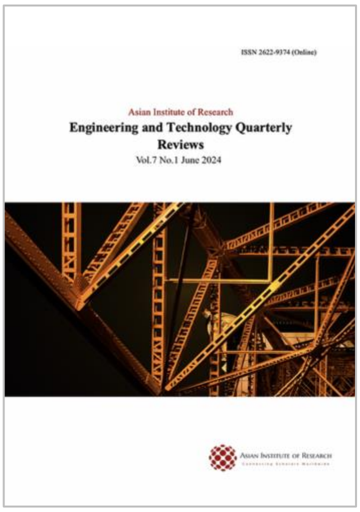

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Enhancing Data Visualization Accessibility: A Case for Equity and Inclusion

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Abstract
Over the decades, information and the transferring of information between parties have led to the evolution of human civilization from the pre-stone age to the AI era. Science, Technology, Engineering, and Mathematics have relied on data visualization to communicate and convey complex information to diverse audiences. However, traditional approaches to data visualization often rely heavily on color variations that have left a specific population with color vision deficiencies to walk the extra mile to decode the information provided in most data visualization boards due to their color selections. The importance of accommodating all forms of color blindness in data visualization to ensure inclusivity and accessibility dispersion of information can't be understated. This paper explores strategies for enhancing data visualization accessibility to accommodate all. Addressing the needs of individuals with diverse color vision deficiencies requires a proactive approach to designing inclusive visualizations. One approach involves adopting color palettes that maintain adequate contrast and employ hues distinguishable by individuals with various color vision deficiencies. Utilizing patterns, textures, and varying line styles alongside color can provide redundant cues for conveying information effectively.

Keywords: Data Visualization, Color Theory, Color Perception, Visualization Quotient

1. Introduction

Communication involves nonverbal, written, and verbal cues. Every conversation on a macro stage has a sender/producer and a recipient/consumer. In data visualization, the sender 'encodes' complex information into graphs, charts, maps, logos, and colors in a mixture to tell a story that provides affordance to the consumer (Norman, 1988). Information visualization systematically examines (interactive) visual depictions of data to enhance cognition. This data encompasses numerical and non-numerical information, such as textual and geographic data. A key element frequently employed in this practice is color, utilized as a medium to encode and convey meaning. However, it is evident through empirical observation that the selection of colors in visualization creation often lacks proper attention. It is imperative to ensure that the chosen colors not only prevent the creation of cluttered visuals but also facilitate comprehension for all individuals, including a significant portion of the population who experience color vision deficiency. The communication channel between the producer of information and the consumer of communication can be broken down in Figure 1.

What drives the preference for conveying information through visual mediums? Of humans' five senses, vision stands out for its unparalleled capacity to process information swiftly and efficiently. This superiority stems from the human brain's intricate pattern recognition and matching capabilities. Indeed, it's commonplace for individuals to engage in mental visualization, whether consciously or subconsciously, while structuring thoughts and reasoning. Visual thinking is ingrained in our cognitive processes. Humans, alongside many other species, can discern light in various dimensions: spatially, by intensity, and by frequency. Variations in intensity manifest as distinctions between light and darkness, while differences in frequency translate into the perception of color. However, it's essential to acknowledge that all visual interpretations are inherently subjective. Whether it's geometric patterns, contrasts between light and dark, or the spectrum of colors, our perception is influenced by the brain's interpretation of electrical signals received through the eyes (Ferreira, 2017).

