and encoded within the first 10s of viewing. At the same time, they found that human recognizable objects in a graph improved a person’s ability to recognize or recall the graphs. For graphs with less easily memorable features or objects standard text elements of a graph were used to recall and recognize those graphs, with title being the most popular point of recognition and recall”.

Kosslyn (2006, p.8739) emphasizes the importance of prior knowledge in enhancing comprehension of material by affirming that “be sure that your intended readers will understand the concepts, symbols, and jargon you use. In addition, be sure that the readers will have the appropriate background knowledge to make sense of your message. A good display presents new information — but the information should not be so new as to be completely unrelated to anything else the readers know. If you assume that the readers know too much, you will rely on concepts, facts, or conventions that are unfamiliar to them — and you may as well be speaking in tongues. If you assume that they know too little, you’ll overstate what they find obvious”, adding that “information is communicated effectively only when it focuses the readers’ attention and interest on a specific message” (Kosslyn, 2006, p.8303).

The author affirms that “graphs and other sorts of visual displays serve to help readers answer a particular question, be it very specific (...) or relatively general (...)” (Kosslyn, 2006, p.8303), and reiterates that “to communicate effectively, a display must be pitched at the right level for the readers you wish to reach. This is true in terms of both the type of display you use (e.g., a standard bar graph is familiar to everyone, but a box-and-whisker chart is not universally understood) and the specific information included (e.g., everyone understands amount, but not everyone knows what a first or second derivative is)" (Kosslyn, 2006, p.8739).

The viewers' goals are a crucial consideration when creating a visual representation of data. Kosslyn (2006, p.34) recommends that "a graph is a device to help people answer specific questions. (...) Readers use displays to answer particular questions, and they expect to be told as much information as is necessary to answer those questions in the context in which the graph appears — but no more", claiming that "visual displays often are more like stories than like pictures of objects; although they have components that must be identified, it is the relations among the components that convey the specific information. This aspect of understanding in part requires recalling the significance of particular patterns, and may require reasoning based on the rules of how a display format work" (Kosslyn, 2006, p.35).

Regarding how human visual perception works, Kosslyn (2006, p.13108) emphasizes that "the reader will interpret any change in the appearance of a display (changing the color or texture, adding, or deleting lines, etc.) as conveying information. By the same token, the reader will expect any piece of information that should be conveyed in a display to be indicated by a visible change in the display".

Kosslyn (2006, p.76) recommends that while discussing different visual symbols, "neurons that do detect changes in one region of space inhibit other neurons that detect changes in nearby regions, and so if a mark is not large or heavy enough, the cells that typically would detect it are inhibited from responding. Detectability depends on a wide range of factors and their interactions, such as the color of the figure and its background, the contrast of intensity of light and dark elements, and the shape of the figure".

Regarding the choice of colors for a data visualization, Kosslyn (2006, p.10488) discusses the 'false stereo effect': "(...) where long-wavelength, warmer colors seem 'closer' to us than short-wavelength, cooler colors. This information leads me to recommend that when two lines cross (as in a line graph), the warmer one should overlap the cooler one. If it does not, the back line will seem to be fighting to come forward, trying to snake around the one in front — which is distracting. Moreover, for the same reason cool colors should be used for the background, and warm colors for the foreground (e.g., for text, graphs, etc.)".

Kosslyn (2006, p. 10489) affirms that “(...) some visual dimensions are automatically integrated together. For example, when you pay attention to the height of a rectangle you will also pay attention to its width. Great effort is required to register changes on one integrated dimension while ignoring changes on another. Such integral dimensions cannot be used effectively to convey different types of information. In contrast, separable dimensions, such as the length of a radius of a circle and its angle, can be used effectively to convey different measurements”, culminating with the knowledge, grounded in Gestalt Principles, that “the law of common fate specifies that lines or marks that seem to be headed in the same direction will be grouped together” (Kosslyn, 2006, p.10925).

Peebles and Ali (2015, p. 3) assert that “the Gestalt principles of proximity, similarity, connectedness, continuity, and common fate determine how graphical features are grouped by the human visual system to form coherent wholes and play a crucial role in determining how data are interpreted(...), with Kosslyn (2006, p.14419) explaining that “it is a psychological, not a moral, fact that people do not like to expend effort and often will not bother to do so, particularly if they are not sure in advance that the effort will be rewarded”.

This psychological phenomenon about individuals' aversion to exerting effort is connected to a previously examined subject, supported by Kahneman’s (2011, p.358) dual systems of human cognition: “System 1 operates automatically and quickly, with little or no effort and no sense of voluntary control. System 2 allocates attention to the effortful mental activities that demand it, including complex computations”.

Kosslyn (2006, p.86) recommends examining the efforts required by a viewer to interpret information in a data visualization and how to mitigate them: “(...) a simple progression of increasing height from left to right is to be preferred over a jagged series, if the ordering along the X axis is arbitrary. If you don’t do this, the reader may assume that each jag means more than it actually does and waste time figuring out what it’s supposed to mean (here the only meaning is that some things have more than others, differences measured by the heights of the steps)”, largely consistent with the Gestalt Principles, as previously observed, and which we will examine in greater detail.

In determining whether a specific piece of data warrants visual representation, a designer ought to heed Kosslyn’s (2006, p.30) advice that “use a graph only if the point is to illustrate relations among measurements. (...) graphs use variations along a visual dimension, such as the height of a bar or line over a specific point of the framework, to convey quantitative information. Our perceptual systems allow us quickly to detect differences among heights or the slopes of lines. However, they do not allow us to register absolute heights or slopes very well, and thus graphs are not well suited for conveying specific absolute values (...) In order to derive a specific value, readers must look from the content element to the scale, and we are not very good at registering precise spatial relations of objects that are not physically connected (...)".

To comprehend how various forms of graphic data representations can affect viewers, we can reference Zhao & Gaschler (2022, p.10), who declare that "moreover, the task of discrete comparisons includes the time of graphical perception (...) For instance, perception of change is direct in bar graphs and line graphs, but not in pie graphs (Hollands and Spence, 1992). Horizontal pictographs (i.e., data points in rectangular form) are perceived more quickly and more accurately than vertical pictographs (Price et al., 2007). Nevertheless, one should be aware that although bar graphs are processed fast in discrete comparison tasks, they lead to biased judgement when estimating the means of all groups (Godau et al., 2016) and when judging if specific data points lie within a distribution (Newman and Scholl, 2012)".

Subsequently, this work will examine the concept of cognitive overload in further detail, when an individual's brain becomes overwhelmed by excessive cognitive demands. Currently, Kosslyn (2006, p.13109) reminds us that "we can keep only a certain amount of information in mind at any one time. A graph (or any information display, for that matter) should not require the reader to hold more than four perceptual groups in mind at once", indicating that, concerning data visualizations: "one of the reasons graphs are useful is that they help to circumvent limitations of human information processing. Although we can consider only about four groups at a time, we can absorb much more information if it is translated into visual patterns" (Kosslyn, 2006, p.13545).

Kosslyn (2006, p.68) elucidates the mechanisms of short- and long-term memory: "when we 'hold something in mind' we are in fact retaining information in short-term memory. To understand a display fully, one often must draw deductions and notice implications, which requires reasoning; these reasoning processes operate on information in short-term memory. Short-term memory has a relatively small capacity, placing severe limits on what we can understand. Many poor displays are incomprehensible in part because they overload the viewer's short-term memory capacity", adding that "presenting complex data in multiple panels not only decreases the load on short-term memory but also simplifies the depicted patterns. If the display is too complex, the resulting pattern probably will not be familiar — and so will not convey meaning in a glance. If a complex display is broken into a number of simpler ones, many of the resultant patterns typically can be read without having to note the precise values of individual points" (Kosslyn, 2006, p.68).

We must also examine the application of textual elements in data visualizations. Reading is a potent instrument devised by humans to transmit information efficiently, particularly once an individual attains literacy. Consequently, we may assert that the textual components of a data visualization constitute a significant asset of the visualization.

Kosslyn (2006, p.74) suggests that "include a caption to clarify unfamiliar terms and specific features. A caption is an explanatory note accompanying the display. (...) [a designer needs to] ensure that the reader knows the terms necessary to understand the graph, and in some cases, labels should be clarified in a caption. If the display is complex, note explicitly in the caption which patterns in the display are of most important", claiming that "to understand a key, the reader must memorize the associations between the names and the content elements, which requires work and may tax our limited-capacity short-term memory" (Kosslyn, 2006, p.69).

Zhao and Gaschler (2022, p.10) assert that the viewer's endeavor to comprehend the data through the use of keys or labels is noteworthy: "for instance, Carpenter and Shah (1998) measured the eye movements while participants interpreted and answered questions about line graphs. They suggested a sequential process of graph comprehension: pattern-recognition, interpretive, and integrative processes. During the integrative processes, participants showed considerable transitions on labels and values of the variables that determine relations. They thus recommended graphic designers reduce the effort required to identify the to-be-compared graphs".

This research study has previously examined the concept of human 'shared attention' and its efficacy as a cognitive instrument for facilitating collaboration and learning among individuals. This work posits that text annotations within data visualizations serve as a means for designers to offer viewers a beneficial 'shared attention' tool, hence enhancing comprehension of the presented data. This notion is bolstered by the research conducted by Acartürk, Habel, and Cagiltay (2008, p. 342), which asserts that "(...) the subjects experienced difficulties in determining the relevant part of the graph in the absence of the annotation icon in the curved graphs. The results of the analysis for mean fixation durations support this idea showing that the absence of the annotation icon in the curved graphs results in longer fixations on the salient regions of the graph", adding that "the results show that on the one hand, the addition of the annotation texts to the graphs does not reveal major changes in the distribution of average number of fixations and gaze time (...) compared to the distributions on the non-annotated graphs. (...) On the other hand, mean fixation counts and gaze time values increase with the addition of the annotation text. The increase in fixation counts and gaze time values on the graph line points to subjects' effort for the integration of information provided by the graphical elements and the annotation text." (Acartürk&Habel&Cagiltay, 2008, p.341).

The literature review for this study has now been completed. We have examined literature pertaining to data visualization, the utilization of Instagram for information consumption, and aspects of human vision, visual perception, and cognition, subsequently delving into the pertinent studies on data visualization and human perception and cognition. We will now discuss the frameworks that facilitate data visualization design, particularly in relation to human cognition.

3. Methodology

3.1. Methodological Precedents

The objective of this work is to establish a framework that aids in the design of data visualizations, optimizing efficiency in information conveyance based on contemporary understanding of human cognition and visual perception.

We have opted to establish a framework, as it fundamentally serves as a method within a methodology. According to the Cambridge University Press (n.d.), a method can be defined as a specific procedure for achieving or addressing a task, particularly one that is systematic or established. Also, as per the Cambridge University Press (n.d.), a methodology can be defined as a systematic collection of approaches employed within a specific field of study or practice. Consequently, we comprehend that this framework will serve as a methodology for facilitating the design of data visualizations, with the aforementioned purpose.

Upon reviewing the literature for this project, we have endeavored to identify pertinent frameworks related to data visualization and human visual perception and cognition, since these are the frameworks that can best relate to our research. Alyahya and Bhat (2024, p. 4) assert that "to design efficient infographics there are many frameworks that guide the development of infographics".

At this point in our investigation, we define a framework as the fundamental structure that underpins a system or concept. Based on our study, we will provide instances that, in our assessment, align with the aforementioned definition of a framework, despite the fact that certain writers of the selected works for this chapter of methodological precedents do not explicitly designate their contributions as frameworks.

The order by which we present the following frameworks was planned to represent an evolution, from the components of a data visualization, to the understanding of how humans retrieve and understand information from a data visualization. We shall commence by introducing a framework put forth by Engelhardt & Richards (2020) for recognizing and comprehending the distinct components of a data visualization. Armed with an understanding of the components of data visualization, we will explore the fundamental procedures required to create an effective data visualization. We shall examine the framework put forward by Panda & Roy (2021). Subsequently, we will examine the Gestalt Principles of design, a framework derived from the research of psychologist Wertheimer, which has significantly influenced design practice for nearly a century and is pertinent to the creation of data visualizations.

Subsequently, we will examine prior studies that connect data visualization with human cognition. We commence with the *Graphical Perception* framework, introduced by Cleveland and McGill in 1983. We then exam the *Cognitive Load Theory* and its ramifications for information consumption, as investigated by Sweller (2002) and Mayer & Moreno (2003). We will conclude by examining Kosslyn's (1989) research on *Understanding Charts and Graphs*.

We shall elucidate the relevance of each framework examined and included in this study, while also providing a concise assessment of our understanding for their inadequacy as substitutes for our suggested framework.

3.1.1. *The DNA Framework for Visualization* by Engelhardt and Richards

The profession of visual data representation encompasses numerous components, concepts, and terminologies. Seeking a cohesive framework that integrates a wide array of data visualizations, Engelhardt & Richards (2020, p. 534) "(...) use this metaphorical idea of the 'DNA of visualization' (...) taking it to the extent of identifying a comprehensive set of individual DNA building blocks of visualizations and the rules for combining them".

The authors introduce a research instrument termed *The DNA Framework of Visualization*: "(...) exploring various kinds of commonalities, family resemblances and differences between visualization patterns within collections of graphic representations" (Engelhardt & Richards, 2020, p.535).

The fundamental components of vision DNA are categorized into five primary groupings, as delineated by Engelhardt & Richards (2020, p. 535): "(...) types of information to be represented, visual encodings to represent them, visual components that make up the visualization, and any directions and layout principles that may be involved. Visual encodings can be used for arranging, varying or linking visual components. Arranging visual components into meaningful configurations is how visualizations are constructed".

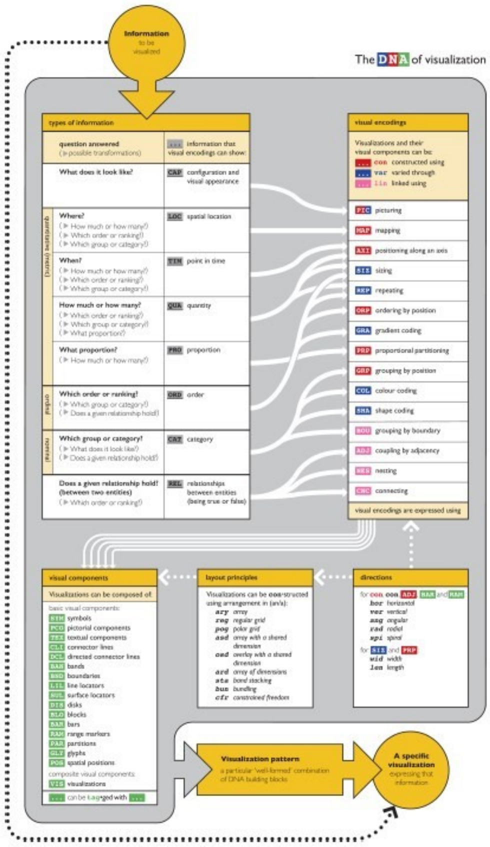


Figure 1 - “Process diagram showing our DNA building blocks and their possible relationships” (Engelhardt&Richards, 2020, p.536)

The authors incorporate several aspects of perception and design about the visual encoding of data, including: “(...) the use of Bertin’s ‘visual variables’, some Gestalt principles of perception (e.g. grouping by proximity) and other fundamental ways of expressing information visually. A visual component can be involved in several different visual encodings, simultaneously representing different types of information” (Engelhardt&Richards, 2020, p.535).

Given the multitude of potential visual data representations and the continuously evolving landscape of data and its visual depiction, Engelhardt and Richards (2020, p. 535) advocate for the adaptability of the proposed framework, as its modular structure can incorporate supplementary components to analyze data visualizations not encompassed by the DNA elements suggested by the authors.

The authors assert that *The DNA Framework of Visualization* possesses the following advantages in relation to the existing fragmented methodologies for analyzing and evaluating data visualizations:

> (...) 1. provides a comprehensive system for exploring and checking design possibilities for visualization. 2. offers a system of tree diagrams for representing (de)composition and visual encoding in visualizations (constructed from their 'DNA'). 3. presents a way of describing visualizations with rigorously systematic natural language sentences, which specify (de)composition and visual encoding. 4. covers a very broad design space of visualization, not only including visual representations that involve numerical information, but also visualizations such as family trees, Venn diagrams, flow charts, texts using indenting, technical drawings and scientific illustrations. (Engelhardt&Richards, 2020, p.534)

This framework is beneficial for categorizing data visualizations; however, *The DNA Framework of Visualization* lacks a practical tool for designers to create visual data representations that align with human cognitive capabilities in perceiving and processing information through the visual system. Moreover, the ease of incorporating additional components into the framework's architecture for data visualization analysis may pose potential challenges, particularly if users lack proficiency in graphical data representation or user interaction.

3.1.2. *Data Driven Framework to Teach Visualization Design* by Panda and Roy

Panda and Roy present a framework for instructing visualization design in their work titled *Data Driven Framework to Teach Visualization Design*. The authors assert that "the data-driven framework consists of three modules; data processing, data transformation and data embellishment. Each of these modules have a motivation and are characterized by sub-modules that help accomplish the motivation" (Panda&Roy, 2021, p.145). To initiate the creation of a visual data representation, the authors assert that two questions must be addressed: "(...) what is the visualization of and what is the visualization for. (...) Responses to these two questions provide sufficient information for the implementation of the model [framework]" (Panda&Roy, 2021, p.145).

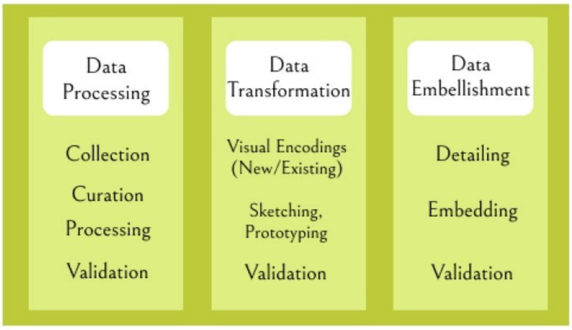


Figure 2 - The Data-Driven Visualization Design Framework with its modules and sub-modules (Panda&Roy, 2021, p.146)

The initial module of the framework is designated as 'data processing'. Panda&Roy (2021, p.145) propose four additional sub-modules: the gathering, curation, processing, and validation of data, to “(...) process the data and prepare it for the visualization design pipeline” (Panda&Roy, 2021, p.145). The following elucidates these four sub-modules: "collection of data refers to gathering relevant datasets for the purpose of visualization. (...) Curation refers to the selection of the most appropriate and relevant data and discarding the rest. (...) Processing of data involves using arithmetic operations or other statistical formulae on the curated dataset. (...) Validation, for the data processing module, is the idea of checking the dataset and its properties" (Panda&Roy, 2021, p.145).

Upon proper data processing, we can proceed to the subsequent module in the *Data Driven Framework to Teach Visualization Design*, which focuses on 'data transformation'.. This module aims to convert the gathered data into a visual representation. The authors assert that "this is accomplished by three sub-modules; choosing a visual encoding, prototyping and validation. The first sub-module is choosing an existing visual encoding for the dataset. Examples include choosing a pie-chart, bar chart or a scatter plot for the dataset. (...) The prototype is a bar chart or a streamgraph or any other visual encoding. (...) Validation for the data transformation module verifies whether the transformation of the data has been accurate" (Panda&Roy, 2021, p.146). The authors propose the creation of a 'sketched' data visualization in this second module, serving as a first visual representation of the data and confirming its accuracy. Upon the completion of this second module, we may go to the third and final module.

The 'Data Embellishment' module, as stated by the authors, is utilized to enhance the design of the previously developed sketch [prototype] and ultimately disseminate the data visualization. For this module, introduce three new sub-modules: “(...) detailing, embedding and validation. (...) The detailing sub-module is the idea of visually elaborating the prototype. (...) The embedding sub-module looks at publishing the visualization in a desired medium; an infographic [SIC], a website, an application or a business report. (...) Validation for the data embellishment module involves verifying the accuracy of the embedding of the visualization in the host domain (...)" (Panda&Roy, 2021, p.146).

The *Data Driven Framework to Teach Visualization Design* serves as a resource for the fundamental stages of the design process associated with data visualization development. However, we observe that this paradigm, for our present research, omits crucial elements necessary for generating data visualizations that align with human cognitive capacities, the processes by which individuals gather and retain visual information, and the mechanisms of human learning, among others. Furthermore, the validation sub-modules (data and data visual representation) are entrusted to the data visualization creator for validation, lacking any established guidelines from the authors, therefore rendering them susceptible to errors due to the designer's insufficient expertise.

3.1.3. *Exploring the Impact of Gestalt Laws of Human Perception in Business Information Visualization Context: An Eye-Tracking Study* by Bačić

In examining human visual perception and data visualizations, which is the objective of this work, we must consider Gestalt theory and its concepts. The authors Grabinger, Hauser, and Mottok (2023, p. 2) assert that “Gestalt principles are law-like observations about human perception of graphical objects. Their beginnings trace back to the early 20th century: with empirical research, the psychologist Wertheimer identified multiple factors that determine the perception of grouping”.

"'Gestalt' is German for 'unified whole'. German psychologists Max Wertheimer, Kurt Koffka, and Wolfgang Kohler created the Gestalt Principles in the 1920s. They wanted to understand how people make sense of the confusing things they see and hear. They identified a set of laws that address the natural compulsion to find order in disorder. According to this, the mind 'informs' what the eye sees by perceiving a series of individual elements as a whole. Graphic designers quickly embraced Gestalt Principles, using them to create eye-catching designs with well-placed elements" (Interaction Design Foundation, 2016).

The Gestalt theory is regarded as law-like findings concerning human perception of graphical objects. Cairo (2013, p. 114) asserts that “at its core, the visual brain is a device that evolved to detect patterns: regions in the vision field that share a nature or that belong to different entities. (...) The main principle behind Gestalt theory is that brains don't see patches of color and shapes as individual entities, but as aggregates. In fact, the word gestalt means pattern". Do the Gestalt principles adequately guide our visual representation of facts in accordance with human cognitive capabilities?

To assess the effectiveness of the Gestalt principles in data visualization design, we will examine an eye-tracking study conducted by Bačić (2024). In his article titled *Exploring the Impact of Gestalt Laws of Human Perception in Business Information Visualization Context: An Eye-Tracking Study*, Bačić (2024, p.1361) asserts that:

> Gestalt principles of proximity, continuity, similarity, and connectedness are fundamental in understanding how we perceive and process information. (...) The Gestalt grouping principles, including proximity, similarity, connectedness, and continuity, have long been recognized as fundamental concepts in psychology. These principles provide a framework for understanding how humans perceive and organize visual elements. (...) Proximity refers to the tendency to perceive objects that are close to each other as belonging together. Similarity suggests that objects sharing similar attributes are grouped in the viewer's mind. Connectedness implies that elements connected by lines or areas are perceived as a single unit, and continuity suggests that the eye will follow a continuous line or curve, grouping elements along its path (Bačić, 2024, p.1361).

The author asserts that these Gestalt principles offer designers a foundation for creating effective data visualizations that facilitate clear interpretation of visual information (Bačić, 2024, p.1361). Conversely, Bačić (2024, p.1361) elucidates that "eye-tracking studies allow researchers to observe and analyze how viewers' eyes move across visualizations, providing insights into their perceptual grouping and attentional processes. By examining gaze metrics, researchers can assess whether visualizations designed according to Gestalt principles indeed facilitate more efficient and accurate data interpretation. This line of research deepens our understanding of visual perception and informs the design of more effective visualizations that align with human cognitive processes".

Ultimately, Bačić (2024, p.1365) conveys that "the study finds support for three out of four principles and contributes empirical data to the field, offering insights into the effectiveness of data visualization design principles and best practices." The Gestalt principle that found no support in the study was the principle of proximity: “(...) did not confirm a significant impact of proximity on user behavior. (...) while proximity is a valuable tool for clustering related data points, its effectiveness may vary depending on the specific context and type of visualization” (Bačić, 2024, p.1365).

The Gestalt theory and its ideas are fundamental to graphic design and have been for almost a century. This study concludes that a Gestalt-based paradigm is inadequate for developing a tool to direct the design of data visualizations aligned with human visual perception and cognition. Bačić’s study reveals that, under specific conditions, not all Gestalt principles may be upheld, and it also indicates that aspects such as cognitive load and human learning processes are not accounted for within the Gestalt framework.

3.1.4 *Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods* by Cleveland and McGill

Cleveland and McGill (1983, p. 531) commence their framework by presenting a significant concept of 'graphical perception.', "(...) the visual decoding of information encoded on graph (...)". They then go on to define their understanding of the strength of data visualizations, stating that “the power of a graph is its ability to enable one to take in the quantitative information, organize it, and see patterns and structure not readily revealed by other means of studying the data” (Cleveland&McGill, 1983, p.535). To clearly discern the 'hidden' patterns and structures within the data, the authors enumerate ten fundamental tasks for visual data representation-and rank these perceptual tasks from the most to the least accurate.

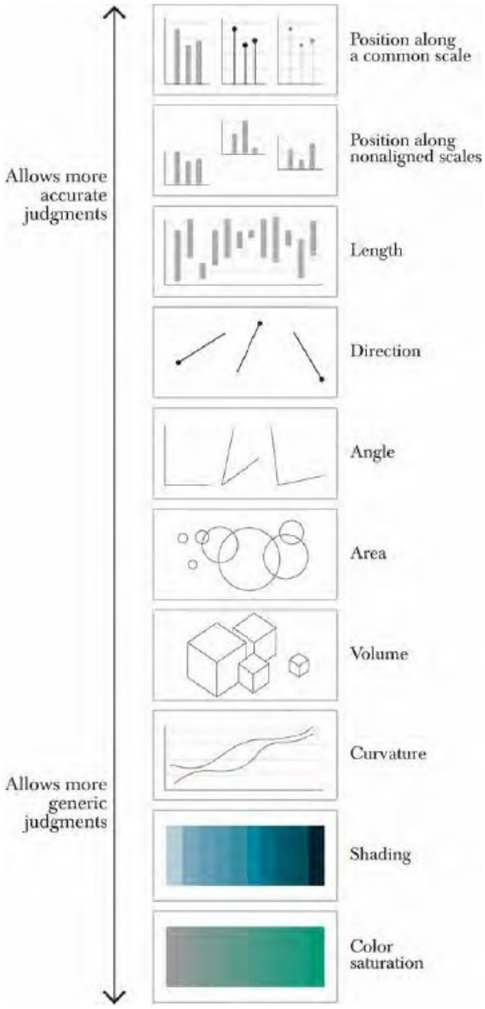


Figure 3 - Cleveland and McGill's elementary perceptual tasks (Cairo, 2013, p. 107)

They proceed to assert that "we have chosen the term elementary perceptual task because a viewer performs one or more of these mental visual tasks to extract the values of real variables represented on most graphs. We do not pretend that the items on our list are completely distinct tasks; for example, judging angle and direction are clearly related" (Cleveland&McGill, 1983, p.532).

For a data visualization designer to employ the Graphical Perception framework, the authors recommend that "the mode of graph design that we advocate is the construction of a graphical form that uses elementary perceptual tasks as high in the hierarchy as possible. The hypothesis is that by selecting as high as possible, we will elicit judgments that are as accurate as possible, and therefore the graph will maximize a viewer's ability to detect patterns and organize the quantitative information" (Cleveland&McGill, 1983, p.544).

Cleveland and McGill (1983, p. 553) acknowledged that the suggested framework has certain advantageous outcomes: “its application to some of the most-used charts in graphical communication (bar charts, divided bar charts, pie charts, and statistical maps with shading) has led to replacements (dot charts, dot charts with grouping, and framed-rectangle charts). We do not lightly recommend the dismissal of some of the most popular graph forms, but it appears to be the inescapable conclusion of this analysis of graph design. If progress is to be made in graphics, we must be prepared to set aside old procedures when better ones are developed, just as is done in other areas of science”.

We find the proposed framework deficient in detail and, most importantly, neglectful of the manner in which humans process and learn from information. A crucial feature of knowledge acquisition from visual data representations is the potential cognitive overload that intricate data visualizations might impose on the observer. That is an aspect we will examine next.

3.1.5. *Nine Ways to Reduce Cognitive Load in Multimedia Learning* by Mayer and Moreno

The definition of data visualization is extensive and includes various aspects of the visual representation of data. Upon examining the literature for this study, we discovered that research on multimedia learning, which constitutes a form of data visualization, might significantly inform the development of a framework for data visualization grounded on human cognition and visual perception. Mayer and Moreno (2003, p.43) have conducted study in the topic, asserting that "the goal of our research is to figure out how to use words and pictures to foster meaningful learning. We define multimedia learning as learning from words and pictures, and we define multimedia instruction as presenting words and pictures that are intended to foster learning". The writers continue by emphasizing that "let us consider what happens in (...) a learning situation in which words and pictures are presented. A potential problem is that the processing demands evoked by the learning task may exceed the processing capacity of the cognitive system — a situation we call cognitive overload" (Mayer&Moreno, 2003, p.45).

In a concurrent study on cognitive overload in learning, Sweller (2002, p.1501) elucidates the structure of human cognition and the functioning of memory, which is invariably engaged in the learning process: “human cognitive architecture includes a working memory of limited capacity and duration with partially separate visual and auditory channels, and an effectively infinite long-term memory holding many schemas that can vary in their degree of automation. These cognitive structures have evolved to handle information that varies in the extent to which elements can be processed successively in working memory or, because they interact, must be processed simultaneously imposing a heavy load on working memory". The author additionally clarifies that "a major consequence of the limitations of working memory is that when faced with new, high element interactivity material, we cannot process it adequately. We invariably fail to understand new material if it is sufficiently complex. In order to understand such material, other structures and other mechanisms must be used. Processing high element interactivity material requires the use of long-term memory and learning mechanisms" (Sweller, 2002, p.1502).

Mayer and Moreno (2003, p. 45) delineate three distinct cognitive demands for a comprehensive grasp of cognitive load theory:

> (...) essential processing, incidental processing, and representational holding. Essential processing refers to cognitive processes that are required for making sense of the presented material, such as the five core processes in the cognitive theory of multimedia learning—selecting words, selecting images, organizing words, organizing images, and integrating. Incidental processing refers to cognitive processes that are not required for making sense of the presented material but are primed by the design of the learning task. For example, adding background music to a narrated animation may increase the amount of incidental processing to the extent that the learner devotes some cognitive capacity to processing the music. Representational holding refers to cognitive processes aimed at holding a mental representation in working memory over a period of time". (Mayer and Moreno, 2003, p. 45)

The authors present examples illustrating how instructional materials may induce cognitive overload in either of the previously discussed cognitive demands (Mayer & Moreno, 2003, p. 46). An example illustrates that during the critical processing of instructional content; the volume of graphically presented data might induce cognitive overload in the observer. The approach should involve 'off-loading' the viewer's visual channel and, by employing narrative, engage the viewer's hearing channel. In another instance, when a viewer experiences an overload due to significant processing demands on both the visual and aural channels, the proposed solution is to incorporate more time (breaks) in the information flow presented by the learning material.

Mayer and Moreno (2003, p.46) and Sweller (2002, p.1506) assert that particular emphasis should be placed on the use of duplicate information in learning materials, with the latter noting that: "the redundancy effect is one of the more surprising cognitive load effects with many people finding it quite counterintuitive. Most of us feel that even if additional explanatory material is not beneficial, at the very least it should be neutral. In fact, the addition of redundant information can have strong, negative consequences" Sweller (2002, p.1506).

Concerning the aim of the present study, we consider cognitive load theory to be pertinent. Nonetheless, the aforementioned research, while potentially associated with data visualization, does not pertain to the subject and seldom references pertinent concepts such as Gestalt theory or graphical perception.

3.1.6. *Understanding Charts and Graphs* by Kosslyn

Concerning frameworks for data visualization, Stephen Kosslyn's 1989 framework, presented in the article 'Understanding Charts and Graphs,' is among the most comprehensive identified in the research conducted for this study. The author's primary objective is to guarantee that “in the ideal case a chart or graph will be absolutely unambiguous, with its intended interpretation being transparent” (Kosslyn, 1989, p.192).

Kosslyn (1989, p. 187) identifies the primary components of data visualization as follows: “the four constituents used here are called the background, the framework, the specifier, and the labels”, and progresses to delineate the definition of each component: “the background is a pattern over which the other components of the display are presented” (Kosslyn, 1989, p.187); “the framework represents the kinds of entities being related (e.g. year and oil production), but does not specify the particular information about them conveyed by the display (e.g. the amount of oil per year)” (Kosslyn, 1989, p.187); “the specifier conveys the particular information about the entities represented by the framework. The specifier serves to map parts of the framework (actually present or inferred by the reader) to other parts of the framework. In graphs the specifier is often a line or bars which pair values on the x and y axes delineated by the framework. In charts the specifier material often consists of directed arrows connecting boxes or nodes” (Kosslyn, 1989, p.188); and, finally, “the labels are composed of letters, words, numbers, or pictures and provide an interpretation of a line or region (which is a component of either the framework or the specifier)” (Kosslyn, 1989, p.189).

Kosslyn primarily addresses charts and graphs within the proposed paradigm, although asserts that "the insight gained from understanding the way charts and graphs convey information applies to all types of displays; we can simply apply the various structures as appropriate when making a map or diagram" (Kosslyn, 1989, p.186); so guaranteeing that his paradigm is relevant to the most (if not all) types of data visualizations.

Kosslyn (1989, p.190) elucidates that "a wide range of activities is interposed between that instant when one first fixates one's gaze upon a visual display and the point at which one has successfully extracted relevant information from it". The author asserts that several aspects of our visual information processing systems influence our reading and perception of charts and graphs, subsequently elaborating that:

> These properties affect our ability to perceive syntactic properties of displays, in the following ways. First, if the stimulus is too small or does not contrast enough with a background, one will simply fail to see it. (...) Second, there are well-known systematic distortions in perceiving size and other properties of objects. For example, if one estimates the relative areas of two circles, one is very likely to underestimate the size difference. (...) Third, some aspects of a stimulus are given priority over others; we pay attention first to abrupt changes of any sort (e.g. heavier marks, brighter colours). Fourth, stimuli are organized into coherent groups and units by the time we become aware of them. Much of this organization is 'automatic', not under voluntary control, and is determined by reasonably well-understood properties of stimuli (e.g. proximity of elements). The grouping imposed by these automatic processes must be respected if a chart or graph is to be seen the way a designer intends (Kosslyn, 1989, p.191).

Cognitive overload is a significant issue for Kosslyn (1989, p.191), particularly due to "given that information is represented in short-term memory, the next constraint we must consider is the capacity limit of short-term memory. (...) if too much information must be held in mind at once, a person will be unable to perform a task. Thus, the complexity of a display will be a major factor in determining its comprehensibility". After the information obtained from the data is stored in short-term memory, it can be encoded into long-term memory. The viewer will derive more insights from the data visualization than the information explicitly recorded within the data by juxtaposing the newly obtained information with previously stored knowledge in their long-term memory. At this juncture, the viewer's knowledge significantly influences the comprehension of the information delivered, however it is not the sole factor.

Kosslyn (1989, p.192) asserts “in addition, if a line is categorized as 'steep' it will be taken to represent a 'sharp rise' in prices or whatever; if it is categorized as 'shallow' it will be taken to represent a 'slow rise' (even if it is the same information, just graphed on different -shaped axes). Furthermore, knowledge of the task at hand can have important consequences: if the initial organization of the display does not help one to interpret the display, knowledge of the task can lead one to consciously reorganize the pattern, using information in long-term memory to reconstrue the stimulus- which in turn leads to a new attempt to interpret the pattern against other stored information”.

The author discusses many constraints impacting the human visual system, asserting that “the first set of principles bears on how lines, colors, and regions are accurately discriminated - which is a necessary prerequisite for further processing” (Kosslyn, 1989, p.194). Kosslyn (1989, p.194) claims that “the variations in marks — defined as the components of a data visualization, such as lines and areas — must be sufficiently pronounced, and each mark must be of adequate size to ensure distinguishability”. Moreover, the author affirms that “(...) the visual system often systematically distorts the magnitude of marks along various dimensions (such as area and intensity)”, including that "(...) marks vary along a number of dimensions, such as hue, size, height, and some of these dimensions cannot be processed independently of others. For example, it is impossible to see the hue of a mark (i.e. its shade of colour, roughly) without seeing its saturation (i.e., the deepness of the colour, roughly). (...) Thus, the width of a bar will influence one's assessment of its size, even when only the height is relevant” (Kosslyn, 1989, p.194).

Finally, Kosslyn offers a counsel concerning the mechanics of human visual perception: “partly because only a limited amount of information can be held in short-term memory at once, some marks will be given priority over others. The information conveyed by these marks should be central to the display's message. (...) Marks should be chosen to be noticed in accordance with their importance in the display. Some colours, weights of line, and sizes are noticed before others. For the most part we do not have formal rules for determining which these are but instead rely primarily on a general principle: the visual system is 'a difference detector'. Any sharp contrast will draw attention” (Kosslyn, 1989, p.195).

A further critical factor to consider in data visualization design, as noted by Kosslyn, is the cognitive processing limits inherent in the human brain. To address these restrictions, the author enumerates some precautions for the designer, including: "(...) perceptual units should be chosen so that separate perceptual units correspond to pieces of information to be sought by a reader. That is, displays should not require readers to decompose perceptual units in order to extract specific information, as occurs if single points along a line must be interpreted" (Kosslyn, 1989, p.197); or that "portions of the chart or graph that are meant to correspond to other portions of the chart or graph should do so unambiguously. Much of the meaning of a display arises from how the marks are organized into a complex symbol. The key, for example, should clearly indicate how labels are paired with different components of the specifier" (Kosslyn, 1989, p.197).

The viewer's interpretations of information are susceptible to processing restrictions, as exemplified by Kosslyn: "(...) labels should name words that are indicative of the class (including the correct connotations) and pictures should depict appropriate objects (a picture of a penguin-like bird should not be used to label birds in general)" (Kosslyn, 1989, p.204), or that "the appearance of the lines and regions themselves should be compatible with their meanings. For example, people have trouble reporting the colour of the ink used to print a word if the words themselves name other colours (e.g. if the word 'red' is printed in blue ink; this is known as the 'Stroop effect'). Similarly, if 'left' and 'right' are labels along the x axis, the 'left' label should be physically to the left (this constraint is sometimes violated in the literature on the specializations of the cerebral hemispheres)" (Kosslyn, 1989, p.204). Kosslyn (1989, p.204) concludes that "a chart or graph should make use of concepts that are likely to be possessed by the intended readership".

The author asserts that, in summarizing his framework, referred to as the analytic scheme by Kosslyn, "the present analytic scheme is designed to reveal features of displays that result in their being difficult to understand. This scheme depends on looking very carefully at a display, and generating a detailed description of it (...) we consider the nature and role of the background, framework, specifier, and labels, and we consider the interrelations among these constituents. Whenever we have difficulty generating the description, we consider whether one of the acceptability principles has been violated", further claiming that "this exercise proves to be a systematic and exhaustive way of characterizing potential problems with a display." (Kosslyn, 1989, p.214).

As previously said, Stephen Kosslyn's framework is among the most comprehensive and pertinent frameworks for our current endeavors. Nonetheless, in the author's own terminology, the suggested framework is an exercise. "(...) systematic and exhaustive (...)" (Kosslyn, 1989, p.214) It, in our view, contradicts the objective of an effective framework. Molich and Nielsen (1990, p. 255) highlighted the principal benefits of heuristic judgments: "[a heuristic evaluation] (...) is intuitive and it is easy to motivate people to do it". Kosslyn's analytic technique rapidly gets intricate, rendering it challenging for non-neuroscientists to utilize.

3.2. Perceptual-Cognitive Data Visualization Framework

We will establish a framework, called Perceptual-Cognitive Data Visualization Framework, for data visualization aligned with human cognitive capacities for perceiving and processing information acquired through our visual system by defining its primary pillars. Such a framework must be explicit, succinct, and user-friendly.

Our proposed framework is designed for visual information designers, serving both as a guide for the data visualization design process and as a means to assess current data visualizations. The proposed framework is underpinned by two primary functionalities: firstly, a compilation of recommendations and insights derived from the literature review conducted for this study, which aids in the design of data visualizations aligned with the principles of human visual perception and cognition. Secondly, we will implement an evaluation system for existing data visualizations, adhering to the principles that informed the development of the first functionality of the proposed framework.

To enhance the usability of the proposed framework and mitigate cognitive overload, we will integrate the aforementioned functionalities to prevent the redundancy of information presented to users. Consequently, for each recommendation or observation within the framework, a corresponding evaluation sentence will be supplied, ensuring the framework's usability remains straightforward and facilitating the comprehension of the concepts for both the visual information designer and the evaluator of existing data visualizations.

The initial functionality of the proposed framework would be grounded on the concept of 'heuristic evaluation' as articulated by Moran and Gordon (2023, p. 1), which asserts that "a heuristic evaluation is a method for identifying design problems in a user interface. Evaluators judge the design against a set of guidelines (called heuristics) that make systems easy to use", with Nielsen (1994, pp. 7) adding that “(...) heuristics are general rules that seem to describe common properties of usable interfaces". Nielsen's proposed 'heuristic evaluation' is regarded as a fundamental method for assessing various user experiences; hence, we view its conceptual foundation as a crucial guideline for developing our own framework.

Molich and Nielsen (1990, p.255) assert that, among several advantages, 'heuristic evaluation' offers several benefits: "it is intuitive and it is easy to motivate people to do it. (...) It does not require advance planning. (...) It can be used early in the development process", with Nielsen (1989, p.395) adding that “heuristic evaluation is used to let designers make informed judgements when they are trying to decide what changes to make in the scenario and how to translate the scenario into a complete design".

Our selection of the 'heuristic evaluation' method, tailored for data visualization and human visual perception and cognition, is further substantiated by Nielsen's (1994, para. 12) assertion that “(...) because heuristic evaluation aims at explaining each observed usability problem with reference to established usability principles, it will often be fairly easy to generate a revised design according to the guidelines provided by the violated principle for good interactive systems. Also, many usability problems have fairly obvious fixes as soon as they have been identified”, with particular emphasis on the assertion that "fairly easy to generate a revised design according to the guidelines provided" and that "problems have fairly obvious fixes as soon as they have been identified", both objectives pertain to the application of our suggested framework.