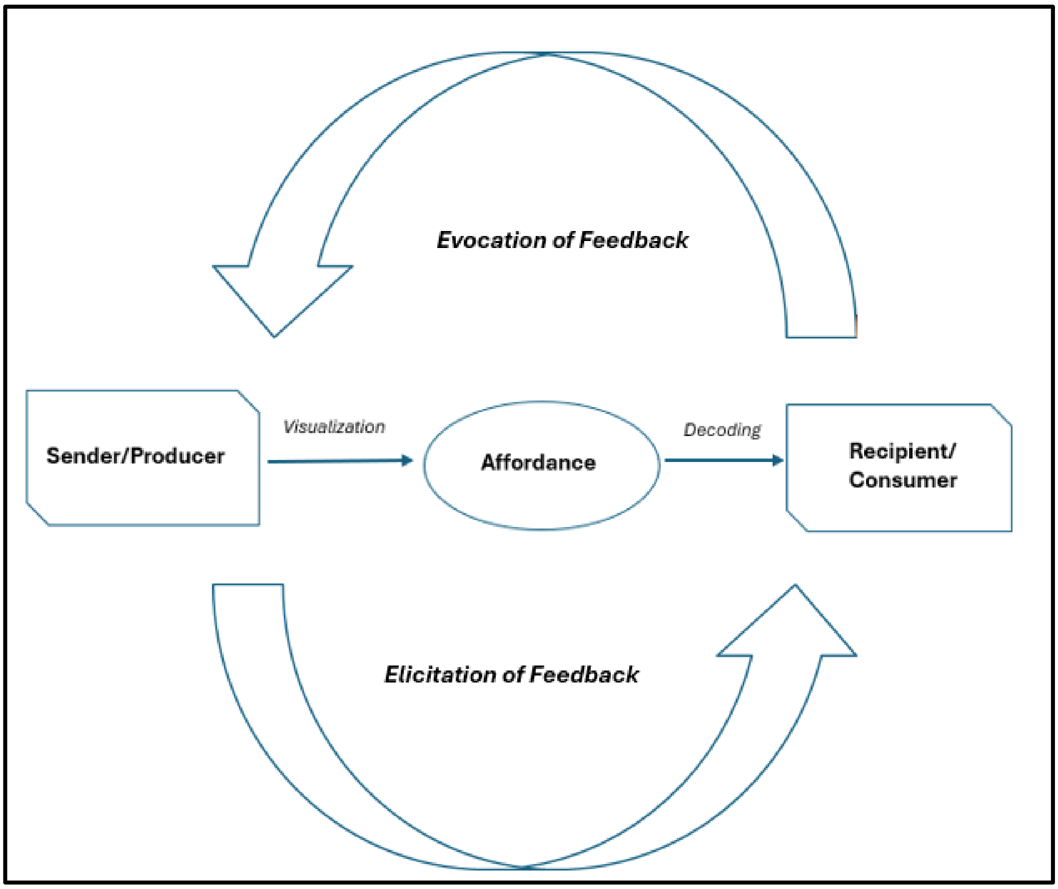


Figure 1: Communication Process Via Visualization
Source: Authors' Creation

Information visualization encompasses the exploration of visual representations, both interactive and static, to enhance human cognition when processing abstract data. These data types span numerical figures, textual information, and geographic data, facilitating a comprehensive understanding of complex datasets. The frequency between the sender of information, affordance, and the recipient of the information in data visualization has to be at equilibrium, with both parties constantly evocating and eliciting feedback from each other. The primary aim of this paper is to highlight how data visualization can accommodate people with monochromatism, dichromatism, and anomalous trichromatism, where dichromatism and anomalous trichromatism are further into tritanopia (deficiency to see blue light) protanopia (deficiency to see red light) and deuteranopia (deficiency to see green light) (Woods, 2021).