The evaluation component of our paradigm will be grounded in the application of the Likert scale, as elucidated by Joshi et al. (2015, p. 397): "the original Likert scale is a set of statements (items) offered for a real or hypothetical situation under study. Participants are asked to show their level of agreement (from strongly disagree to strongly agree) with the given statement (items) on a metric scale. Here all the statements in combination reveal the specific dimension of the attitude towards the issue, hence, necessarily inter-linked with each other". Koo&Yang (2025, p.1) adds that "it consists of a series of statements or questions, each accompanied by a symmetric range of response options that allow respondents to indicate their level of agreement or disagreement. A typical five-point scale includes options ranging from 'Strongly Disagree' to 'Strongly Agree', with intermediate responses such as 'Disagree', a neutral 'Neither Agree nor Disagree', and 'Agree'".

The rationale for employing a Likert scale-based evaluation tool is enhanced by recognizing that "the Likert-type scale is a valuable research tool due to its ability to capture human sentiments in a standardized manner, enabling respondents to express varying degrees of opinion rather than binary choices. (...) This versatility makes the scale an indispensable tool in disciplines such as psychology, marketing, social sciences, and healthcare, where understanding participants' perspectives is critical" (Koo&Yang, 2025, p.1).

Our framework will incorporate both a recommendation regarding a crucial element of data visualization design aligned with human visual perception and cognition, as well as an evaluative sentence to assess the successful integration of these observations or recommendations into the design of existing data visualizations. Regarding the second functionality of the proposed framework, which is the evaluation instrument utilizing a Likert scale, it is essential to comprehend that "designing effective Likert-type scale questions is essential for capturing accurate and meaningful data in survey research. The quality of the data collected depends on the clarity and precision of the questions posed. (...) Questions should be clearly worded, concise, and devoid of ambiguity to ensure consistent interpretation among respondents" (Koo&Yang, 2025, p.2). Consequently, a succinct and clearly articulated inquiry will be formulated to follow each observation or recommendation of our suggested framework.

An additional significant consideration in selecting the development of an evaluative instrument utilizing Likert scales is the recognition that data visualization design, as a form of creative expression, cannot adhere to a rigid, immutable set of guidelines. Despite our efforts to offer a definitive framework of observations to inform the design of data visualizations in alignment with human visual perception and cognition, the 'correct' implementation of these observations is contingent upon subjective factors that may differ among designers and evaluators. The utility of a Likert-type scale lies in its capacity to facilitate "(...) respondents to express varying degrees of opinion rather than binary choices", and we believe this is essential for the practical utility of our Perceptual-Cognitive Data Visualization Framework as a tool for assessing existing data visualizations, where individuals may evaluate different aspects of the design variably. Ultimately, we must consistently remember that "(...) just because a design choice violates a heuristic, that does not necessarily mean it's a problem that needs to be fixed — it depends on the particular context and the available alternatives" (Gordon&Moran, 2023, para. 36).

Regarding the framework, we will categorize our observations and recommendations into three principal categories for improved usability:

As previously noted, “effective data visualizations employ organization and structure to illustrate relationships, depict interactions among components of a whole, and unveil an underlying narrative” (Dunlap & Lowenthal, 2016, p.44). Consequently, the initial group will include observations pertaining to the narrative aspect of data visualizations. This category presents five recommendations.

The following category will focus on the information design element of visual data representations, emphasizing graphic design decisions that align visual solutions with human visual perception and cognition. The first two categories are generically relevant to all data visualizations. Encompassing this category are eleven recommendations.

The third and final category focuses on the unique attributes of Instagram as a publishing platform for data visualizations, which is the main aim of our work. This category presents two recommendations.

The suggested framework will include an assessment sentence to measure the effective integration of the aforementioned observations or recommendations into the design of existing data visualizations. Each observation within the framework must include an evaluative statement, which can be responded to using a conventional five-point scale ranging from 'Strongly Disagree' to 'Strongly Agree', incorporating intermediate responses of 'Disagree', a neutral 'Neither Agree nor Disagree', and 'Agree'. All statements will be preceded by the sentence “Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents Strongly Disagree and 5 represents Strongly Agree:”.

We will now analyze each recommendation, understand the importance of each in the creation of data visualizations that account for human visual perception and cognition, based on the studied literature, and formulate an evaluative phrase for each observation.

We will subsequently provide the complete framework in its final configuration and assess the proposed framework utilizing data visualizations shared on Instagram, as previously indicated.

Concerning the initial category of observations related to the narrative dimension of data visualizations, we commence with the inquiry:

1.	To comprehend a data visualization, viewers should require no prior knowledge beyond general understanding. All pertinent information and context must be included in the data visualization.

The initial observation is critically significant, since Kosslyn (2006, p.8739) underscores the role of prior knowledge in augmenting material comprehension, claiming that "be sure that your intended readers will understand the concepts, symbols, and jargon you use. Furthermore, ensure that the readers possess the requisite prior information to comprehend the content. An effective display introduces novel information; nonetheless, this information must remain relevant to the readers' existing knowledge. Assuming that readers possess extensive knowledge may lead the visual information designer to depend on concepts, facts, or norms that are new to them, rendering communication unintelligible. Assuming viewers possess little knowledge will lead designers to exaggerate what readers consider self-evident". Kosslyn and Koenig (1995, p. 931) clarify the manner in which individuals analyze relevant information: “we do not search randomly when seeking supplementary information. Instead, retained information is utilized to infer our visual perception, and this inference subsequently directs additional encoding. One actively pursues new facts relevant to the hypothesis”.

The necessity of requiring only a general understanding from a viewer to interpret a data visualization is further substantiated by the assertion that "the primary limitation in long-term memory is an individual's knowledge. The interpretation of a display, in terms of semantics and pragmatics, is contingent upon the stored knowledge most closely linked to the categorization of the display's sensory qualities. If an individual is unfamiliar with the definition of a term or the arrangement of lines constituting a display's framework, they will encounter difficulties in correlating the display with the appropriate stored information” Kosslyn (1989, p.192). Kosslyn (1989, p.204) asserts that “a chart or graph should utilize concepts likely familiar to the target audience.”

For this first recommendation, the assessment sentence will be “All requisite information and context necessary for comprehending this data visualization is available”.

2.	All data visualizations must convey a narrative to the audience. Data visualizations should be crafted to deliver sufficient information swiftly, structured to offer viewers a narrative experience.

The second observation pertains to the narrative component that data visualizations should strive to incorporate. Visual displays resemble narratives more than mere representations of objects; while they have identifiable components, it is the relationships among these components that communicate the specific information. This facet of comprehension necessitates the recollection of the importance of specific patterns and may involve reasoning according to the principles governing a display format (Kosslyn, 2006, p.35). Dunlap and Lowenthal (2016, p.44) further emphasize the importance of the elements used in data visualizations: "infographics frequently incorporate charts, maps, diagrams, and illustrations to rapidly convey a narrative, illustrate relationships, and disclose structure". This underscores the significance of the storytelling component of data visualizations.

For the evaluative aspect of this second recommendation, the statement shall be “The information presented in this data visualization initially communicates a cohesive narrative.”

3.	Viewers of a data visualization should comprehend both the inquiry and the response that the composition seeks to convey. A visual information designer must strive to formulate a precise query from the data and provide a definitive answer.

It is crucial for a visual information designer to be able to formulate a precise query from the data and provide a definitive answer. This is supported by Kosslyn (2006, p.68), who asserts that "a graph is intended to make a specific point, and its visual appearance should convey that point". Kosslyn (2006, p.34) also emphasizes the significance of context in numerous psychological principles, stating that "a graph is a device to help people answer specific questions. It is imperative to determine the specific questions that readers will wish to address within the context of the graph, as well as the precise information that readers will require to be able to answer those questions from the display. The data should be organized accordingly”.

Additional justification is provided by the following: “readers utilize displays to address specific inquiries, and they anticipate receiving only the minimum amount of information required to address those inquiries within the context of the graph — but not more" (Kosslyn, 2006, p.34), with the additional consideration that "information is communicated effectively only when it focuses the readers' attention and interest on a specific message. Graphs and other visual representations provide readers with the ability to address a specific question, whether it is highly specific (e.g., whether girls are typically taller than boys in early adolescence; whether the dollar is more valuable in China than in the U.K.) or relatively general (e.g., the cost of office space per square foot in various cities; what was the exchange rate between the U.S. dollar and Euro over the past five years)" (Kosslyn, 2006, p.8303).

In light of this observation, we suggest the following assessment sentence: "The information utilized in this data visualization articulates a distinct query and provides a corresponding solution".

4.	All visual elements in a data visualization, including language, must be sufficiently clear and comprehensible for a layperson to grasp the conveyed message. All terminology must be removed from the text, and all visual elements must prioritize simplicity.

In order for a layperson to comprehend the message conveyed by a data visualization, it is crucial that all visual elements, including language, are sufficiently plain and comprehensible. This recommendation is supported by the following: "in general, a graph with the fewest variables and extraneous clutter is the easiest to understand, while a graph that is visually striking or has natural objects is more memorable" (Harrison et al, 2017, p.150), which supports Kosslyn's (2006, p.11797) assertion that "for effective communication, your display should be comprehensible at a glance and subsequently recollected without effort".

Additional justification is that a sentence that is printed in a clear font, has been repeated, or has been primed will be processed fluently with cognitive ease. Cognitive ease is also induced by listening to a speaker when one is in a pleasant mood, or even when one has a pencil inserted crosswise in their mouth to induce a smile. In contrast, cognitive strain is induced when instructions are presented in a poor font, in feeble colors, or in a complex language, or when the reader is in a foul mood or even frowns, (Kahneman, 2011, p.1080), with the additional observation by (Kosslyn, 1989, p.204): "(...) labels should name words that are indicative of the class (including the correct connotations) and pictures should depict appropriate objects (a picture of a penguin-like bird should not be used to label birds in general)".

The assessment sentence for this recommendation will be "All information presented in this data visualization is lucid and comprehensible, devoid of jargon and employing straightforward text and graphic elements."

5.	A data visualization should not require users to engage in data manipulations, such as mental calculations, hence reducing cognitive strain. The design must incorporate all the computations, displaying the resultant information right within the visualization. This method guarantees that viewers can easily understand the facts without requiring more cognitive effort.

Visual information designers must prioritize the reduction of cognitive strain for observers while they access information from a data visualization. This ensures that users are not required to perform mental calculations or engage in data manipulations. Kosslyn (2006, p.14419) posits that the reluctance of individuals to exert effort is a psychological, rather than a moral, phenomenon, and that they will frequently refrain from doing so if they are uncertain about the potential rewards. By requesting that readers extrapolate a trend from a bar graph, designers are imposing additional work on them by requiring them to mentally connect the peaks of the bars in order to create a line that they can follow. However, if a designer wishes to emphasize specific values, she should refrain from employing a line that requires readers to mentally segment into points. Instead, a designer must provide them with a bar graph that promptly illustrates precise values. In both of these scenarios, the adoption of a graph type that is not appropriate for the data results in an increased likelihood that the graph will not effectively convey the intended message and additional work for the reader.

Kosslyn (2006, p.30) also recommends that a graph should be employed solely to demonstrate the relationships between measurements. In order to convey quantitative data, graphs utilize variations in a visual dimension, such as the elevation of a bar or line at a specific location within the framework. Our perceptual mechanisms enable us to rapidly identify variations in the gradients of lines or in heights. Nevertheless, they are not well-suited for the accurate representation of specific absolute values, as they do not enable us to register exact heights or slopes in a particularly effective manner. The reader must not only register the components of the graph but also relate a specific point on a content element (a line) to the corresponding locations on the X and Y axes in order to derive a specific value. Additionally, we are not very adept at registering precise spatial relations of objects that are not physically connected. In order for a graph to be beneficial, it must contain essential components that are appropriately related. A graph is not merely the sum of its elements; it is essential that the components are organized in a manner that facilitates the identification of their interactions. (Kosslyn, 2006, p. 27).

Lastly, it is imperative that data visualization designers remain cognizant of the fact that "when we ‘hold something in mind’ we are actually retaining information in short-term memory. In order to completely comprehend a presentation, it is necessary to make deductions and identify implications, which necessitates the use of reasoning. These reasoning processes operate on information stored in short-term memory. Our comprehension is significantly restricted by the limited capacity of short-term memory. Numerous displays that are inadequate are perplexing in part because they place an excessive burden on the viewer's short-term memory capacity” (Kosslyn, 2006, p.68).

The data visualization assessor must convey her level of agreement with the following statement in order to evaluate this observation: “All cognitive processing required to comprehend this data visualization has been conveyed to the viewer.”

Having reviewed the initial category of observations linked to the narrative dimension of data visualizations, we shall delve into the recommendations concerning the information design aspects of a data visualization. Our initial observation is:

6.	Optimal readability must be ensured in a data visualization. All textual and visual elements in the data visualization must be unequivocal and straightforward, and clear contrast must be unsured.

One of the most critical components of a data visualization is readability. Kosslyn (2006, p.76) suggests that neurons that detect changes in one region of space inhibit other neurons that detect changes in nearby regions. Consequently, if a mark is not sufficiently large or heavy, the cells that would typically detect it are prevented from responding. Detectability is contingent upon a variety of factors and their interactions, including the color of the figure and its background, the contrast of intensity of light and dark elements, and the shape of the figure. Kosslyn (1989, p.194) further explains that the variations in marks — defined as the components of a data visualization, such as lines and areas — must be sufficiently pronounced, and each mark must be of an appropriate size to ensure distinguishability. Kosslyn (1989, p.195) asserts that the visual system functions as a 'difference detector'. Attention will be attracted to any stark contrast.

The assessment sentence for this recommendation will be as follows: "This data visualization ensures readability through the use of unequivocal and straightforward solutions, including clear contrast."

7.	All visual information components in a data visualization must be distinct from the decorative visuals (illustrations, supplementary images, etc.) and the background.

Special consideration must be given to all visual information components in a data visualization, as these elements are where the information is conveyed, similar to legibility. Consequently, these components must be distinguished from the background and decorative visuals (such as supplementary images and illustrations). The reviewed literature provides justification for this, as Kosslyn (1989, p.191) asserts that if the stimulus is too small or does not contrast sufficiently with a background, it will be invisible. Masland (2020, p.535) further explains that the early retinal cells also enhance the edges of the visual input, and that the most significant elements of the visual stimulus are objects, which are defined by their edges. Masland (2020, p.1359) posits that the brain can generate an accurate estimate of the object's form by providing it with information regarding the orientation of its edges only.

Kosslyn (2006, p.8740) elaborates that a good display should capture the attention of the reader and guide them through the display, allowing them to first identify the most significant information and subsequently make all the necessary distinctions. He also suggests that in order to communicate effectively, a display should be able to be understood at a glance and subsequently recalled without effort (Kosslyn, 2006, p.11797). Kosslyn concludes that the most visually striking aspects of a display should be used to signal the most critical information (Kosslyn, 2006, p.8740).

"All visual elements in this data visualization are readily discernible, encompassing both its decorative aspects and the background.", is the sentence selected for the evaluation of this recommendation.

8.	The selection of colors in a data visualization must optimize contrast among all visual components. A color palette must be selected to ensure clear visual distinction among graphic assets. Moreover, a designer must account for the 'false stereo effect' in human visual perception, a form of visual distortion that perceives warmer colors as nearer than cooler hues, and organize the color of visual assets accordingly.

The selection of colors is a critical component of information visual design. The contrast among all visual components must be optimized through the selection of color combinations in a data visualization. In order to guarantee that graphic assets are visually distinct, it is necessary to select a color palette. Additionally, a designer must consider the ‘false stereo effect’ in human visual perception, which is characterized by the perception that long-wavelength, warmer colors are ‘closer’ to us than short-wavelength, cooling colors. This phenomenon is explained by Kosslyn (2006, p.10488). Based on this information, the author suggests that the warmer line should overlap the cooler line when two lines intersect, as in a line graph. If it fails to do so, the back line will appear to be in a state of competition to advance, attempting to spiral around the one in front, which is disconcerting. Additionally, for the same reason, it is recommended that cold colors be employed in the background and warm colors in the foreground (e.g., for text, graphs, etc.).

During the discussion of contrast and colors Kosslyn (2006, p.76) suggests that neurons that detect changes in a single region of space inhibit other neurons that detect changes in adjacent regions. Consequently, if a mark is not sufficiently large or heavy, the cells that would typically detect it are prevented from responding. The detectability of a figure is contingent upon a variety of factors and their interactions, including the color of the figure and its background, the contrast of intensity of light and dark elements, and the shape of the figure.

The subsequent formulation has been selected as the evaluation sentence for this observation: "The colors employed in this data visualization enhance the contrast and comprehension of its visual components."

9.	The selected scale for a data visualization must adequately illustrate the disparities in the supplied data.

In order to facilitate comprehension of the disparities in the displayed data and facilitate comparison between various elements, the selection of a scale for a data visualization must be carefully considered. In accordance with Kosslyn (2006, p.87-88), the visual representation generated by a display should accurately represent the patterns and distinctions among the data. In order to generate an accurate impression, only the pertinent range of the scale along the Y axis should be displayed. A designer should begin the visible scale at a value that is slightly lower than the smallest value in the data, and make the upper value slightly larger than the largest value, unless the zero value is inherently significant. To indicate that a portion of the scale is omitted, a designer must create a distinct gap in the Y axis slightly above the origin. In addition, it is imperative that a visual information designer guarantees that the height-to-width ratio of the axes is such that it is possible to differentiate between content differences. The aspect ratio is the ratio of the height to the length. Differences in bar heights (or line heights, for line graphs) may not be easily discernible if the X axis is excessively long in relation to the Y axis (Kosslyn, 2006, p.77).

The level of agreement with the following statement must be indicated by the evaluator in order to judge this recommendation: "The selected scale(s) for this data visualization optimize comprehension of the disparities in the displayed data and ensures easy comparison between different elements."

10.	The primary visual information elements of a data visualization should be displayed collectively and centrally within the composition. A visual information designer must account for the limited focal region of the human eye and organize pertinent information to minimize unwanted saccades in the viewers' gaze.

The primary visual information elements of a data visualization should be centrally and collectively displayed within the composition. As Masland (2020, p.418) asserts, the central region of the human visual field has a significantly higher pixel density than the periphery. The retinal ganglion cells, the final cells in the retina closest to the brain, are the pixels that are relevant in this instance. Their axons are responsible for the formation of the optic nerve.

Dehaene (2009, p.224) posits that the fovea, which occupies approximately 15 degrees of the visual field, is the sole region of the retina that is truly beneficial for reading.

Kosslyn, Thompson, and Ganis (2006, p. 1034) clarify that in vision, we typically shift attention by making rapid saccades, which produce the phenomenology of one point of view being replaced by another. Consequently, a visual information designer must consider the limited focal region of the human eye and organize pertinent information to minimize unwanted saccades in the viewers' gaze.

The assessment sentence for this recommendation will be as follows: "All primary visual information assets of this data visualization are collectively displayed in a central position within the composition."

The following three recommendations pertain to the Gestalt Principles that should be considered when developing a data visualization. In order to assess the degree of alignment between a data visualization design and these principles, we have developed an observation for each Gestalt Principle. For these observations, we will compile the three recommendations and their respective assessment sentences. Subsequently, we will examine the literature reviewed for this work and identify the rationale behind the relevance of the Gestalt Principles when applied to the design of visual information.

11.	All visual information elements of the data visualization must adhere to the proximity Gestalt Principle. This Gestalt principle asserts that elements in proximity are viewed as a cohesive group, regardless of variations in attributes such as color or shape. Data visualizations must be constructed in accordance with this principle.

With the assessment sentence: "All components of this data visualization that should be interpreted collectively are positioned in proximity to one another."

12.	All visual information components in the data visualization must adhere to the similarity Gestalt Principle. This Gestalt principle asserts that items with shared visual attributes are regarded as interconnected or part of the same group. Data visualizations should be constructed in accordance with this approach.

For this recommendation, the assessment shall be: "All components of this data visualization that should be recognized as part of the same category exhibit identical visual attributes."

13.	All visual information components in the data visualization must adhere to the continuity Gestalt Principle. This Gestalt principle asserts that when visual elements are aligned, our perception tends to interpret them as continuous forms rather than as separate segments. Data visualizations should be constructed in accordance with this approach.

For this observation, the assessment sentence is: "All components of this data visualization that should be perceived as continuous are aligned with one another."

As previously mentioned, the Gestalt Principles are relevant to graphic design. Cairo (2013, p. 114) argues that the visual brain is fundamentally a device that has evolved to identify patterns: regions in the vision field that are either shared by different entities or have a shared nature. He also asserts that the primary principle of Gestalt theory is that brains do not perceive patches of color and shapes as individual entities, but rather as aggregates. In reality, the term "gestalt" denotes a pattern. Kosslyn (2006, p.10486) offers further insight into the process of interpreting visual patterns and constructing an understanding of the universe by asserting that human eyes and minds endeavor to interpret visual patterns as representing three-dimensional objects whenever feasible. In particular, the mind functions as if it unconsciously assumes that shapes have regular, closed contours characterized by parallel and perpendicular sides, that objects have consistent shading and markings across their surfaces, and that the world is composed of cohesive surfaces rather than clouds composed of tiny drops or shards. Consequently, individuals frequently arrange lines on a page (or screen) as if they denoted the existence of three-dimensional objects.