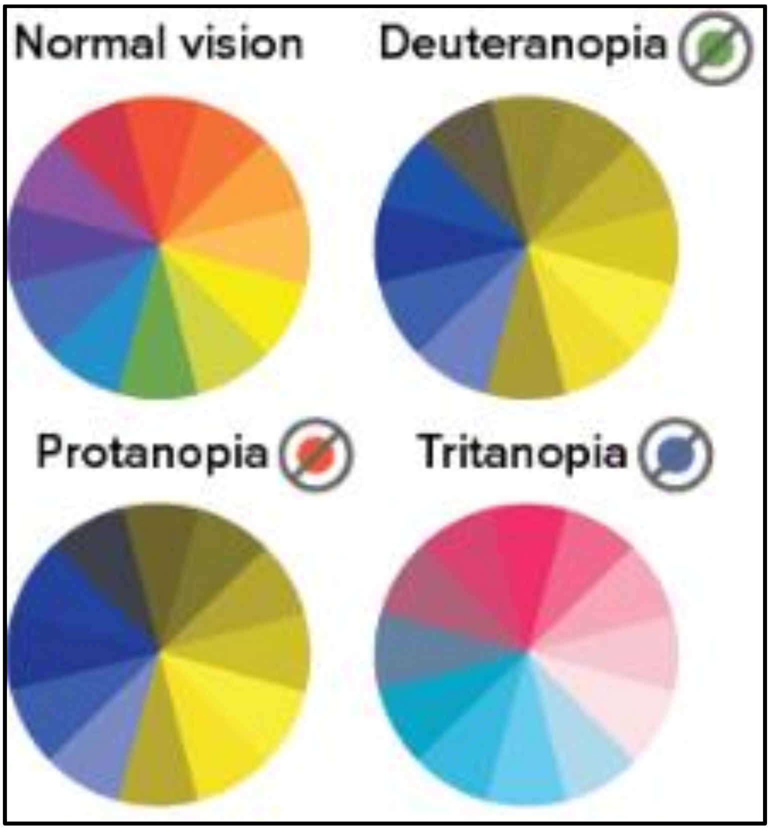


Figure 2: Anomalous Trichromatism Spectrum
(Woods, 2021)

The challenge arises from the subjectivity inherent in our perceptual systems, posing a significant hurdle for achieving accurate and objective data interpretation, a primary aim of information visualization. This hurdle stems from not all individuals possessing identical visual capabilities; a substantial portion of the population experiences color blindness, known as color vision deficiency. Color blindness entails a diminished capacity to perceive colors or distinctions between them. It's crucial to note that most individuals with color blindness still retain some degree of color perception, contrary to the misconception that they perceive images solely in grayscale, a condition referred to as monochromatism (Ferreira, 2017).

In the colorblind population, deuteranomalous (or green-weak) vision is the most prevalent. The official breakdown is as follows: protanopes 12.5%, protanomalous 12.5%, deuteranopes 12.5%, and deuteranomalous 62.5% (Woods, 2021). Typically, colorblind individuals maintain the ability to discern between blue and yellow hues, and many fall under the category of anomalous trichromats rather than complete dichromats. While they may exhibit a diminished ability to distinguish colors along the red-green axis of the color space, they still retain some discrimination, albeit limited (see Fig. 1). Regrettably, there is currently no known cure for this form of vision deficiency.

2. How to be more Mindful?

When working with a visual board, a data analyst should ask the following questions to exhibit a high Visualization Quotient (VQ). This study defines VQ as the ability to present complex information using data visualization tools while creating a conceptual and visual affordance environment. Does the information perceived by individuals differ for those with color blindness? Is it imperative to complement images, graphs, or charts with captions, contrary to the adage "a picture is worth a thousand words"? Is there a predetermined necessity to meticulously select colors for information visualization to prevent conflicts in interpretation? To what extent can individuals with color blindness adapt to interpret visual artifacts? Should we meticulously analyze each case of color blindness to establish an ideal color model, thereby precluding the existence of a "universal artifact" suitable for all? Will these considerations overly constrain creators of visual information, or can they flexibly adapt their visual display and aesthetic ideals?

Understanding the essence and prevalence of color deficiencies proves instrumental in devising displays catering to a broad spectrum of users, encompassing a substantial portion of color deficiency in data visualization. An elemental directive in crafting displays accessible to color-deficient individuals resides in implementing redundant luminance cues to underscore pivotal distinctions within the image (see Figure 3).