Bačić (2024, p.1361) affirms that the Gestalt Principles of proximity, continuity, similarity, and connectedness are fundamental in understanding how we perceive and process information. He also adds that the Gestalt grouping principles, including proximity, similarity, connectedness, and continuity, have long been recognized as fundamental concepts in psychology. Peebles and Ali (2015, p. 3) further assert that the Gestalt Principles of proximity, similarity, connectedness, continuity, and common fate determine how graphical features are grouped by the human visual system to form coherent wholes. These principles establish a framework for comprehending the manner in which humans perceive and arrange visual elements, with proximity denoting the inclination to perceive objects that are in close proximity as belonging together. Similarity implies that objects with comparable attributes are associated in the viewer's mind. Continuousness implies that the eye will follow a continuous line or curve, grouping elements along its path, while connectedness implies that elements connected by lines or areas are perceived as a single unit.

We will now adhere again to our established practice of disclosing the recommendation and its rationale as derived from the pertinent information discovered during the literature review conducted for this work for the remaining observations. The assessment sentence that was employed to evaluate each of the observations will be also presented.

14.	In a data visualization, the viewer should not be required to memorize more than four distinct details to comprehend the information presented. An example of this is the utilization of over four colors in a data visualization to distinguish between visual elements. Humans possess a finite capacity for short-term memory, necessitating that visual information designers create graphical solutions that prevent cognitive overload for viewers.

Visual information designers must develop graphical solutions that prevent cognitive overload for observers, as we have previously learned, due to the finite capacity of short-term memory that humans possess. The information presented in a data visualization should not necessitate the viewer to memorize more than four distinct details in order to understand it. As Kosslyn (2006, p.69) illustrates, the reader must memorize the associations between the names and the content elements in order to comprehend a key. This process necessitates effort and may strain her limited-capacity short-term memory.

The author acknowledges that humans are capable of retaining a finite quantity of information at any given moment. A graph (or any information display, for that matter) should not necessitate the reader to maintain more than four perceptual groups simultaneously. This suggests that one of the benefits of graphs in the context of data visualizations is their ability to overcome the constraints of human information processing. While humans are limited to considering approximately four groups simultaneously, we can acquire significantly more information when it is converted into visual patterns (Kosslyn, 2006, p. 13545). Kosslyn (2006, p.68) elucidates the mechanisms of short- and long-term memory by asserting that when humans ‘hold something in mind’ they are actually retaining information in short-term memory. In order to comprehend a data visualization in its entirety, it is frequently necessary to make deductions and observe implications, which necessitates the application of reasoning.

These reasoning processes are based on information stored in short-term memory. The capacity of short-term memory is relatively limited, which severely restricts the extent of human comprehension.

Retaining a mental image necessitates effort, and an image can only retain a finite quantity of information for a finite period of time. This is significant because the majority of imagery reasoning tasks cannot be completed immediately; they require time to be completed. (Kosslyn&Koenig, 1995, p.2463), with Kosslyn (2006, p.13108) also stating that viewers have a restricted capacity to retain and process information, and they will be unable to comprehend a message if an excessive amount of information is required to be retained or processed. The author explains that the capacity limit of short-term memory is the subsequent constraint that visual information designers must consider, given that information is represented in this memory. A person will be unable to complete a task if an excessive amount of information is required to be retained at once. Consequently, the comprehensibility of a data visualization will be significantly influenced by its complexity (Kosslyn, 1989, p.191).

The assessment sentence that evaluators are to employ for this recommendation is as follows: “The information required to comprehend this data visualization is limited to four distinct details.”

15.	The act of pointing is a potent instrument in human communication and is intrinsic to our species. Visual information designers must utilize graphic assets (pointers) that adeptly direct readers' focus to essential elements in a data visualization, enhancing the visual information beneficial to the audience.

This recommendation is predicated on a distinctive characteristic of the human species, according to Dehaene (2021, p.3323): social attention sharing, which further accelerates learning. More than any other primate, Homo Sapiens' attention and learning are contingent upon social signals: ‘I learn from what you teach me and attend where you attend’. Dehaene (2021, p.1243) offers a thorough elucidation of the functionality of this feature: in general, the speaker is attentive to the subject matter. Babies can significantly minimize the abstract space in which they search for meaning once they comprehend this rule. They are not required to correlate every word with all the objects in the visual scene, as a computer would, until they accumulate sufficient data to demonstrate that the small, colored insect is present whenever they hear about a butterfly. The infant can infer the subject matter from his mother's speech by following her gaze or the direction of her finger. This is a fundamental principle of learning, known as ‘shared attention’.

Chun (2023, p.112) posits that pointing is a deictic mechanism that directs the visual attention of our audience to what is important or relevant. Hill and Hollan (1991) contend that effective data visualizations also incorporate a graphical form of deixis. The visualization counterparts of linguistic deixis are explanatory text and labels, as well as arrows, brackets, and pointers that are overlaid on top of an image.

Acartürk, Habel, and Cagiltay (2008, p. 342) observed that subjects of an eye tracking experience encountered challenges in identifying the pertinent portion of the graph in the absence of the annotation symbol in the curved graphs while testing this human feature in data visualizations. This notion is corroborated by the analysis of mean fixation durations, which demonstrates that the absence of the annotation icon in the curved graphs leads to longer fixations on the salient regions of the graph. Additionally, the experience results indicate that the addition of annotation texts to the graphs does not manifest significant changes in the distribution of the average number of fixations and gaze time in comparison to the distributions on the non-annotated graphs.

Conversely, the annotation text results in an increase in mean fixation counts and gaze time values. The subjects' endeavor to integrate the information provided by the graphical elements and the annotation text is indicated by the increase in fixation counts and gaze time values on the graph line (Acartürk&Habel&Cagiltay, 2008, p.341).

" This data visualization employs visual elements that emphasize essential information and direct users' focus towards it" is the assessment sentence to be used for evaluating this recommendation.

16.	When precise data comprehension is essential for interpreting provided information, such as in comparisons of different quantities, data visualizations must include labels for all visual elements that represent exact amounts. Visual information designers must position labels in proximity to all pertinent visual information assets.

Data visualizations must include labels for all visual elements that represent exact amounts when precise data comprehension is necessary for interpreting provided information, such as in comparisons of distinct quantities. Kosslyn (2006, p.13108) elucidates that the viewer will interpret any alteration in the appearance of a data visualization (such as the addition or removal of lines, or the alteration of color or texture) as a means of conveying information. In the same vein, the viewer will anticipate that any information that should be conveyed in a data visualization will be indicated by a visible change in the display. For instance, it is crucial to clearly delineate the point at which a scale has been truncated, to indicate the transition from current to projected data, and to label all significant components of a display. Additionally, if a data visualization designer wishes to provide the viewer with precise amounts, the segments should be labeled directly. A scale is permissible if the designer's objective is to provide the viewer with an impression of the actual quantities of each segment, rather than to indicate the precise value (Kosslyn, 2006, p.44).

The evaluating sentence for this recommendation will be as follows: “All components of this data visualization that denote specific data essential for comprehending the information are labeled.”

The final category of the Perceptual-Cognitive Data Visualization Framework, which pertains to the distribution of data visualizations on Instagram, can now be examined after all the recommendations regarding the information design aspects of a data visualization have been presented and substantiated.

17.	Visual assets shared on Instagram must adhere to designated dimensions. Visual information designers should produce data representations that adhere to Instagram's predefined dimensions, leveraging among the different types of media supported by the platform.

Visual information designers should produce data representations that comply with the specified dimensions of all visual assets shared on Instagram, while also utilizing the various media types supported by the platform. Cara (2018, p. 334) posits that the digital content has reached a state of ubiquity as a result of the combination of the portability of smartphones and the functionalities of Instagram. This content has acquired distinctive characteristics in terms of production, ease of manipulation, and its relevant role in the edition, dissemination, consumption, and storage of information.

Shahin (2021, p.7) examines the work of Mona Chalabi's Instagram Infographics in order to illustrate the leverage that can be obtained from the various types of media supported by Instagram. In one post, Chalabi compares the percentage of American police officers who received a conviction for killing someone, a charge but no conviction, or no charges at all. The first two percentages are immediately visible at 0.3% and 1.0%, respectively. However, the viewer must swipe through the post's images nine times to reach the end of the visualization. There, the viewer is ultimately able to observe that 98.7% of the killings committed by police officers did not result in any charges. As the author asserts, the post's impact is “sobering”.

On the other hand, if a designer is required to break the data visualizations into continuous images due to the requirement that all visual assets shared on Instagram adhere to specific dimensions, they must do so in a manner that aligns with Kosslyn's (2006, p.68) recommendation that the separation of complex data into multiple panels not only reduces the load on short-term memory but also simplifies the depicted patterns. The resulting pattern may not be recognizable, and as a result, it will not be able to convey meaning at a glance if the data visualization is overly intricate. Many of the resulting patterns can be interpreted without the need to record the precise values of individual elements when a complex data visualization is divided into a series of simpler ones.

The assessment sentence for this recommendation will be as follows: "The data visualized is clear to the viewers and makes the most of the different types of media supported by Instagram"

18.	On Instagram, the textual component of a post may be partially concealed or entirely imperceptible to viewers while scrolling through the feed. Consequently, pertinent information essential for comprehending a data visualization should be incorporated inside the visualization itself rather than included in the accompanying text. Visual information designers ought to utilize the written content of posts solely to convey supplementary contextual information.

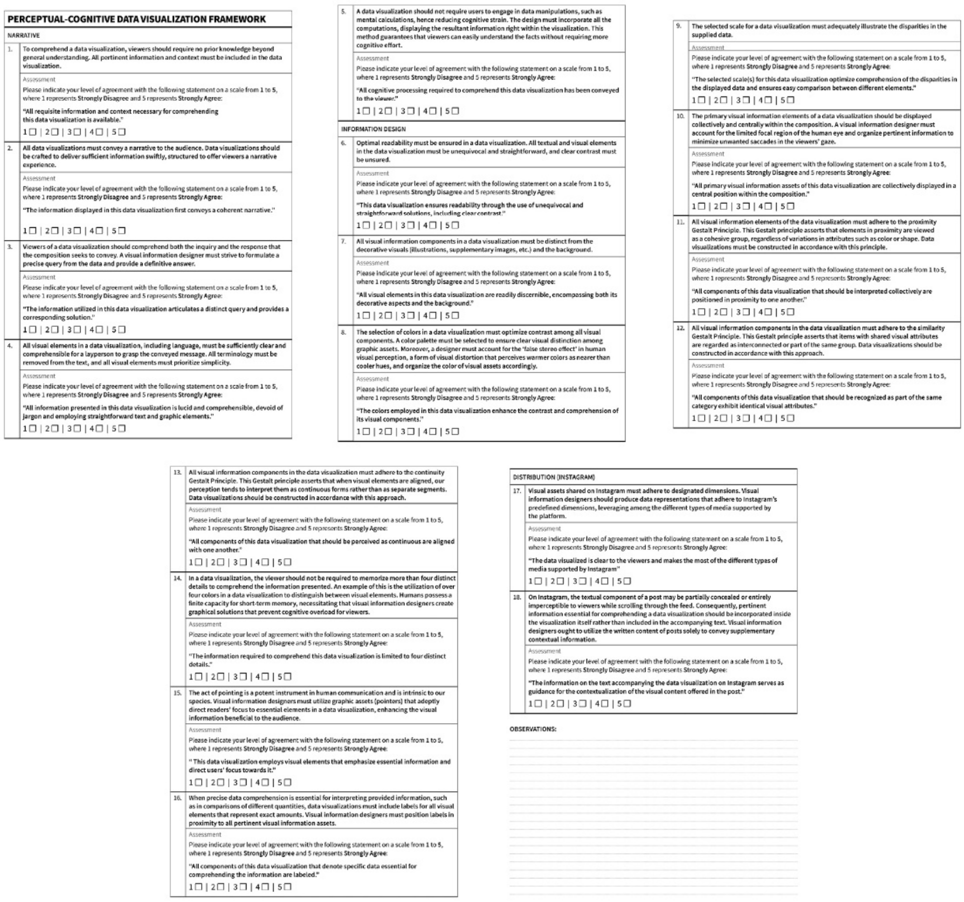
While scrolling through the Instagram feed, the textual component of a post may be partially concealed or entirely imperceptible to viewers. As a result, the critical information required to understand a data visualization should be integrated into the visualization itself, rather than in the accompanying text. Kosslyn (2006, p.74) suggests that data visualizations should include a caption to elucidate specific features and unfamiliar terms. A caption is a descriptive note that accompanies the visual representation of information. Consequently, it is imperative for a designer to guarantee that the reader is familiar with the terms required to comprehend the visualization. In certain instances, labels may need to be elucidated in a caption. In the event that the display is intricate, it is imperative that the designer explicitly specify the most significant patterns in the caption. Zhao and Gaschler (2022, p.10) contend that the viewers' attempt to understand the data by employing keys or labels is significant.

Given that the textual component of a post may be partially concealed or entirely imperceptible to viewers, it is crucial to include germane information necessary for understanding a data visualization within the visualization itself, rather than in the accompanying text.

The assessment sentence shall be as follows in order to evaluate the degree of compliance of a data visualization with this recommendation: " The information on the text accompanying the data visualization on Instagram serves as guidance for the contextualization of the visual content offered in the post."

Having observed all the recommendations for the Perceptual-Cognitive Data Visualization Framework, the arguments for each one of these as well as the corresponding assessment sentences, we can now present a workable layout for the framework. On this layout, both data visualization designers and assessors should be able to confirm that a visual information representation is in agreement with key facts about humans' visual perception and cognition.

Regarding the framework's assessment functionality, assessors should utilize the provided Linkert scale-based evaluative statement. This statement can be answered using a standard five-point scale that goes from "Strongly Disagree" to "Strongly Agree," including "Disagree," "Neither Agree nor Disagree," and "Agree." All statements will be preceded by the sentence “Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents Strongly Disagree and 5 represents Strongly Agree”.



PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

NARRATIVE

1. **To comprehend a data visualization, viewers should require no prior knowledge beyond general understanding. All pertinent information and context must be included in the data visualization.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All requisite information and context necessary for comprehending this data visualization is available."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

2. **All data visualizations must convey a narrative to the audience. Data visualizations should be crafted to deliver sufficient information swiftly, structured to offer viewers a narrative experience.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information displayed in this data visualization first conveys a coherent narrative."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

3. **Viewers of a data visualization should comprehend both the inquiry and the response that the composition seeks to convey. A visual information designer must strive to formulate a precise query from the data and provide a definitive answer.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information utilized in this data visualization articulates a distinct query and provides a corresponding solution."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

4. **All visual elements in a data visualization, including language, must be sufficiently clear and comprehensible for a layperson to grasp the conveyed message. All terminology must be removed from the text, and all visual elements must prioritize simplicity.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All information presented in this data visualization is lucid and comprehensible, devoid of jargon and employing straightforward text and graphic elements."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

5. **A data visualization should not require users to engage in data manipulations, such as mental calculations, hence reducing cognitive strain. The design must incorporate all the computations, displaying the resultant information right within the visualization. This method guarantees that viewers can easily understand the facts without requiring more cognitive effort.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All cognitive processing required to comprehend this data visualization has been conveyed to the viewer."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

INFORMATION DESIGN

6. **Optimal readability must be ensured in a data visualization. All textual and visual elements in the data visualization must be unequivocal and straightforward, and clear contrast must be unsured.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"This data visualization ensures readability through the use of unequivocal and straightforward solutions, including clear contrast."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

7. **All visual information components in a data visualization must be distinct from the decorative visuals (illustrations, supplementary images, etc.) and the background.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All visual elements in this data visualization are readily discernible, encompassing both its decorative aspects and the background."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

8. **The selection of colors in a data visualization must optimize contrast among all visual components. A color palette must be selected to ensure clear visual distinction among graphic assets. Moreover, a designer must account for the 'false stereo effect' in human visual perception, a form of visual distortion that perceives warmer colors as nearer than cooler hues, and organize the color of visual assets accordingly.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The colors employed in this data visualization enhance the contrast and comprehension of its visual components."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

9. **The selected scale for a data visualization must adequately illustrate the disparities in the supplied data.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The selected scale(s) for this data visualization optimize comprehension of the disparities in the displayed data and ensures easy comparison between different elements."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

10. **The primary visual information elements of a data visualization should be displayed collectively and centrally within the composition. A visual information designer must account for the limited focal region of the human eye and organize pertinent information to minimize unwanted saccades in the viewers' gaze.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All primary visual information assets of this data visualization are collectively displayed in a central position within the composition."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

11. **All visual information elements of the data visualization must adhere to the proximity Gestalt Principle. This Gestalt principle asserts that elements in proximity are viewed as a cohesive group, regardless of variations in attributes such as color or shape. Data visualizations must be constructed in accordance with this principle.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that should be interpreted collectively are positioned in proximity to one another."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

12. **All visual information components in the data visualization must adhere to the similarity Gestalt Principle. This Gestalt principle asserts that items with shared visual attributes are regarded as interconnected or part of the same group. Data visualizations should be constructed in accordance with this approach.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that should be recognized as part of the same category exhibit identical visual attributes."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

13. **All visual information components in the data visualization must adhere to the continuity Gestalt Principle. This Gestalt principle asserts that when visual elements are aligned, our perception tends to interpret them as continuous forms rather than as separate segments. Data visualizations should be constructed in accordance with this approach.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that should be perceived as continuous are aligned with one another."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

14. **In a data visualization, the viewer should not be required to memorize more than four distinct details to comprehend the information presented. An example of this is the utilization of over four colors in a data visualization to distinguish between visual elements. Humans possess a finite capacity for short-term memory, necessitating that visual information designers create graphical solutions that prevent cognitive overload for viewers.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information required to comprehend this data visualization is limited to four distinct details."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

15. **The act of pointing is a potent instrument in human communication and is intrinsic to our species. Visual information designers must utilize graphic assets (pointers) that adeptly direct readers' focus to essential elements in a data visualization, enhancing the visual information beneficial to the audience.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

" This data visualization employs visual elements that emphasize essential information and direct users' focus towards it."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

16. **When precise data comprehension is essential for interpreting provided information, such as in comparisons of different quantities, data visualizations must include labels for all visual elements that represent exact amounts. Visual information designers must position labels in proximity to all pertinent visual information assets.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that denote specific data essential for comprehending the information are labeled."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

DISTRIBUTION (INSTAGRAM)

17. **Visual assets shared on Instagram must adhere to designated dimensions. Visual information designers should produce data representations that adhere to Instagram's predefined dimensions, leveraging among the different types of media supported by the platform.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The data visualized is clear to the viewers and makes the most of the different types of media supported by Instagram"

1☐ | 2☐ | 3☐ | 4☐ | 5☐

18. **On Instagram, the textual component of a post may be partially concealed or entirely imperceptible to viewers while scrolling through the feed. Consequently, pertinent information essential for comprehending a data visualization should be incorporated inside the visualization itself rather than included in the accompanying text. Visual information designers ought to utilize the written content of posts solely to convey supplementary contextual information.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information on the text accompanying the data visualization on Instagram serves as guidance for the contextualization of the visual content offered in the post."

1☐ | 2☐ | 3☐ | 4☐ | 5☐

OBSERVATIONS:

Figure 4 - Perceptual-Cognitive Data Visualization Framework

4. Framework for data visualization

The Perceptual-Cognitive Data Visualization Framework is presented as a PDF file to both the visual information designer and data visualization evaluator. Designers should use the framework accompanying their work as a data visualization is being designed. Therefore, we cannot have a precise estimate of the time needed to use this functionality of the framework, since its usage is based on complementing the designers' work.

For the evaluators of data visualization, we estimate that the usage of the assessment functionality should not take more than fifteen minutes. Evaluators should use the Linkert scale-based evaluative sentences for assessments using the framework. These statements can be responded on a five-point scale from 'Strongly Disagree' to 'Strongly Agree', including 'Disagree', 'Neither Agree nor Disagree' and 'Agree'. All statements will be preceded by the sentence 'Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents Strongly Disagree and 5 represents Strongly Agree' and the evaluator should advocate for graphical solution revision whenever the assessment sentence is 1, with less emphasis when it is 2. Assessments with an agreement level of 3 may need to be changed or ignored if the sentence is not relevant to the data visualization being evaluated, while those with levels of 5 should not need any changes, and those with levels of 4 may need minor changes or not require further modifications.

4.1. Choosing the sample space

For this work, we have chosen the data visualizations shared by Eurostat on its' official Instagram channel[1] because, as previously discussed on this work, this social network is one of the most used media to inform a large set of Europeans. Accordingly, Eurostat is European's Union official data and statistics office. Accessing the Eurostats' Instagram channel, we can observe that it has 175 thousand followers (as of late May) and most of the publications on the channel are data visualizations about important data from Eurostat. Most of the time, these data visualizations have a link to a news article on Eurostats' website, but that's not the case for every publication.