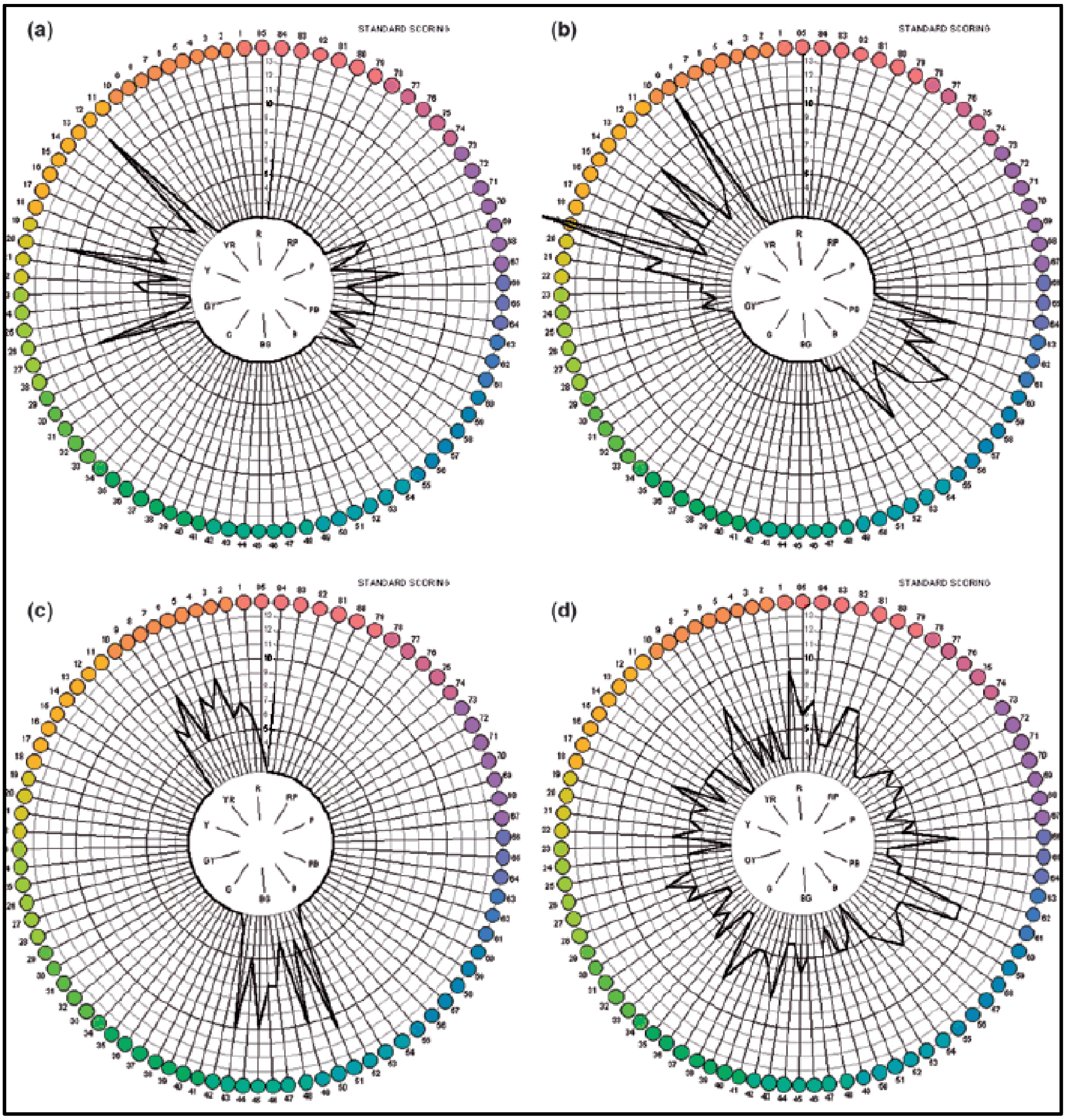


Figure 3: Farnsworth-Munsell 100 Hue's Online Color Test
(Ferreira, 2017)

This principle mandates the incorporation of differential coloration alongside distinct variations in brightness. For instance, optimizing user experience necessitates highlighting discovered terms within the browser by juxtaposing dissimilar hues and luminosity levels in the context of a World-Wide Web search tool (Ferreira, 2017). In tandem with leveraging redundant luminance cues, it is imperative to abstain from utilizing colors along prominent opponent-processes chromatic channels, notably the red-green axis, given the prevalence of red-green color deficiency. Instead, strategic color coding must be directed along an axis that amalgamates red-green and yellow-blue channels, enhancing perceptual differentiation (Ferreira, 2017). Other mindfulness steps one can take in displaying a high VQ include but are not limited to:

2.1. Integration of mindful color palettes

One of the simplest ways to improve your data visualizations for colorblind users is to choose colors that are easy to differentiate for most types of color blindness. For example, avoid using red and green together, as people with protanopia or deuteranopia often confuse them. Instead, use contrasting colors like blue and orange or purple and yellow. You can also use tools like ColorBrewer or Color Oracle to test and select color palettes suitable for different vision impairments (Nichols, 2024).

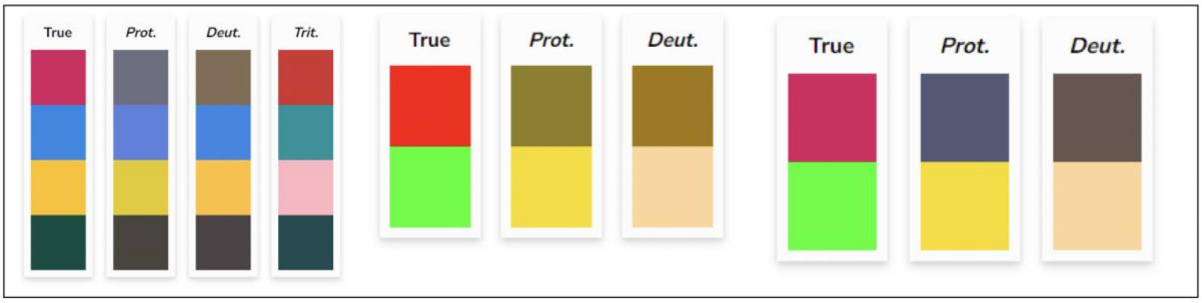


Figure 4: Color Palette Viual Diferenation
(Nichols, 2024)

Where:
True: Actual color visualization
Prof: Protanopia
Deut: Deuteranopa
Trit: Tritanopia

2.2. Integration of patterns, textures, or symbols

Another way to enhance your data visualizations for colorblind users is to add patterns, textures, or symbols to your data points, bars, or areas. This way, you can create more visual cues that help users distinguish between different categories or values, regardless of the color. For example, you can use dots, stripes, or checks to fill your bar chart bars or use circles, squares, or triangles to mark your points in a scatter plot. You can also use tools like Plotly or Matplotlib to customize your ML models' patterns, textures, or symbols.