For choosing what data visualizations we should apply to our framework, we first looked at one year of data visualizations published by Eurostat on its' Instagram channel. We have ignored all publications that were not data visualizations, like publications about events, services, etc.

[1] https://www.instagram.com/eu_eurostat/

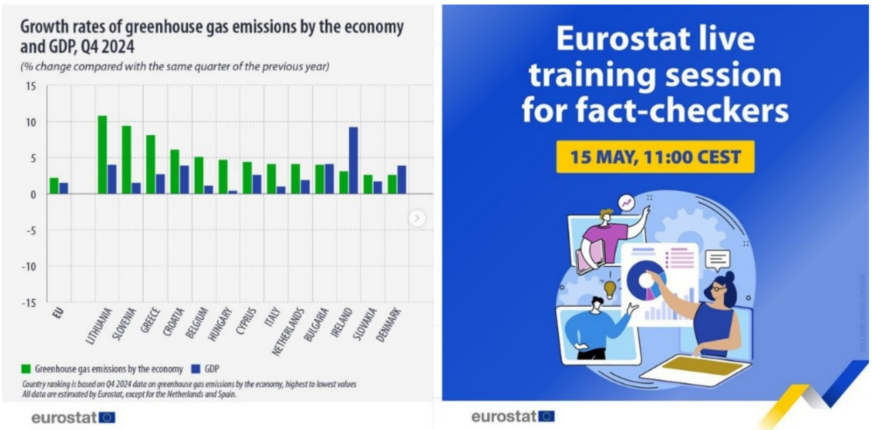


Figure 5 – Example of data visualization and of disregarded post (Eurostat, 2025)

Our data collection was made on the 21st of May 2025, analyzing the publications made going back to 21st of May 2024. During this time frame, the data visualizations published on the Eurostats' official Instagram channel were as follows:

Type of data visualization	Number of publications	% of type of data visualization
Static		
Bar charts	230	46,5
Maps	110	22,2
Pictographs	62	12,5
Line charts	41	8,3
Pie charts	22	4,4
Divided bar charts	13	2,6
Animated		
Animated data visualizations	17	3,4
TOTAL	**478**	**100**

Table 2 - Data visualizations published on the Eurostats' official Instagram channel, from 21st of May 2024 to 21st of May 2025

For each type of data visualization, we have chosen to use the nomenclature provided by Kosslyn on the previous literature reviewed, in order to maintain coherency across this work. We have chosen to distinguish between static data visualizations, in the sense that these types of visualizations don't present any kind of 'moving parts', and animated visualizations, in which some parts of the data visualization are animated. In the example chosen for this work, a horizontal bar chart has its bars animated, growing towards their final state as time elapses. Regarding the animated data visualizations, we have found that the only important feature to distinguish these kinds of visualizations from the static ones is the animation itself and the looping characteristics of the animation. Regarding all other features, the assessment of these visualizations is equal to that of static data visualizations.

As we can see, almost five hundred data visualizations were published during the year we investigated, with bar charts being the most used format and stacked bar charts being the last used type of data visualization. Seventeen publications were made using some type of animated visual assets.

To test our proposed framework, we have chosen the most recent example for each of the above-mentioned data visualization types, since all publications made during the researched timeframe were considered equally important and, therefore, a choice based solely on the data of publication was regarded as sufficient for this work. For the ‘bar charts’ type, we have chosen two examples, since we have found some bar charts that were presented as a slideshow and, therefore, we needed to analyze this type of publication apart from the analyses of a typical bar chart. Other data visualizations were found using this slideshow solution (probably because of the maximum media size allowed by Instagram for publication), but for our purpose of applying the proposed framework, we decided that a single example of data visualizations presented has a slideshow would suffice. For the ‘maps’ type, we have chosen three examples, since we were faced with three different type of map usage as a basis for data visualizations: maps with data represented by colors and hues for each country, with and without data labels per country, and maps with data represented by visual signs (mostly by circles placed above each country with dimension variations used to represent the data). For the remaining types of data visualization, we have chosen just an example for each.

We have chosen to add the posts’ description or legend because important data is shared on those descriptions, and it is our understanding that those elements should be analyzed with corresponding data visualizations, as recommended on the Perceptual-Cognitive Data Visualization Framework.

4.2. Applying the framework

We will begin by evaluating instances of data visualization distributed by Eurostat on its Instagram channel, focusing on two examples of their predominant form of data representation, the bar chart.

4.2.1. Unaccompanied minors in the EU, February 2025

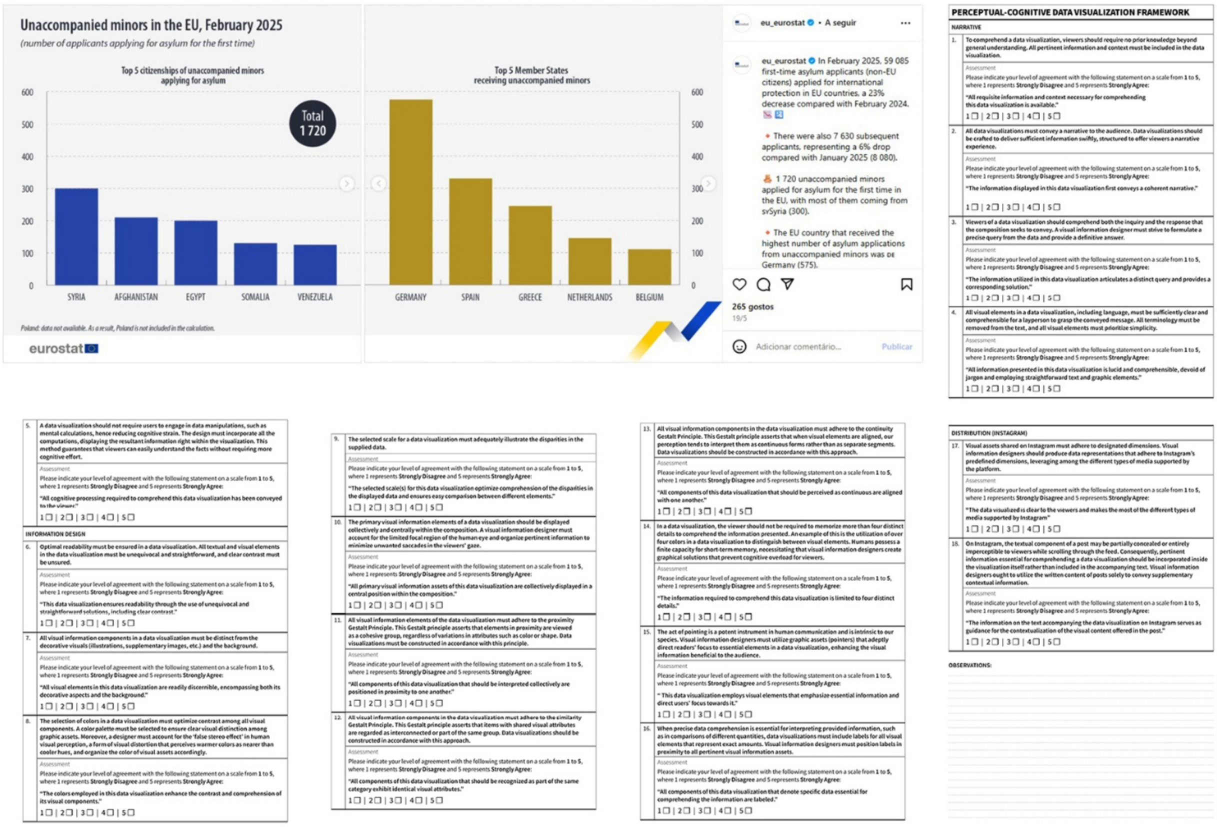


Figure 6 - Unaccompanied minors in the EU, February 2025 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization

We commence the application of the framework to a bar chart depicted in two distinct images, utilizing the slideshow feature offered by Instagram. The assessment of this data visualization yielded two evaluations indicating 'Agree' on the scale, necessitating minimal tweaks or no further alterations, and one evaluation indicating 'Disagree', hence needing revisions to the graphical solutions. Concerning the 'Agree' assessments, we identified flaws in the data visualization according to observations 5 and 9 of the framework. The rationale for both assessments is same and pertains to the challenge, without the use of labels (see to below), in comparing the values of minors seeking asylum from Somalia and Venezuela. The absence of labels led to a 'Disagree' assessment for compliance with observation 16, and we advocate for the incorporation of labels to ensure accurate data interpretation, particularly between Somalia and Venezuela, as previously mentioned.

For the following assessments, the framework usage can be found in Appendix I.

4.2.2. Intentional homicide in the EU, 2013-2023

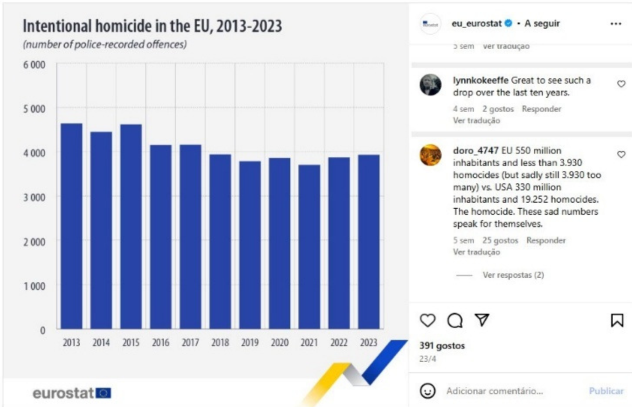


Figure 7 – Intentional homicide in the EU, 2013-2023 (Eurostat, 2025)

In the data visualization *Intentional homicide in the EU, 2013-2023* released by Eurostat on Instagram, we have identified three faults. Concerning observation 9 and the selection of a scale that effectively represents disparities in the data, we determined that the data visualization employed a scale that might be marginally modified to enhance the depiction of differences between annual values. Consequently, we assessed that observation with a 'Agree' on the framework's scale and recommend adjusting the scale to 5000 to enhance understanding of the distinctions between 2020 and 2022, for instance. The data visualization lacked pointers, resulting in our assessment of observation 15 as ‘Strongly Disagree’, necessitating a redesign of the graphical solutions. An indication may be noted regarding the rise of intentional homicides in 2022 and 2023, albeit in lesser quantities than in 2017 and prior years. Lastly, concerning the application of labels as suggested in observation 16 of the framework, we determined that understanding the data displayed in the visualization did not require precise comprehension. However, in evaluating adherence to this observation, we rated it as 'Agree' since the inclusion of labels would enhance the detail of the presented data without disrupting the overall presentation.

4.2.3. Share of electric passenger cars, by NUTS 2 regions, 2023

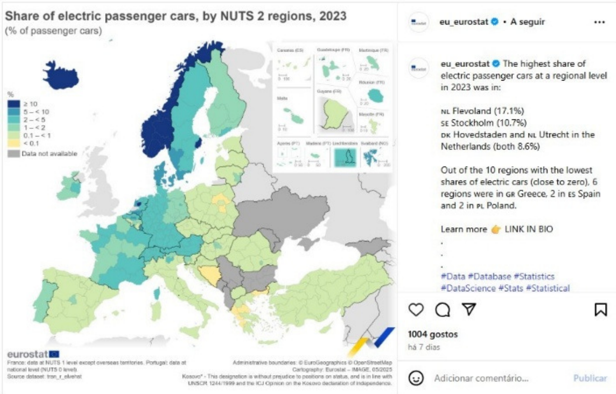


Figure 8 – Share of electric passenger cars, by NUTS 2 regions, 2023 (Eurostat, 2025)

The evaluation of the *Share of electric passenger cars, by NUTS 2 regions, 2023* data visualization yielded five findings necessitating a revision of the graphical solutions, in accordance with the established usage guidelines previously communicated in this project. Concerning the application of clear and intelligible visual components, including language, we have determined that the term 'NUTS 2 regions' in the title contravenes observation 1 and 4 of the framework, resulting in a compliance evaluation of 'Disagree'. Many individuals are unfamiliar with the term 'NUTS 2 regions' in Europe, which leads to the use of jargon in the title. We advocate revising the document by either incorporating a legend to elucidate the term 'NUTS 2 areas' or excluding it from the title and utilizing it in another context. Concerning recommendation 5, which emphasizes the necessity of preventing viewers from engaging in mental calculations and other tasks that may induce cognitive strain, we have determined that the use of colors for the key, absent labels in the data visualization, compels viewers to frequently reference the key to comprehend the presented data fully (the assessment was 'Disagree').

This evaluation also pertains to the assessment of observation 14, as viewers must memorize seven distinct colors and values utilized in the key, significantly surpassing the recommended maximum of four distinct details necessary for comprehending the data visualization. For this assessment, we have selected the 'Strongly Disagree' category on the scale. Ultimately, both assessments pertain to the evaluation of observation 16 of the framework, wherein we 'Strongly Disagree' regarding the data visualization's adherence to the recommendation of utilizing labels when precise data comprehension is crucial for interpreting the presented information. We recommend revising to include labels on the map, even if only the median values of all the NUTS 2 region per country, and limiting the key elements to four, in addition to the element for 'data not available'. Finally, concerning observation 15 of the framework, which pertains to the utilization of pointers to direct the reader's attention, we have evaluated the compliance of the data visualization with that recommendation as 'Disagree' and suggest the incorporation of a pointer that emphasizes the increased usage of electric passenger cars in Central and Northern Europe.

4.2.4. Listening to or downloading music online, 2024

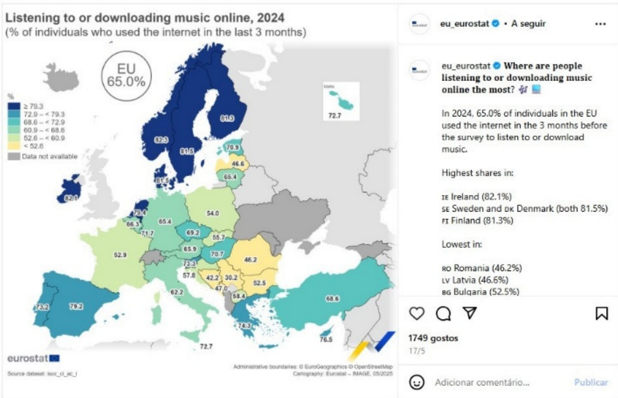


Figure 9 - Listening to or downloading music online, 2024 (Eurostat, 2025)

The evaluation of the *Listening to or downloading music online, 2024* data visualization identified only two aspects requiring attention. Initially, similar to the previous case examined, concerning observation 14, it is evident that viewers are required to recall seven various colors and values employed in the key, considerably exceeding the advisable maximum of four separate elements essential for understanding the data visualization. For this evaluation, we have chosen the 'Strongly Disagree' category on the scale. Concerning observation 15, we again note the absence of pointer usage in the data presentation, which highlights critical information. We have evaluated this factor and assigned it a 'Disagree' on the given scale. Concerning point 14, as this data visualization employs labels with specific information for each country, we recommend use only four distinct colors, in addition to a fifth key for 'Data not available.' On accordance with observation 15, we may offer a reference for the peak of online music consumption on the Iberian Peninsula, for instance.

4.2.5. Countries of control of multinational enterprises groups, 2023

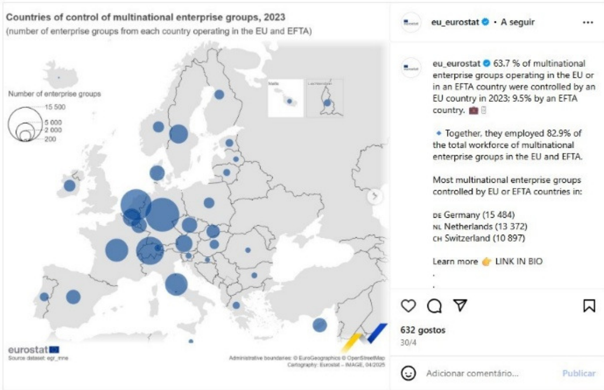


Figure 10 - Countries of control of multinational enterprises groups, 2023 (Eurostat, 2025)

The application of the framework to the *Countries of control of multinational enterprises groups, 2023* data visualization yielded five recommendations concerning compliance with the observations. Concerning observation 5, this data presentation necessitates extensive mental computations for users to compare data across countries, leading to a 'Strongly Disagree' assessment from us. The distinction between multinational firm groups controlled by Portugal and Finland is nearly indiscernible. To address this issue, we recommend either include labels with exact values for the countries (as detailed below) or employing an alternative graphical solution. Concerning recommendation 9, pertaining to the selection of a scale that enhances the understanding of inequalities in the supplied data, we have determined that the proposed solution elicited a 'Disagree' assessment from us. The initial part of the key, denoting 200 multinational enterprise groups, is insufficiently comprehensive, making it challenging to discern the distinctions between 2000 and 5000 multinational enterprise groups. We recommend addressing this issue by using a scale that accentuates the area variations between circles. Observation 12, pertaining to the Gestalt Principle of likeness, yielded an evaluation of 'Agree'. As previously mentioned, evaluations rated at level 4 may require slight modifications. To enhance adherence to the likeness principle of Gestalt theory, we recommend utilizing a blue hue for the key, thereby reinforcing the similarity with the circles that reflect the data. This data visualization, like previously, does not utilize pointers, resulting in the assessment for observation 15 being classified as 'Disagree'. A pointer could be utilized to highlight the significant influence of multinational corporate groups in Germany and the Netherlands. In conclusion, the absence of labels in this data visualization hinders accurate understanding, leading us to assign a rating of 'Strongly Disagree' regarding compliance with this observation. We urge the inclusion of labels with specific values for each country.

4.2.6. Main extra-EU import partners of honey, 2024

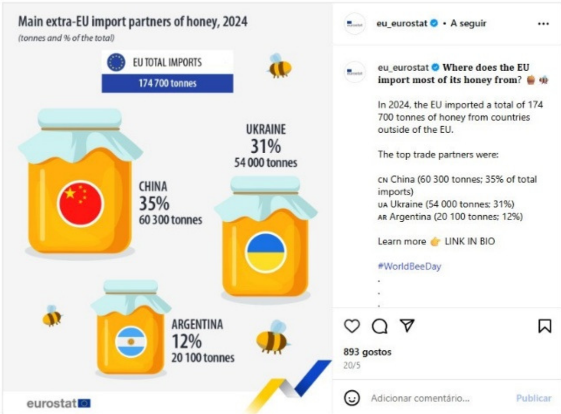


Figure 11 - Main extra-EU import partners of honey, 2024 (Eurostat, 2025)

The evaluation of the *Main extra-EU import partners of honey, 2024* data visualization revealed no concerns pertaining to any of the framework's recommendations. All observations were assessed as 'Strongly Agree'. We understand that the simplicity of this data presentation ensured the implementation of all recommendations from our framework in this task.

4.2.7. EU trade in goods with the United Kingdom, 2014-2024

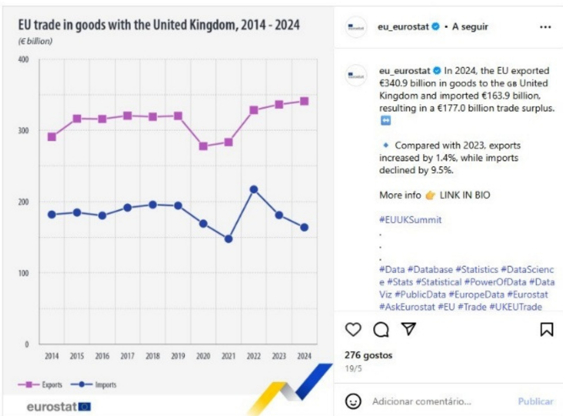


Figure 12 - EU trade in goods with the United Kingdom, 2014-2024 (Eurostat, 2025)

Utilizing the framework on the line chart data visualization shared by Eurostat on Instagram *EU trade in goods with the United Kingdom, 2014-2024* yielded two recommendations rated as 'Strongly Disagree' and one rated as 'Agree', indicating the necessity to revise the graphical solutions for two elements of the data visualization and to implement minor adjustments on one element. The initial observation that resulted in a 'Strongly Disagree' assessment was recommendation 5, concerning the lack of mental computations for comprehending the supplied facts. This example illustrates that comprehending the disparity between exports and imports, as well as their year-on-year comparisons, might pose a difficulty for viewers, necessitating extensive mental computations and memorization, hence heightening the potential for cognitive strain on the audience. We advocate revising this issue by visualizing the data using dual bars (one representing exports and the other imports) for each year. Observing the disparities between imports and exports over the years in this manner would facilitate comprehension for the viewers.

Concerning the utilization of pointers, similar to the majority of the data visualizations analyzed under the proposed framework, we rated observation 15 with a 'Strongly Disagree' due to the absence of pointers. To modify this facet of the data visualization, a pointer might be created indicating the year when the disparity between exports and imports was the most pronounced. Finally, concerning observation 16 and the application of labels, we have determined that precise values were unnecessary for data understanding. Moreover, the inclusion of labels would increase the necessity for viewers to engage in mental calculations, as previously stated. However, upon assessing the data visualization within the framework, due to the lack of labels, we rated this recommendation as 'Agree,' indicating that some consideration should be given to this matter and that an evaluation should be conducted regarding the necessity for minor adjustments or the decision to implement no further modifications.