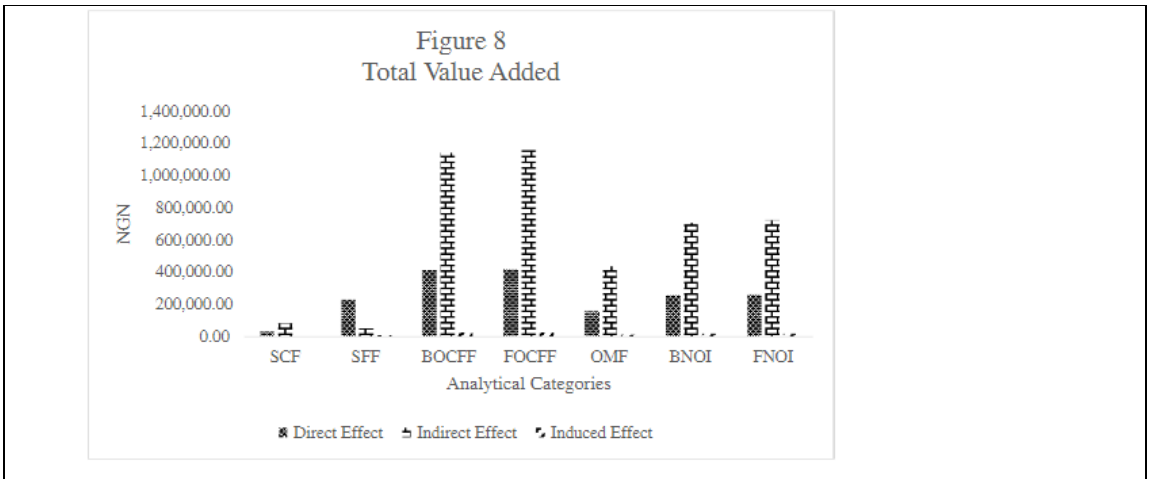


Figure 5

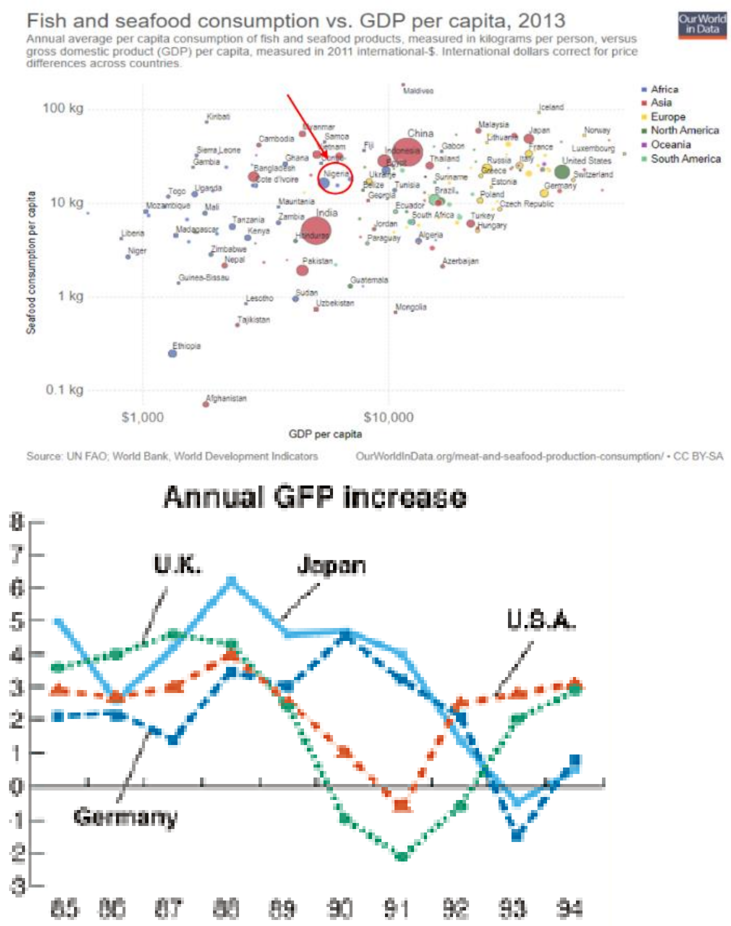
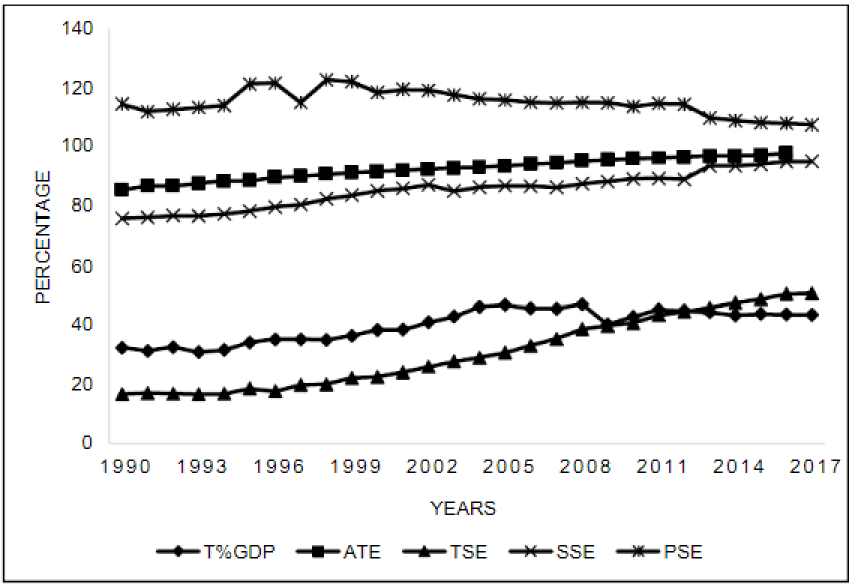


Figure 5: Integration of Patterns, Textures, or Symbols in Bar Charts & Line Graphs
(Ferreira, 2017) & (Osiobe, 2018)

2.3. Integration of labels, legends, and annotations

A third way to improve your data visualizations for colorblind users is to use labels, legends, and annotations to provide more information and context to your charts and graphs. Labels are text identifying your visualization's axes, titles, or data points. Legends are boxes that explain the meaning of the colors, patterns, textures, or symbols used in your visualization. Annotations are notes that highlight or illustrate specific features or trends in your visualization. By using labels, legends, and annotations, you can make your data visualizations clearer and more understandable for colorblind users.

Figure 3: Economic Indicators of our SLACs



Source: (WDI, 2019)
Author's creation

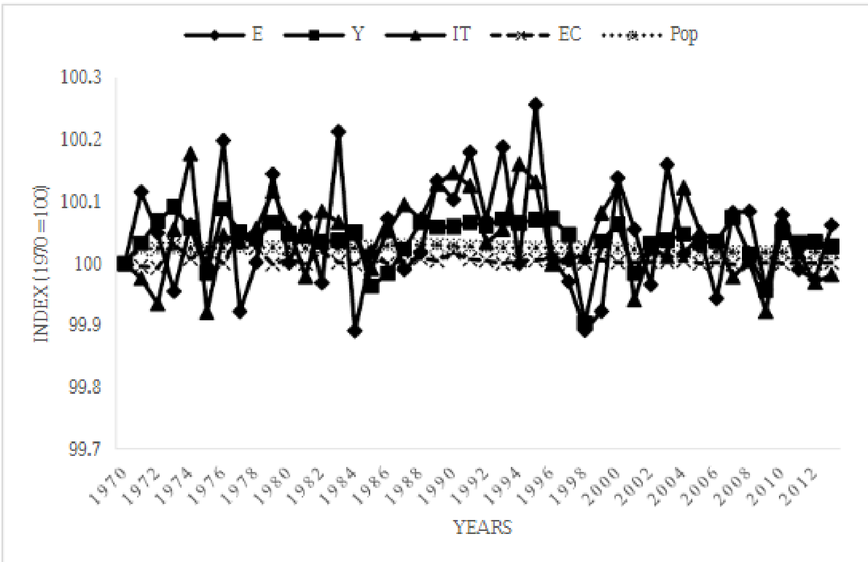


Figure 6: Line Graph with Unique shapes.
(Osiobe, 2019) & (Osiobe E. U., 2020)

2.4. A method of color, text, and shapes

A fourth way to improve your data visualizations for colorblind users is to avoid using color alone to convey meaning or importance in your charts and graphs. Color can help emphasize or differentiate data, but it should not be the only way. If you rely solely on color to convey meaning, you risk losing or confusing your colorblind users. Instead, use other visual elements, such as size, shape, position, or text, to reinforce or supplement color's message. For example, you can use larger or smaller circles to show the magnitude of data points in a scatter plot or arrows or labels to show the direction or significance of data trends in a line chart.