4.2.8. Main exporters of alcoholic beverages to countries outside the EU, 2024

Figure 13 - Main exporters of alcoholic beverages to countries outside the EU, 2024 (Eurostat, 2025)

The review of Eurostats' *Main exporters of alcoholic beverages to countries outside the EU, 2024* data visualization utilizing a pie/donut chart yielded just two 'Agree' assessments, indicating that only minimal alterations were necessary or that no additional modifications were required, in accordance with the usage guidelines of the proposed framework. The initial 'Agree' assessment pertained to observation 10, which asserts that the key visual information components of a data visualization must be presented together and centrally within the composition. We have observed that certain labels are somewhat distant from the pie chart segments. We recommend repositioning the labels for France, Italy, and Other EU Countries closer to the chart, or alternatively, resizing the chart proportionally to the right and upwards to enhance the proximity of the labels to the segments. The second evaluation, marked with a 'Agree' on the specified scale, pertained to the redundancy of information between the data visualization and the supporting text in the Instagram post, indicating some concerns regarding adherence to guideline 18 of the framework. A potential resolution for this issue may involve omitting the information from the text.

4.2.9. Unemployment rates, March 2025

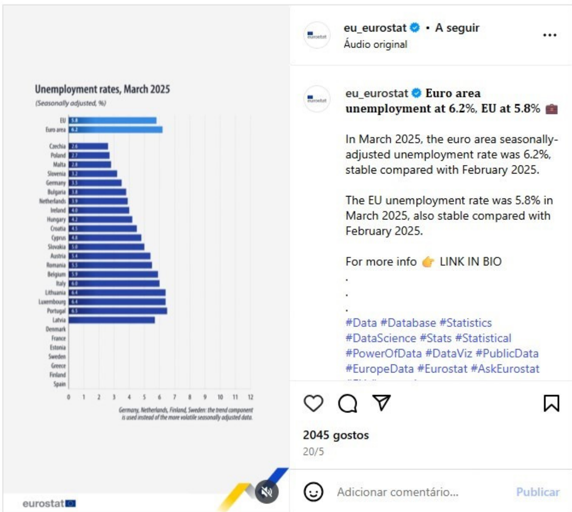


Figure 14 - Unemployment rates, March 2025 (Eurostat, 2025)

Concerning an animated data visualization *Unemployment rates, March 2025* published on Instagram by Eurostat, we have assessed only three of the framework suggestions with a rating below 'Strongly Agree.' In observation 6, concerning optimal readability, we saw that the label sizes were diminutive, hence we rated it as 'Agree' on the supplied scale. We propose utilizing a higher letter size or selecting a bold variant within the typeface family to address this issue. Concerning the utilization of pointers, as advised in observation 15 of the framework, we have selected 'Neither Agree nor Disagree' because the type of animation employed in this data visualization may render such an observation inapplicable, as indicated in the framework's usage guidelines. Finally, concerning observation 17 of the framework, which recommends that data representations conform to Instagram's specified dimensions and utilize various media types supported by the platform, we have opted to assess the animated data visualization with an ‘Agree.' This decision underscores the importance of considering the format of a looping video animation in contrast to a static chart. This choice is based on the characteristics of a looping video and the duration available for a spectator to observe the chart in its entirety before the animation restarts.

4.2.10. Enterprise characteristics for 14 countries in 2022

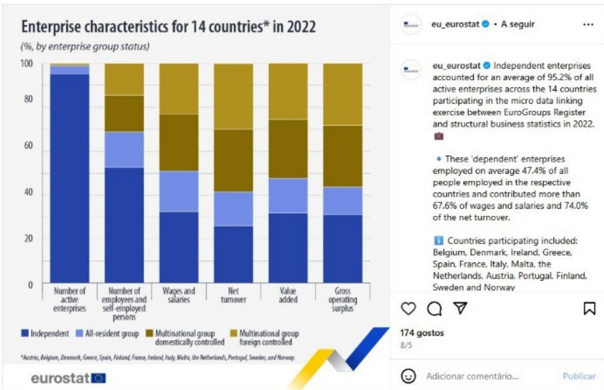


Figure 15 - Enterprise characteristics for 14 countries in 2022 (Eurostat, 2025)

In our final assessment of Eurostats' data visualizations for Instagram, *Enterprise characteristics for 14 countries in 2022*, we identified four flaws concerning the guidelines outlined by our framework. Concerning the application of clear and comprehensible features, as indicated in observation 4 of the framework, we have assessed the data visualization with a 'Agree' on the supplied scale, as certain terminology used in the chart, such as 'Net turnover,' may be unknown to some viewers. This evaluation mirrors the issue present in the assessment for observation 18, which asserts that the language element of a post should provide assistance for contextualizing the accompanying visual content. In reference to observation 18, we selected 'Strongly Disagree' from the given scale and propose that an elucidation of some terms utilized in the data visualization be incorporated into the accompanying text, thereby addressing the concerns raised in both observation 18 and observation 4. In observation 9 of the framework, we used the 'Agree' evaluation to emphasize the importance of the scale option utilized for data display. Selecting a scale that effectively highlights the data disparities, particularly in the first bar, would be advantageous; however, such a scale may be impractical due to the necessity for the data visualization to adhere to Instagram's specified dimensions. Finally, observation 15 received a 'Strongly Disagree' assessment due to the consistent absence of pointers highlighting critical parts in the data visualization, as outlined in the framework. Upon revisiting this problem, one might highlight the gap between the number of multinational group firms and their contribution to wages and salaries among the 14 nations depicted in the data visualization.

4.3. Discussion

Based on the insights acquired from the implementation of the framework, we will discuss the results obtained by its application and suggest enhancements to the framework discussed in this work.

Upon evaluating the Perceptual-Cognitive Data Visualization Framework on ten distinct data visualizations disseminated via the official Instagram account, we found several revisions were needed, as per the framework usage. With twelve ‘Agree’ assessments to various recommendations, we have found that minor adjustments might be needed on some of the assessed data visualizations. Several full revisions were found to be needed, with nine ‘Strongly Disagree’ assessments. Eight assessments for ‘Disagree’ revealed the need for revision, without the emphasis needed for the previously mentioned nine full revisions. Lastly, we have found one instance where a recommendation was not applicable to the data visualization being assessed.

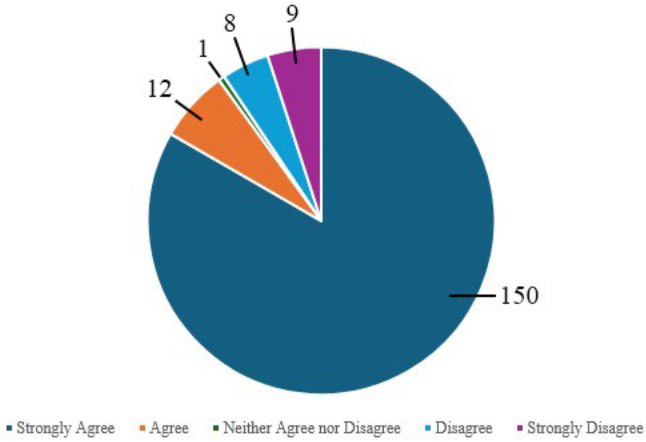


Figure 16 – Usage of Likert scale on previous assessments

Regarding the recommendations that had the most need for some kind of revision, recommendation 15, about using pointers on data visualizations, was assessed seven times. Recommendations 5 (need for mental calculations), 9 (selection of scale), and 16 (use of labels) had four assessments that provided guidance for some kind of revision. All data visualizations being assessed found no need for revision concerning recommendations 2 (conveying a narrative), 3 (clear question and answer), 7 (information elements distinct from decorative visuals and the background), 8 (color choice), 11 (Gestalt Principle of proximity) and 13 (Gestalt Principle of continuity).

Applying the Perceptual-Cognitive Data Visualization Framework allowed us to determine that employing the framework for assessment was predominantly straightforward. We have encountered minimal challenges in utilizing the framework as an assessment instrument, with limited ambiguities between the framework and the evaluated data visualizations. In the majority of instances, the evaluation and formulation of recommendations for the examination of certain graphical solutions required, on average, under 10 minutes.

Despite our development of the Perceptual-Cognitive Data Visualization Framework, its initial implementation, utilizing the framework in PDF format as previously demonstrated, necessitated a continued examination of the guidelines regarding the use of the Likert scale outlined earlier. We found ourselves needing to remember the distinct instructions for what to do when a sentence was assessed as ‘Agree’, or ‘Strongly Disagree’, for example. Consequently, in refining the framework, we have developed a cover that delineates the utilization guidelines to assist assessors in utilizing the framework more effectively.

As previously mentioned, employing the framework to assess Eurostat's data visualizations revealed minimal challenges due to ambiguity. However, we encountered some ambiguity while utilizing the framework as an evaluative instrument in certain instances, necessitating a review of the rationale for key assessment statements previously articulated in this study. Consequently, we included concise summaries of the justifications for each recommendation in the framework at the document's conclusion.

The improved iteration of the Perceptual-Cognitive Data Visualization Framework is as follows (the full framework is accessible in Appendix II):

PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

INSTRUCTIONS

When using this framework to **guide the design of a data visualization**, visual information designers should comply with the recommendations presented as closely as possible.

When using this framework to **evaluate existing data visualizations**, assessors should use the Linkert scale-based evaluative statement.

These statements can be responded on a five-point scale from "*Strongly Disagree*" to "*Strongly Agree*," including "*Disagree*," "*Neither Agree nor Disagree*," and "*Agree*."

All statements will be preceded by the sentence "*Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents Strongly Disagree and 5 represents Strongly Agree*"

Whenever the assessment sentence is **1**, the evaluator should advocate for graphical solution revision.

Whenever the assessment sentence is **2**, the evaluator should advocate for graphical solution revision, but with less emphasis.

Assessments with an agreement level of **3** may need to be changed or ignored if the sentence is not relevant to the data visualization being evaluated.

Whenever the assessment sentence is **4**, the evaluator may call for minor changes or not require further modifications.

Whenever the assessment sentence is **5**, the evaluator should not require any changes.

	RECOMMENDATIONS CONTEXT AND JUSTIFICATION
1.	Prior knowledge is crucial to material comprehension. Ensure readers have the background to understand. A good display adds new information while remaining relevant. Assuming readers know everything may lead the visual information designer to employ unfamiliar concepts, facts, or standards, making communication confusing. If viewers know little, designers will stress self-evident items. We do not search randomly when seeking supplementary information; instead, we infer visual perception from conserved information to guide encoding. One actively seeks hypothesis-related facts. The primary limitation in long-term memory is an individual's knowledge. Semantic and pragmatic interpretation of a display depends on sensory-related stored knowledge. Those unfamiliar with a term definition or a display framework line arrangement will have problems matching the display to the data.
2.	Data visualizations should include a narrative. Visual displays resemble narratives more than mere representations of objects; while they have identifiable components, it is the relationships among these components that communicate the specific information.
3.	Visual information designers must formulate a precise query and derive an answer from the data. A graph is designed to illustrate a particular argument, and its visual presentation should effectively communicate that argument. Numerous psychological ideas are contingent upon circumstances. It is essential to ascertain the inquiries viewers wish to pose regarding the visualization and the facts required to address them. Effective communication of information occurs alone when it directs the readers' attention and interest towards a certain message.
4.	For a layperson to comprehend the meaning of a data visualization, it is imperative that all visual components, including language, are clear and easily understandable. For efficient communication, a data visualization must be instantly understood and easily remembered. A sentence displayed in a legible font, repeated, or emphasized will be processed with cognitive fluidity and efficiency. Cognitive strain results from the utilization of inferior typefaces, inadequate colors, or convoluted wording. Labels must precisely reflect their categories, and images should portray suitable items.
5.	Visual information designers must prioritize minimizing cognitive load for viewers when accessing information from a data visualization. This guarantees that users are not obligated to execute mental computations or undertake data manipulations. Individuals' hesitance to make an effort is psychological rather than moral, and they frequently evade it when uncertain of the rewards. Data visualization designers must recognize that when we "keep something in mind," we retain information in short-term memory. Rational thought is essential for comprehending a data visualization by drawing conclusions and recognizing implications. These cognitive functions utilize short-term memory. The constrained capacity of short-term memory restricts our understanding.
6.	Readability constitutes a critical component of data visualization. The neurons that detect changes in a specific spatial region inhibit the activity of neighboring neurons monitoring adjacent areas. If a visual element is insufficient in size or weight, the cells responsible for its detection are inhibited from responding. Detectability is influenced by multiple factors and their interactions, including the color of the figure and background, the contrast between light and dark elements, and the shape of the figure. Elements of a data visualization, such as lines and areas, must be sufficiently
6. (cont.)	pronounced, and each mark should be appropriately sized to ensure distinguishability. The visual system functions as a mechanism for detecting differences. A significant contrast will attract attention.
7.	All visual components in a data visualization necessitate careful study, as these features are essential for expressing information. Consequently, it is imperative to distinguish these elements from the background and ornamental visuals, including supplementary images and illustrations. Early retinal cells amplify the edges of visual stimuli, with the most prominent features being objects delineated by their contours. An successful data visualization must captivate viewers' attention and enhance navigation, allowing for the identification of essential information and the distinction of pertinent elements. The most visually prominent pieces of a visualization must communicate the most critical information.
8.	The selection of color is essential to information visual design. Color decisions for data visualization must enhance contrast among all visual elements. A designer must also account for the "false stereo effect" in human visual perception, which causes long-wavelength, warmer colors to seem "closer" than short-wavelength, cooler hues. The warmer line must overlap with the cooler line at the point of intersection in a data visualization. Should it fail, the rear line will appear to compete for advancement, looping around the one ahead, which is disconcerting. Consequently, data visualizations should employ cool background colors and warm foreground colors.
9.	The selection of data visualization scales requires meticulous examination to facilitate the visual comprehension of data disparities and enable comparisons. Exhibit solely the pertinent scale range to obtain a precise impression. Unless the zero value is pertinent, a designer should initiate the visible scale at a value marginally below the smallest data point and extend the upper value somewhat over the maximum.
10.	The composition must emphasize the primary visual attributes of a data visualization. The core visual field possesses significantly greater pixel density compared to the periphery. Only the fovea, encompassing 15 degrees of the visual field, is effective for reading. Rapid saccades shift our attention from one visual location to another. A visual information designer must systematically arrange pertinent information to minimize saccades in the viewer's gaze, given the human eye's restricted focal area.
11. 12. 13.	Gestalt theory posits that the brain perceives color and shape as cohesive aggregates rather than as separate entities. Human eyes and minds perceive visual patterns as three-dimensional objects whenever feasible. The mind instinctively presumes that shapes possess regular, closed contours, that things exhibit uniform coloration and markings, and that the environment comprises cohesive surfaces rather than dispersed particles or fragments. The Gestalt Principles of proximity, continuity, and similarity are essential for understanding information processing, directing the human visual system's organization of graphical elements into unified entities. These principles elucidate how people perceive and organize visual elements, with proximity signifying the inclination to cluster adjacent items. Similarity denotes the association of analogous things by observers. Continuity refers to the eye's ability to trace a line or curve, thereby organizing things along its trajectory.
14.	Humans possess constrained short-term memory; therefore, visual information designers must deliver graphical solutions that prevent cognitive overload. A data visualization should necessitate the memorization of no more than four details. To comprehend a key, viewers must remember the associations between names
14. (cont.)	and content. This necessitates exertion and may deplete their limited short-term memory ability. Maintaining a mental representation necessitates effort and can only retain a limited amount of information for a finite duration. This is significant as the majority of imagery reasoning issues require considerable time. Viewers possess a finite ability to retain and digest information; hence, they will fail to comprehend a message if it is excessively intricate. Given that information resides in short-term memory, visual information designers must consider its capacity constraints. Excessive knowledge retention limits task completion. Consequently, complexity influences the comprehensibility of data visualization.
15.	Social signals influence Homo Sapiens' attention and learning more than those of any other primate. Human learning depends on "shared attention" between the learner and the teacher. Pointing is a deictic mechanism that emphasizes significant elements. Data visualizations ought to employ graphical deictic mechanisms. These mechanisms are represented using explanatory text, labels, arrows, brackets, and pointers superimposed on a data visualization.
16.	For precise data analysis, particularly in quantity comparison, data visualizations must clearly label all visual features that denote exact values. Viewers will perceive any alteration in a data visualization's aesthetics (such as the addition or removal of lines, modification of color, or texture) as conveying information. A data visualization viewer anticipates a discernible alteration in the display to signify information. Labeling visual data representations is essential for data visualization designers to provide accurate figures. If the designer aims to convey a sense of amount rather than exact value, labeling is unnecessary.
17.	Visual information designers must utilize Instagram's approved media formats and adhere to the specified dimensions for any visual assets shared on the platform. If a designer must break data visualizations into continuous images to meet Instagram's dimensions, they must understand that dividing complex data into multiple panels reduces short-term memory load and simplifies patterns. However, if the data visualization is overly intricate, the pattern may remain obscured and fail to communicate information immediately. When a complex data visualization is deconstructed into simpler components, several patterns can be discerned without the necessity of recording element values.
18.	While browsing Instagram, the text of a post may be partially or entirely obscured. Consequently, essential information required for understanding a data visualization should be integrated within the picture rather than the accompanying text. Data visualizations must use captions to elucidate attributes and unfamiliar terminology. Captions elucidate visual information; therefore, a designer must guarantee that the reader comprehends the terminology of the visualization.

Figure 17 – New additions to the Perceptual-Cognitive Data Visualization Framework, after revision

This research has a number of limitations, which must be taken into consideration when assessing the usefulness and reliability of the Perceptual-Cognitive Data Visualization Framework.

The fact that the framework was constructed and tested by the author of this study is the key limitation that must be considered. It is impossible to deny the fact that the insights gained from our study influenced both our utilization of the assessment tool and our appraisal of its effectiveness, despite the fact that we made an effort to maintain our impartiality during the testing phase of the framework.

The author, who has previously emphasized the importance of designers conducting relevant research in the field, recognizes that his limited comprehension of the human brain's diverse functions, in comparison to that of a specialist, may have influenced the decisions made during the development of the Perceptual-Cognitive Data Visualization Framework.

A further limitation is that the objective of creating a user-friendly framework for designers and evaluators may have led us to omit significant aspects of human visual perception and cognition, hence diminishing the utility of the proposed framework compared to our original intentions. Conversely, because of the framework having 18 recommendations and 15 contextual reasons, it may thus be less effective than our intended objectives of ease of usage.

In the end, the author was unable to pursue further research methodologies, such as interviews with experienced visual information designers, which could have improved the understanding of the utility of the suggested framework. This was due to time restrictions.

These various limitations highlight the necessity for additional research and optimization of the Perceptual-Cognitive Data Visualization Framework. This makes it possible to ensure the development of a tool that is both effective and accessible, with the purpose of guiding the creation and evaluation of data visualizations that are in alignment with human visual perception and cognition.

5. Conclusion

The objective of this study was to establish a paradigm for the creation and assessment of data visualizations aligned with human visual perception and cognition. The graphical depiction of data has been a crucial instrument for comprehending pertinent and occasionally intricate information. Data visualization is a relatively new human innovation, as is contemporary research into the working of the human brain, including our perception of visual information, information parsing, reading and learning processes, and the transformation of information into knowledge. The relationship between data visualization and human cognition has been examined; nevertheless, our research indicates that the majority of studies have been conducted by psychologists or neuroscientists, with a notable deficiency of inquiry from designers.

From the inception of this project, we have maintained that an understanding of human cognitive processes should inform the creation of data visualizations that are more comprehensible to viewers. The literature review conducted for this work has confirmed our hypothesis. The human mind, particularly the visual system, is sophisticated and replete with significant details, functioning in a complex manner to gain knowledge.

Upon analyzing current frameworks that address the development of data visualization in conjunction with human cognitive understanding, we have determined that no framework exists that simultaneously directs the design of data visualizations in accordance with perceptual and cognitive principles of human brain functions, while also facilitating the evaluation of existing data visualizations based on the same criteria. This final functionality is particularly pertinent as data visualizations are frequently produced within organizations where the creation and revision of content are handled by distinct individuals, such as in newsrooms, for instance. Our objective was to develop a framework that remains as uncomplicated as possible, enabling its utilization by those without a comprehensive grasp of human brain activity.

After developing a framework grounded in comprehensive research of pertinent literature and existing models, we proceeded to evaluate it by applying the framework to analyze data visualizations created and disseminated on Instagram by the European Union statistical agency, Eurostat. We determined that the framework's application was straightforward and minimally time-consuming, and its implementation uncovered issues in the majority of the analyzed examples, with varying degrees of significance regarding the efficacy of the data visualizations, as indicated by the Likert scale utilized in the assessment tool within the framework. The framework was beneficial in addressing these issues due to its diverse and numerous recommendations, which simplified the examination of the tested situations and thereby rendered the problems more manageable.

Taking into consideration the limitations of this project, we suggest that future research should concentrate on evaluating the Perceptual-Cognitive Data Visualization Framework by professionals working in the industry. We propose that the testing of the framework be carried out with data visualizations that were developed for dissemination on platforms other than Instagram. The utilization of more complex data visualizations is another recommendation that we have for evaluating the effectiveness of the framework.