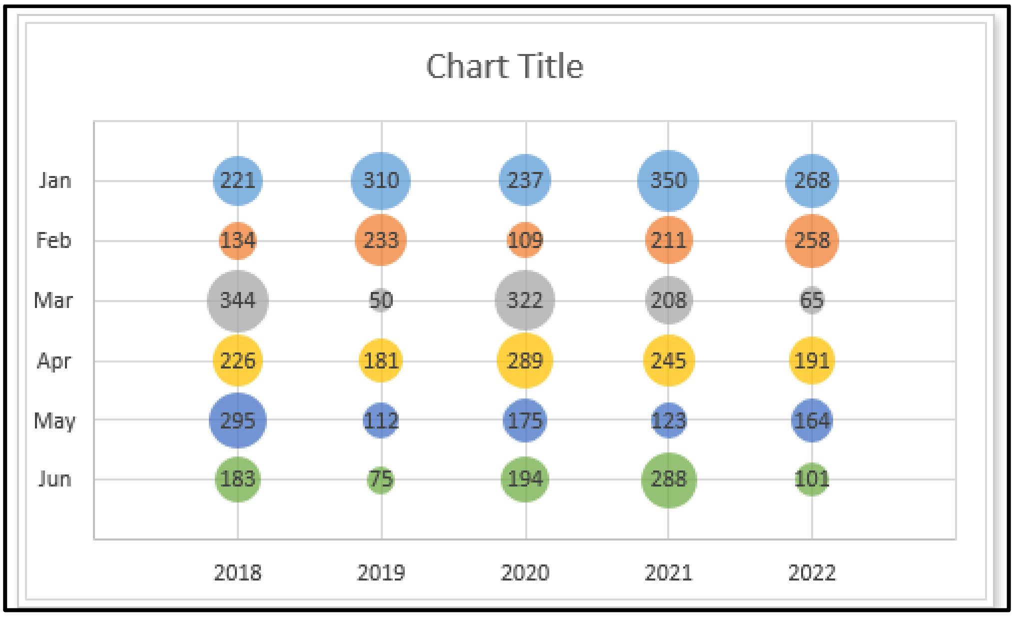


Figure 7: Martrix Bubble Chart
(Extend Office, 2020)

3. Recommendation and Conclusion

More education on data visualization for students, academics, practitioners, and designers about how to increase their VQ and be mindful of their visual boards and the impact of color blindness on visual perception will lead to more accommodating guidelines for creating inclusive visualizations in academia and mainstream economy are essential steps toward fostering accessibility and inclusivity in data communication. Testing one's charts and graphs with colorblind users or simulations can help you get feedback and suggestions on making your charts and graphs more accessible and practical. Simulating their vision with tools or apps can help you check and improve your data visualizations' color contrast, clarity, and readability. Some examples of tools or apps that can help you test or simulate color blindness are the Color Blindness Simulator, Color Blind Check, or Sim Daltonism.

Following data visualization best practices that apply to all users, regardless of their vision, and adopting them as the new visualization standard are best practices for a more engaging presentation; these include but are not limited to choosing the right type of chart for your data, using clear and consistent labels and legends, avoiding clutter and distortion, and telling a story with your data. By following data visualization best practices, you can ensure that your data visualizations are not only accessible for colorblind users but also practical for all users. Addressing the needs of individuals with color vision deficiencies in data visualization is imperative for promoting inclusivity and ensuring equitable access to information. By employing thoughtful design principles, utilizing alternative visual cues, and embracing user-centric approaches, data visualization can effectively accommodate all forms of color blindness, enhancing accessibility and fostering universal understanding and engagement with data-driven insights.

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