We argue that it would be beneficial to have neuroscientists participate in future research on the framework, as this would make it easier to make improvements that are relevant to the recommendations that are given in the framework that is already in possession.

The creation of an interactive version of the framework has the potential to reduce the amount of mental strain experienced by designers and evaluators who make use of it. The research carried out for this work reveals that this is a significant issue; yet the Perceptual-Cognitive Data Visualization Framework may be too extensive for practical use due to the fact that it contains 18 recommendations. An interactive iteration of the framework, on the other hand, could reduce the strain of such an excessive amount of labor, making it easier to incorporate further recommendations in the event that they are required.

Lastly, we argue that a better understanding of human cognitive processes ought to serve as a guiding principle for design practices in a broader sense, and we anticipate additional research that investigates the intersection between design practices and the comprehension of human brain function.

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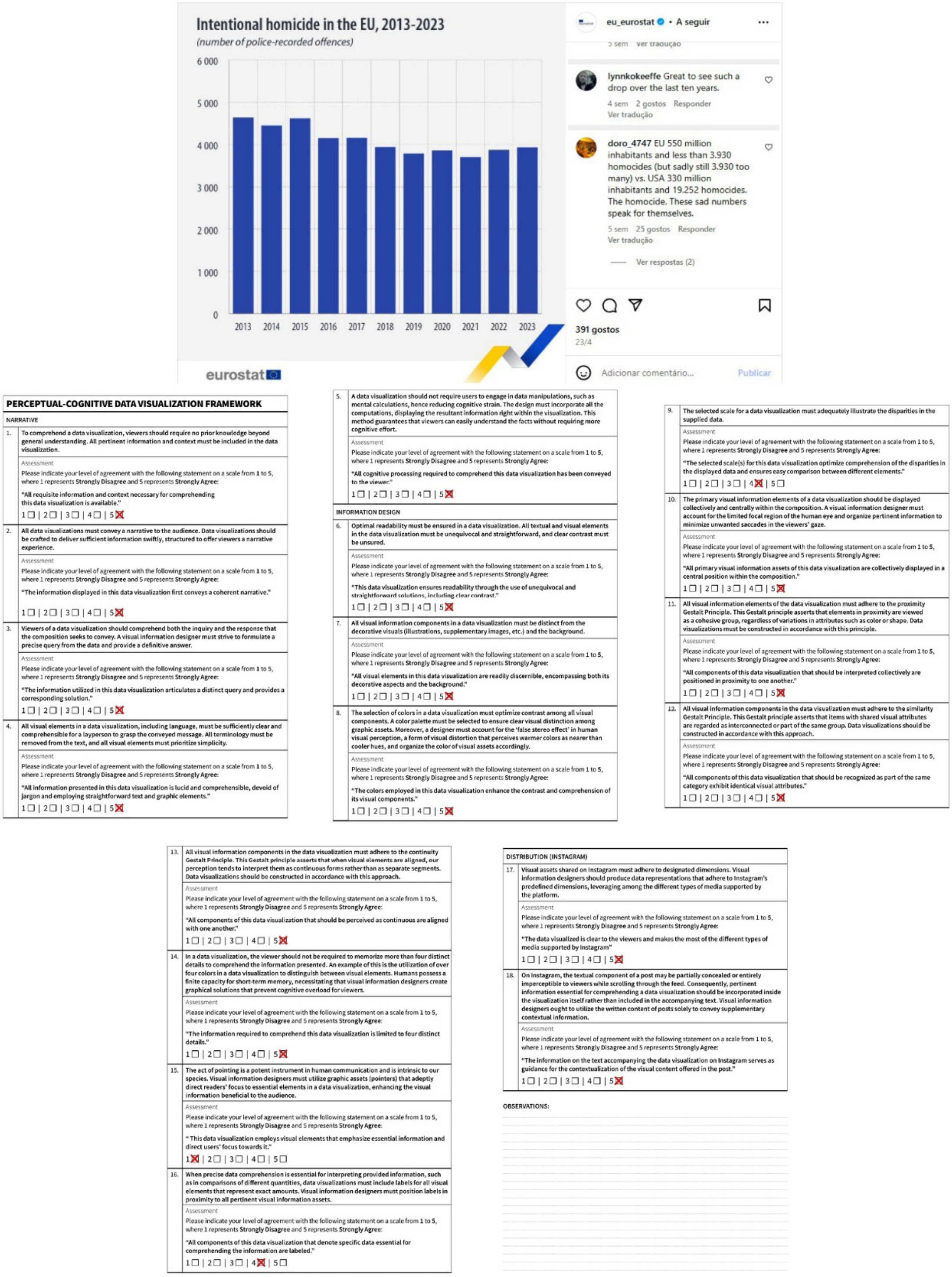
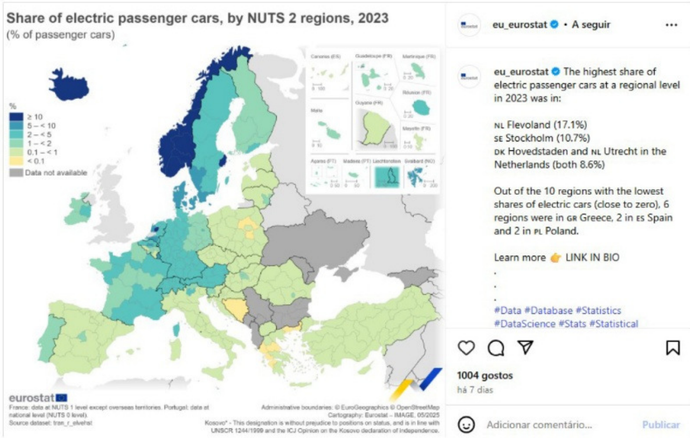
7. Appendixes

7.1. Appendix I – Eurostats Data Visualization assessments using the Perceptual-Cognitive Data Visualization Framework



Intentional homicide in the EU, 2013-2023 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization



PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

NARRATIVE

1. **To comprehend a data visualization, viewers should require no prior knowledge beyond general understanding. All pertinent information and context must be included in the data visualization.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All requisite information and context necessary for comprehending this data visualization is available."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

2. **All data visualizations must convey a narrative to the audience. Data visualizations should be crafted to deliver sufficient information swiftly, structured to offer viewers a narrative experience.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"The information displayed in this data visualization first conveys a coherent narrative."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

3. **Viewers of a data visualization should comprehend both the inquiry and the response that the composition seeks to convey. A visual information designer must strive to formulate a precise query from the data and provide a definitive answer.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"The information utilized in this data visualization articulates a distinct query and provides a corresponding solution."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

4. **All visual elements in a data visualization, including language, must be sufficiently clear and comprehensible for a layperson to grasp the conveyed message. All terminology must be removed from the text, and all visual elements must prioritize simplicity.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All information presented in this data visualization is lucid and comprehensible, devoid of jargon and employing straightforward text and graphic elements."

1☐ | 2☒ | 3☐ | 4☐ | 5☐

5. **A data visualization should not require users to engage in data manipulations, such as mental calculations, hence reducing cognitive strain. The design must incorporate all the computations, displaying the resultant information right within the visualization. This method guarantees that viewers can easily understand the facts without requiring more cognitive effort.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All cognitive processing required to comprehend this data visualization has been conveyed to the viewer."

1☐ | 2☒ | 3☐ | 4☐ | 5☐

INFORMATION DESIGN

6. **Optimal readability must be ensured in a data visualization. All textual and visual elements in the data visualization must be unequivocal and straightforward, and clear contrast must be unsured.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"This data visualization ensures readability through the use of unequivocal and straightforward solutions, including clear contrast."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

7. **All visual information components in a data visualization must be distinct from the decorative visuals (illustrations, supplementary images, etc.) and the background.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All visual elements in this data visualization are readily discernible, encompassing both its decorative aspects and the background."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

8. **The selection of colors in a data visualization must optimize contrast among all visual components. A color palette must be selected to ensure clear visual distinction among graphic assets. Moreover, a designer must account for the 'false stereo effect' in human visual perception, a form of visual distortion that perceives warmer colors as nearer than cooler hues, and organize the color of visual assets accordingly.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"The colors employed in this data visualization enhance the contrast and comprehension of its visual components."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

9. **The selected scale for a data visualization must adequately illustrate the disparities in the supplied data.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"The selected scale(s) for this data visualization optimize comprehension of the disparities in the displayed data and ensures easy comparison between different elements."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

10. **The primary visual information elements of a data visualization should be displayed collectively and centrally within the composition. A visual information designer must account for the limited focal region of the human eye and organize pertinent information to minimize unwanted saccades in the viewers' gaze.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All primary visual information assets of this data visualization are collectively displayed in a central position within the composition."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

11. **All visual information elements of the data visualization must adhere to the proximity Gestalt Principle. This Gestalt principle asserts that elements in proximity are viewed as a cohesive group, regardless of variations in attributes such as color or shape. Data visualizations must be constructed in accordance with this principle.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All components of this data visualization that should be interpreted collectively are positioned in proximity to one another."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

12. **All visual information components in the data visualization must adhere to the similarity Gestalt Principle. This Gestalt principle asserts that items with shared visual attributes are regarded as interconnected or part of the same group. Data visualizations should be constructed in accordance with this approach.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All components of this data visualization that should be recognized as part of the same category exhibit identical visual attributes."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

13. **All visual information components in the data visualization must adhere to the continuity Gestalt Principle. This Gestalt principle asserts that when visual elements are aligned, our perception tends to interpret them as continuous forms rather than as separate segments. Data visualizations should be constructed in accordance with this approach.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree:**

"All components of this data visualization that should be perceived as continuous are aligned with one another."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

14. **In a data visualization, the viewer should not be required to memorize more than four distinct details to comprehend the information presented. An example of this is the utilization of over four colors in a data visualization to distinguish between visual elements. Humans possess a finite capacity for short-term memory, necessitating that visual information designers create graphical solutions that prevent cognitive overload for viewers.**

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1☐ | 2☒ | 3☐ | 4☐ | 5☐

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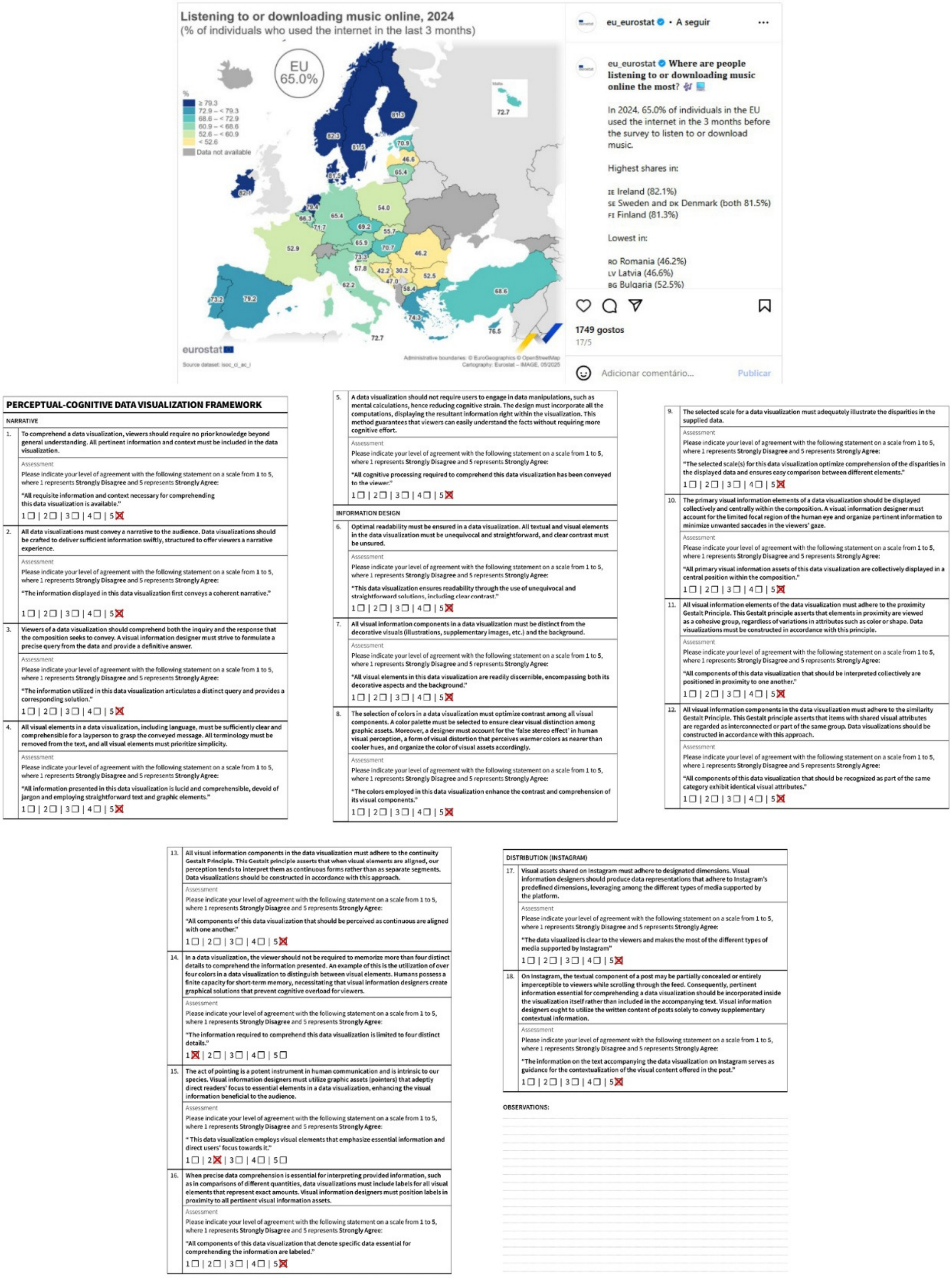
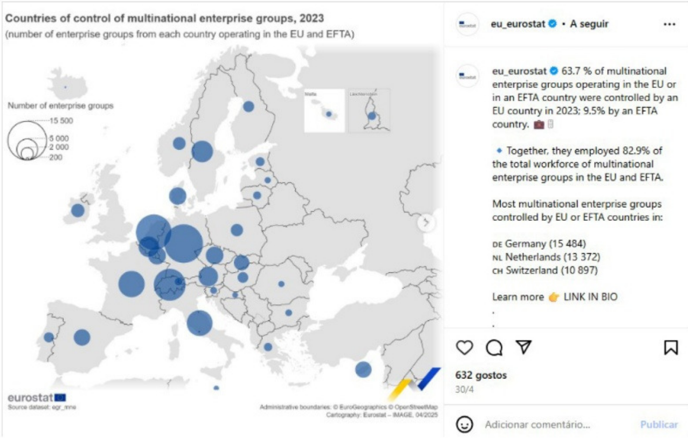
OBSERVATIONS:

Share of electric passenger cars, by NUTS 2 regions, 2023 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization



Listening to or downloading music online, 2024 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization



PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

NARRATIVE

1. **To comprehend a data visualization, viewers should require no prior knowledge beyond general understanding. All pertinent information and context must be included in the data visualization.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All requisite information and context necessary for comprehending this data visualization is available."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

2. **All data visualizations must convey a narrative to the audience. Data visualizations should be crafted to deliver sufficient information swiftly, structured to offer viewers a narrative experience.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information displayed in this data visualization first conveys a coherent narrative."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

3. **Viewers of a data visualization should comprehend both the inquiry and the response that the composition seeks to convey. A visual information designer must strive to formulate a precise query from the data and provide a definitive answer.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information utilized in this data visualization articulates a distinct query and provides a corresponding solution."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

4. **All visual elements in a data visualization, including language, must be sufficiently clear and comprehensible for a layperson to grasp the conveyed message. All terminology must be removed from the text, and all visual elements must prioritize simplicity.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All information presented in this data visualization is lucid and comprehensible, devoid of jargon and employing straightforward text and graphic elements."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

5. **A data visualization should not require users to engage in data manipulations, such as mental calculations, hence reducing cognitive strain. The design must incorporate all the computations, displaying the resultant information right within the visualization. This method guarantees that viewers can easily understand the facts without requiring more cognitive effort.**

Assessment

Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All cognitive processing required to comprehend this data visualization has been conveyed to the viewer."

1☒ | 2☐ | 3☐ | 4☐ | 5☐

INFORMATION DESIGN

6. **Optimal readability must be ensured in a data visualization. All textual and visual elements in the data visualization must be unequivocal and straightforward, and clear contrast must be unsured.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

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1☐ | 2☐ | 3☐ | 4☐ | 5☒

7. **All visual information components in a data visualization must be distinct from the decorative visuals (illustrations, supplementary images, etc.) and the background.**

Assessment

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1☐ | 2☐ | 3☐ | 4☐ | 5☒

8. **The selection of colors in a data visualization must optimize contrast among all visual components. A color palette must be selected to ensure clear visual distinction among graphic assets. Moreover, a designer must account for the 'false stereo effect' in human visual perception, a form of visual distortion that perceives warmer colors as nearer than cooler hues, and organize the color of visual assets accordingly.**

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Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

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1☐ | 2☐ | 3☐ | 4☐ | 5☒

9. **The selected scale for a data visualization must adequately illustrate the disparities in the supplied data.**

Assessment

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Assessment

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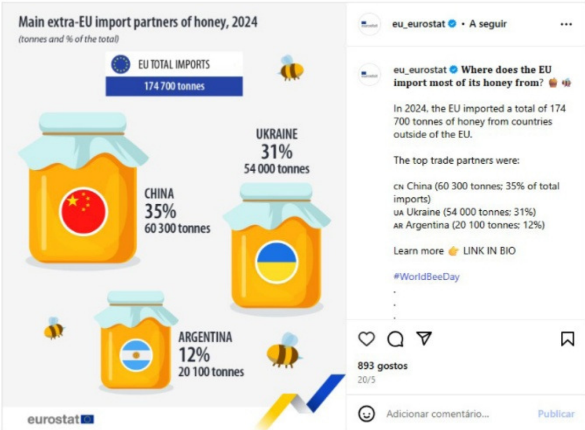
OBSERVATIONS:

Countries of control of multinational enterprises groups, 2023 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization



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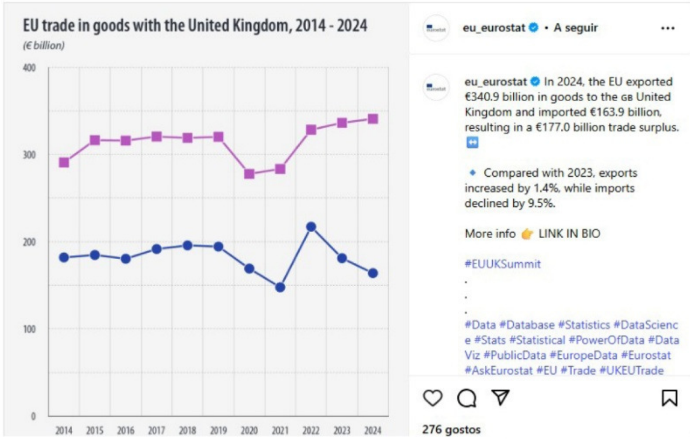
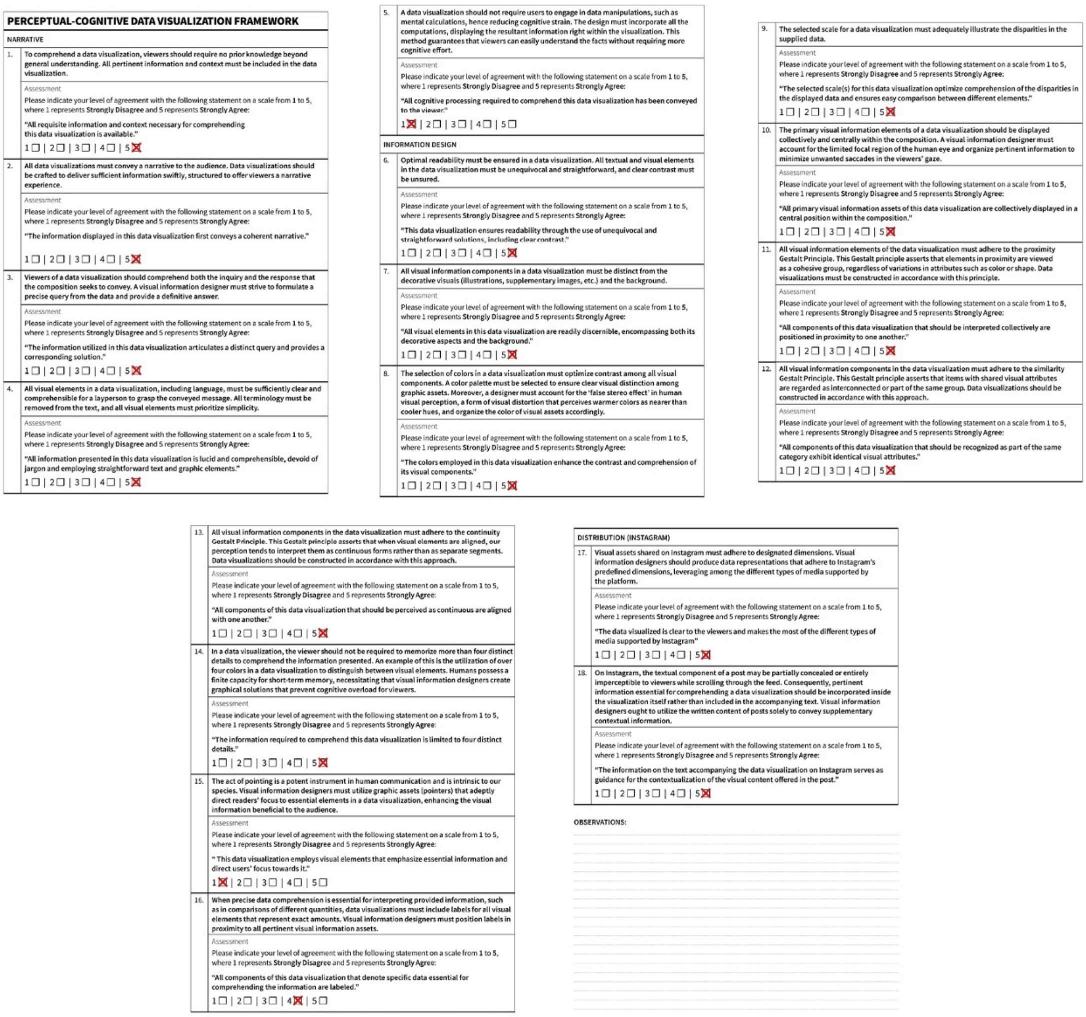
OBSERVATIONS:

Main extra-EU import partners of honey, 2024 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization





PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

NARRATIVE

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   Assessment
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OBSERVATIONS:

EU trade in goods with the United Kingdom, 2014-2024 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization

PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

NARRATIVE

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   Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:
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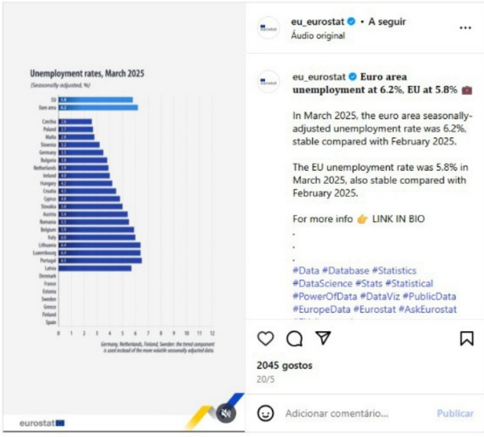
OBSERVATIONS:

Main exporters of alcoholic beverages to countries outside the EU, 2024 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization



PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

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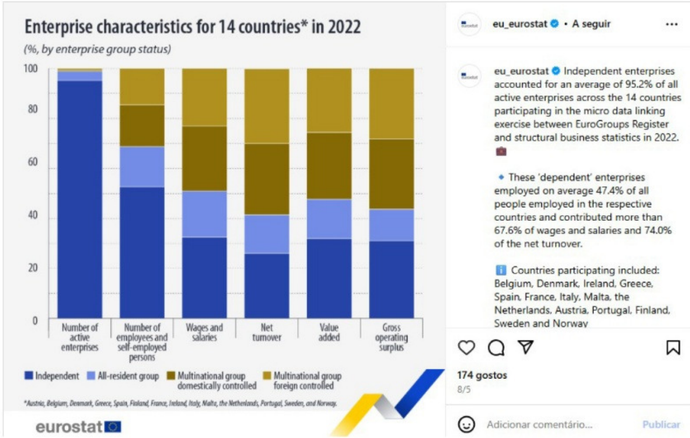
OBSERVATIONS:

Unemployment rates, March 2025 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization



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Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that should be interpreted collectively are positioned in proximity to one another."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

12. **All visual information components in the data visualization must adhere to the similarity Gestalt Principle. This Gestalt principle asserts that items with shared visual attributes are regarded as interconnected or part of the same group. Data visualizations should be constructed in accordance with this approach.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that should be recognized as part of the same category exhibit identical visual attributes."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

13. **All visual information components in the data visualization must adhere to the continuity Gestalt Principle. This Gestalt principle asserts that when visual elements are aligned, our perception tends to interpret them as continuous forms rather than as separate segments. Data visualizations should be constructed in accordance with this approach.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that should be perceived as continuous are aligned with one another."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

14. **In a data visualization, the viewer should not be required to memorize more than four distinct details to comprehend the information presented. An example of this is the utilization of over four colors in a data visualization to distinguish between visual elements. Humans possess a finite capacity for short-term memory, necessitating that visual information designers create graphical solutions that prevent cognitive overload for viewers.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information required to comprehend this data visualization is limited to four distinct details."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

15. **The act of pointing is a potent instrument in human communication and is intrinsic to our species. Visual information designers must utilize graphic assets (pointers) that adeptly direct readers' focus to essential elements in a data visualization, enhancing the visual information beneficial to the audience.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

" This data visualization employs visual elements that emphasize essential information and direct users' focus towards it."

1☒ | 2☐ | 3☐ | 4☐ | 5☐

16. **When precise data comprehension is essential for interpreting provided information, such as in comparisons of different quantities, data visualizations must include labels for all visual elements that represent exact amounts. Visual information designers must position labels in proximity to all pertinent visual information assets.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"All components of this data visualization that denote specific data essential for comprehending the information are labeled."

1☐ | 2☐ | 3☐ | 4☐ | 5☒

DISTRIBUTION (INSTAGRAM)

17. **Visual assets shared on Instagram must adhere to designated dimensions. Visual information designers should produce data representations that adhere to Instagram's predefined dimensions, leveraging among the different types of media supported by the platform.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The data visualized is clear to the viewers and makes the most of the different types of media supported by Instagram"

1☐ | 2☐ | 3☐ | 4☐ | 5☒

18. **On Instagram, the textual component of a post may be partially concealed or entirely imperceptible to viewers while scrolling through the feed. Consequently, pertinent information essential for comprehending a data visualization should be incorporated inside the visualization itself rather than included in the accompanying text. Visual information designers ought to utilize the written content of posts solely to convey supplementary contextual information.**

Assessment

Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**:

"The information on the text accompanying the data visualization on Instagram serves as guidance for the contextualization of the visual content offered in the post."

1☐ | 2☒ | 3☐ | 4☐ | 5☐

OBSERVATIONS:

Enterprise characteristics for 14 countries in 2022 (Eurostat, 2025) and usage of the Perceptual-Cognitive Data Visualization Framework assessing the data visualization

7.2. Appendix II – Final version of the Perceptual-Cognitive Data Visualization Framework

PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK

INSTRUCTIONS

When using this framework to **guide the design of a data visualization**, visual information designers should comply with the recommendations presented as closely as possible.

When using this framework to **evaluate existing data visualizations**, assessors should use the Linkert scale-based evaluative statement.

These statements can be responded on a five-point scale from "*Strongly Disagree*" to "*Strongly Agree*," including "*Disagree*," "*Neither Agree nor Disagree*," and "*Agree*."

All statements will be preceded by the sentence "*Please indicate your level of agreement with the following statement on a scale from 1 to 5, where 1 represents Strongly Disagree and 5 represents Strongly Agree*"

Whenever the assessment sentence is **1**, the evaluator should advocate for graphical solution revision.

Whenever the assessment sentence is **2**, the evaluator should advocate for graphical solution revision, but with less emphasis.

Assessments with an agreement level of **3** may need to be changed or ignored if the sentence is not relevant to the data visualization being evaluated.

Whenever the assessment sentence is **4**, the evaluator may call for minor changes or not require further modifications.

Whenever the assessment sentence is **5**, the evaluator should not require any changes.

PERCEPTUAL-COGNITIVE DATA VISUALIZATION FRAMEWORK	
NARRATIVE	
1.	**To comprehend a data visualization, viewers should require no prior knowledge beyond general understanding. All pertinent information and context must be included in the data visualization.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“All requisite information and context necessary for comprehending this data visualization is available.”** 1☐ | 2☐ | 3☐ | 4☐ | 5☐
2.	**All data visualizations must convey a narrative to the audience. Data visualizations should be crafted to deliver sufficient information swiftly, structured to offer viewers a narrative experience.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“The information displayed in this data visualization first conveys a coherent narrative.”** 1☐ | 2☐ | 3☐ | 4☐ | 5☐
3.	**Viewers of a data visualization should comprehend both the inquiry and the response that the composition seeks to convey. A visual information designer must strive to formulate a precise query from the data and provide a definitive answer.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“The information utilized in this data visualization articulates a distinct query and provides a corresponding solution.”** 1☐ | 2☐ | 3☐ | 4☐ | 5☐
4.	**All visual elements in a data visualization, including language, must be sufficiently clear and comprehensible for a layperson to grasp the conveyed message. All terminology must be removed from the text, and all visual elements must prioritize simplicity.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“All information presented in this data visualization is lucid and comprehensible, devoid of jargon and employing straightforward text and graphic elements.”** 1☐ | 2☐ | 3☐ | 4☐ | 5☐

5.	**A data visualization should not require users to engage in data manipulations, such as mental calculations, hence reducing cognitive strain. The design must incorporate all the computations, displaying the resultant information right within the visualization. This method guarantees that viewers can easily understand the facts without requiring more cognitive effort.**	
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"All cognitive processing required to comprehend this data visualization has been conveyed to the viewer."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐	
INFORMATION DESIGN		
6.	**Optimal readability must be ensured in a data visualization. All textual and visual elements in the data visualization must be unequivocal and straightforward, and clear contrast must be unsured.**	
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"This data visualization ensures readability through the use of unequivocal and straightforward solutions, including clear contrast."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐	
7.	**All visual information components in a data visualization must be distinct from the decorative visuals (illustrations, supplementary images, etc.) and the background.**	
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"All visual elements in this data visualization are readily discernible, encompassing both its decorative aspects and the background."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐	
8.	**The selection of colors in a data visualization must optimize contrast among all visual components. A color palette must be selected to ensure clear visual distinction among graphic assets. Moreover, a designer must account for the 'false stereo effect' in human visual perception, a form of visual distortion that perceives warmer colors as nearer than cooler hues, and organize the color of visual assets accordingly.**	
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"The colors employed in this data visualization enhance the contrast and comprehension of its visual components."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐	

9.	**The selected scale for a data visualization must adequately illustrate the disparities in the supplied data.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“The selected scale(s) for this data visualization optimize comprehension of the disparities in the displayed data and ensures easy comparison between different elements.”** 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐
10.	**The primary visual information elements of a data visualization should be displayed collectively and centrally within the composition. A visual information designer must account for the limited focal region of the human eye and organize pertinent information to minimize unwanted saccades in the viewers’ gaze.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“All primary visual information assets of this data visualization are collectively displayed in a central position within the composition.”** 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐
11.	**All visual information elements of the data visualization must adhere to the proximity Gestalt Principle. This Gestalt principle asserts that elements in proximity are viewed as a cohesive group, regardless of variations in attributes such as color or shape. Data visualizations must be constructed in accordance with this principle.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“All components of this data visualization that should be interpreted collectively are positioned in proximity to one another.”** 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐
12.	**All visual information components in the data visualization must adhere to the similarity Gestalt Principle. This Gestalt principle asserts that items with shared visual attributes are regarded as interconnected or part of the same group. Data visualizations should be constructed in accordance with this approach.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **“All components of this data visualization that should be recognized as part of the same category exhibit identical visual attributes.”** 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐

13.	**All visual information components in the data visualization must adhere to the continuity Gestalt Principle. This Gestalt principle asserts that when visual elements are aligned, our perception tends to interpret them as continuous forms rather than as separate segments. Data visualizations should be constructed in accordance with this approach.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"All components of this data visualization that should be perceived as continuous are aligned with one another."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐
14.	**In a data visualization, the viewer should not be required to memorize more than four distinct details to comprehend the information presented. An example of this is the utilization of over four colors in a data visualization to distinguish between visual elements. Humans possess a finite capacity for short-term memory, necessitating that visual information designers create graphical solutions that prevent cognitive overload for viewers.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"The information required to comprehend this data visualization is limited to four distinct details."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐
15.	**The act of pointing is a potent instrument in human communication and is intrinsic to our species. Visual information designers must utilize graphic assets (pointers) that adeptly direct readers' focus to essential elements in a data visualization, enhancing the visual information beneficial to the audience.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **" This data visualization employs visual elements that emphasize essential information and direct users' focus towards it."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐
16.	**When precise data comprehension is essential for interpreting provided information, such as in comparisons of different quantities, data visualizations must include labels for all visual elements that represent exact amounts. Visual information designers must position labels in proximity to all pertinent visual information assets.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"All components of this data visualization that denote specific data essential for comprehending the information are labeled."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐

DISTRIBUTION (INSTAGRAM)	
17.	**Visual assets shared on Instagram must adhere to designated dimensions. Visual information designers should produce data representations that adhere to Instagram's predefined dimensions, leveraging among the different types of media supported by the platform.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"The data visualized is clear to the viewers and makes the most of the different types of media supported by Instagram"** 1☐ | 2☐ | 3☐ | 4☐ | 5☐
18.	**On Instagram, the textual component of a post may be partially concealed or entirely imperceptible to viewers while scrolling through the feed. Consequently, pertinent information essential for comprehending a data visualization should be incorporated inside the visualization itself rather than included in the accompanying text. Visual information designers ought to utilize the written content of posts solely to convey supplementary contextual information.**
	Assessment Please indicate your level of agreement with the following statement on a scale from **1** to **5**, where 1 represents **Strongly Disagree** and 5 represents **Strongly Agree**: **"The information on the text accompanying the data visualization on Instagram serves as guidance for the contextualization of the visual content offered in the post."** 1☐ | 2☐ | 3☐ | 4☐ | 5☐

OBSERVATIONS:

RECOMMENDATIONS CONTEXT AND JUSTIFICATION	
1.	Prior knowledge is crucial to material comprehension. Ensure readers have the background to understand. A good display adds new information while remaining relevant. Assuming readers know everything may lead the visual information designer to employ unfamiliar concepts, facts, or standards, making communication confusing. If viewers know little, designers will stress self-evident items. We do not search randomly when seeking supplementary information; instead, we infer visual perception from conserved information to guide encoding. One actively seeks hypothesis-related facts. The primary limitation in long-term memory is an individual's knowledge. Semantic and pragmatic interpretation of a display depends on sensory-related stored knowledge. Those unfamiliar with a term definition or a display framework line arrangement will have problems matching the display to the data.
2.	Data visualizations should include a narrative. Visual displays resemble narratives more than mere representations of objects; while they have identifiable components, it is the relationships among these components that communicate the specific information.
3.	Visual information designers must formulate a precise query and derive an answer from the data. A graph is designed to illustrate a particular argument, and its visual presentation should effectively communicate that argument. Numerous psychological ideas are contingent upon circumstances. It is essential to ascertain the inquiries viewers wish to pose regarding the visualization and the facts required to address them. Effective communication of information occurs alone when it directs the readers' attention and interest towards a certain message.
4.	For a layperson to comprehend the meaning of a data visualization, it is imperative that all visual components, including language, are clear and easily understandable. For efficient communication, a data visualization must be instantly understood and easily remembered. A sentence displayed in a legible font, repeated, or emphasized will be processed with cognitive fluidity and efficiency. Cognitive strain results from the utilization of inferior typefaces, inadequate colors, or convoluted wording. Labels must precisely reflect their categories, and images should portray suitable items.
5.	Visual information designers must prioritize minimizing cognitive load for viewers when accessing information from a data visualization. This guarantees that users are not obligated to execute mental computations or undertake data manipulations. Individuals' hesitance to make an effort is psychological rather than moral, and they frequently evade it when uncertain of the rewards. Data visualization designers must recognize that when we "keep something in mind," we retain information in short-term memory. Rational thought is essential for comprehending a data visualization by drawing conclusions and recognizing implications. These cognitive functions utilize short-term memory. The constrained capacity of short-term memory restricts our understanding.
6.	Readability constitutes a critical component of data visualization. The neurons that detect changes in a specific spatial region inhibit the activity of neighboring neurons monitoring adjacent areas. If a visual element is insufficient in size or weight, the cells responsible for its detection are inhibited from responding. Detectability is influenced by multiple factors and their interactions, including the color of the figure and background, the contrast between light and dark elements, and the shape of the figure. Elements of a data visualization, such as lines and areas, must be sufficiently

6. (cont.)	pronounced, and each mark should be appropriately sized to ensure distinguishability. The visual system functions as a mechanism for detecting differences. A significant contrast will attract attention.
7.	All visual components in a data visualization necessitate careful study, as these features are essential for expressing information. Consequently, it is imperative to distinguish these elements from the background and ornamental visuals, including supplementary images and illustrations. Early retinal cells amplify the edges of visual stimuli, with the most prominent features being objects delineated by their contours. An successful data visualization must captivate viewers' attention and enhance navigation, allowing for the identification of essential information and the distinction of pertinent elements. The most visually prominent pieces of a visualization must communicate the most critical information.
8.	The selection of color is essential to information visual design. Color decisions for data visualization must enhance contrast among all visual elements. A designer must also account for the "false stereo effect" in human visual perception, which causes long-wavelength, warmer colors to seem "closer" than short-wavelength, cooler hues. The warmer line must overlap with the cooler line at the point of intersection in a data visualization. Should it fail, the rear line will appear to compete for advancement, looping around the one ahead, which is disconcerting. Consequently, data visualizations should employ cool background colors and warm foreground colors.
9.	The selection of data visualization scales requires meticulous examination to facilitate the visual comprehension of data disparities and enable comparisons. Exhibit solely the pertinent scale range to obtain a precise impression. Unless the zero value is pertinent, a designer should initiate the visible scale at a value marginally below the smallest data point and extend the upper value somewhat over the maximum.
10.	The composition must emphasize the primary visual attributes of a data visualization. The core visual field possesses significantly greater pixel density compared to the periphery. Only the fovea, encompassing 15 degrees of the visual field, is effective for reading. Rapid saccades shift our attention from one visual location to another. A visual information designer must systematically arrange pertinent information to minimize saccades in the viewer's gaze, given the human eye's restricted focal area.
11. 12. 13.	Gestalt theory posits that the brain perceives color and shape as cohesive aggregates rather than as separate entities. Human eyes and minds perceive visual patterns as three-dimensional objects whenever feasible. The mind instinctively presumes that shapes possess regular, closed contours, that things exhibit uniform coloration and markings, and that the environment comprises cohesive surfaces rather than dispersed particles or fragments. The Gestalt Principles of proximity, continuity, and similarity are essential for understanding information processing, directing the human visual system's organization of graphical elements into unified entities. These principles elucidate how people perceive and organize visual elements, with proximity signifying the inclination to cluster adjacent items. Similarity denotes the association of analogous things by observers. Continuity refers to the eye's ability to trace a line or curve, thereby organizing things along its trajectory.
14.	Humans possess constrained short-term memory; therefore, visual information designers must deliver graphical solutions that prevent cognitive overload. A data visualization should necessitate the memorization of no more than four details. To comprehend a key, viewers must remember the associations between names

14. (cont.)	and content. This necessitates exertion and may deplete their limited short-term memory ability. Maintaining a mental representation necessitates effort and can only retain a limited amount of information for a finite duration. This is significant as the majority of imagery reasoning issues require considerable time. Viewers possess a finite ability to retain and digest information; hence, they will fail to comprehend a message if it is excessively intricate. Given that information resides in short-term memory, visual information designers must consider its capacity constraints. Excessive knowledge retention limits task completion. Consequently, complexity influences the comprehensibility of data visualization.
15.	Social signals influence Homo Sapiens' attention and learning more than those of any other primate. Human learning depends on "shared attention" between the learner and the teacher. Pointing is a deictic mechanism that emphasizes significant elements. Data visualizations ought to employ graphical deictic mechanisms. These mechanisms are represented using explanatory text, labels, arrows, brackets, and pointers superimposed on a data visualization.
16.	For precise data analysis, particularly in quantity comparison, data visualizations must clearly label all visual features that denote exact values. Viewers will perceive any alteration in a data visualization's aesthetics (such as the addition or removal of lines, modification of color, or texture) as conveying information. A data visualization viewer anticipates a discernible alteration in the display to signify information. Labeling visual data representations is essential for data visualization designers to provide accurate figures. If the designer aims to convey a sense of amount rather than exact value, labeling is unnecessary.
17.	Visual information designers must utilize Instagram's approved media formats and adhere to the specified dimensions for any visual assets shared on the platform. If a designer must break data visualizations into continuous images to meet Instagram's dimensions, they must understand that dividing complex data into multiple panels reduces short-term memory load and simplifies patterns. However, if the data visualization is overly intricate, the pattern may remain obscured and fail to communicate information immediately. When a complex data visualization is deconstructed into simpler components, several patterns can be discerned without the necessity of recording element values.
18.	While browsing Instagram, the text of a post may be partially or entirely obscured. Consequently, essential information required for understanding a data visualization should be integrated within the picture rather than the accompanying text. Data visualizations must use captions to elucidate attributes and unfamiliar terminology. Captions elucidate visual information; therefore, a designer must guarantee that the reader comprehends the terminology of the visualization.