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REGULAR PAPER

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ChinaVis24.MapCraft: dissecting and designing custom geo-infographics

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Abstract Geographic infographics are increasingly utilized across various domains to convey spatially relevant information effectively. However, creating these infographics typically requires substantial expertise in design and visualization, as well as proficiency with specialized tools, which can deter many potential creators. To address this barrier, our research analyzed and categorized 118 geographic infographics and sketches designed by 8 experienced visualization practitioners, leading to the development of a structured design space encompassing four critical dimensions: basic map representations, encoding channels, label design and placement, and highlighting techniques. Based on this design space, we developed a web-based authoring tool that allows users to explore and apply these design choices interactively. The tool's effectiveness was evaluated through a user study involving 12 participants without prior design experience. Participants were first required manually to create geographic infographics using provided datasets, then utilize our authoring tool to recreate and refine their initial drafts. We also conducted pre- and post-use assessments of the participants' knowledge of geographic infographic design. The findings revealed significant improvements in understanding and applying information encoding channels, highlighting techniques, and label design and placement strategies. These results demonstrate the tool's dual capacity to assist users in creating geographics while educating them on key visualization strategies. Our tool, therefore, empowers a broader audience, including those with limited design and visualization backgrounds, to effectively create and utilize geo-infographics.

1 Introduction

Infographics are a form of static visualization that transforms complex and voluminous data into clear, visually appealing representations, making intricate information accessible and engaging for a broad audience Naparin and Saad (2017). By combining visual elements with minimal text, infographics allow

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audiences to grasp the purpose quickly, focus on key points, and obtain an overview of the data Harrison et al. (2015). This method of visual communication is particularly effective across different cultural and linguistic backgrounds, enhancing comprehension and retention of information Mansour (2022); Lerman Ginzburg et al. (2021); Barral et al. (2020); Zhu et al. (2020). Infographics are widely used in various fields, such as education, where they improve learning outcomes by simplifying complex concepts Bicen and Beheshti (2017); Gebre and Polman (2016); business, where they present data-driven insights Young and Hinesly (2014); and healthcare, where they disseminate critical health information to enhance public health literacy Martin et al. (2019).

One specific and significant type of infographic is the geographic infographic, or geo-infographic, which combines traditional thematic mapping with infographic techniques to visually represent spatially relevant information in an engaging and understandable manner He et al. (2011). Geo-infographics have emerged as crucial tools in various fields. For example, Wang et al. (2022) utilized geo-infographics to express landscape ecological risk (LER), aiding environmental scientists in identifying high-risk areas. Similarly, Wu et al. (2023) employed geo-infographics to display the distribution and changes in land use patterns across different topographic gradients, providing valuable insights for land management and planning. Moreover, Dailey et al. (2025) extended the use of geo-infographics to governmental agencies, enabling effective communication of planning, evaluation, and risk-related information to the broader public.

Despite the growing prevalence of geo-infographics, creating them still requires a high level of expertise in visualization techniques and proficiency with advanced design tools like Adobe Illustrator or Photoshop. This necessity for specialized skills creates a barrier for many potential users. Moreover, existing commercial tools for map visualization, for example, Google Data Studio, Google Map, and Tableau, often lack the flexibility needed for creating highly customized geo-infographics, offering only a limited selection of visualization options.

To address these challenges, we propose a comprehensive design space for geo-infographics, which informs the development of geo-infographic authoring tools, *MapCraft*. We conducted a user study with 12 participants to evaluate its usability and educational impact. Our contributions can be summarized as follows:

(1) We decompose the design elements of geo-infographics into a comprehensive design space (see Fig. 1).
(2) We develop a web-based authoring tool, *MapCraft*, based on proposed design space, enabling a wide range of people to create geo-infographics.
(3) We offer findings and reflections based on results from user studies, which provide suggestions on future geographic data visualization and visualization authoring and education tools.

2 Related work

2.1 Geographic visualization

Geographic information has always been essential for understanding spatial data and navigating our world Wieczorek and Delmerico (2009); Feng et al. (2021). From ancient times, when maps were etched into the ground, to the advent of precise measurement tools and data collection technologies, the evolution of geographic visualization has been remarkable. Early maps provided basic spatial understanding, but modern techniques have enabled the creation of accurate and detailed maps. The development of geographic information systems (GIS) such us ArcGIS Scott and Janikas (2010) and QGIS (Quantum GIS) QGIS Development Team (2017) allows for the collection, storage, and analysis of spatial data, leading to more sophisticated and informative maps Wieczorek and Delmerico (2009).

The ability to layer information onto maps has further enhanced their utility, giving rise to interactive map systems. These systems enable users to explore and manipulate spatial data in real time. For instance, Chen et al. (2018) developed the Visual Analyzer for Urban Data (VAUD), which aggregates and visualizes various types of information—cyber, physical, social, and temporal—on maps, facilitating effective querying and exploration of urban datasets. Zhou et al. (2020) have created visualization interfaces for large-scale geo-tagged social media data, and Bosch et al. (2013) introduced ScatterBlogs2, a tool for real-time monitoring and analysis of microblog messages, crucial for emergency management and disaster response. Additionally, Splechtna et al. (2023) implemented an interactive map view allowing users to visualize various statistical values directly on maps, contextualizing spatial relationships to analyze urban economic health. Li et al. (2023) proposed GeoCamera, which democratizes map visualization by enabling users without filmmaking expertise to design camera movements for geographic data videos. Lei et al. (2023) developed GeoExplainer to help analysts create explainable documentation for spatial analyses. These examples underscore the versatility and indispensability of interactive maps in various applications.

While interactive map systems are powerful tools for exploring and analyzing spatial data, there is also a need to present and disseminate this data effectively. This is where geo-infographics come into play. Geo-infographics combine the precision of maps with the visual storytelling power of infographics, presenting spatially relevant information in a static yet visually appealing manner. They are designed to convey complex geographic data clearly and concisely, making them ideal for communication and information dissemination Roth (2021); Song et al. (2022). Unlike interactive maps that require user engagement for data exploration, geo-infographics provide a straightforward, static representation that can be easily shared and understood by a broad audience.

Both interactive maps and geo-infographics are valuable tools, each serving distinct purposes. Interactive maps excel in dynamic data exploration and real-time analysis, catering to users who need to interact with and manipulate spatial data Hogräfer et al. (2020). On the other hand, geo-infographics are suited for static presentations that prioritize clarity, visual appeal, and ease of understanding, making them ideal for conveying complex information to a wide audience without requiring user interaction He et al. (2011).

2.2 Infographics

Infographics transform complex and voluminous data into clear, visually compelling representations, simplifying intricate information into understandable graphic forms Harrison et al. (2015). They offer numerous advantages, such as enabling audiences to quickly grasp their purpose, focus on key points, and obtain an overview of the data through engaging visual elements Mansour (2022). The predominant use of graphics with minimal text makes infographics a powerful tool for communication across different cultural and linguistic backgrounds, effectively transcending language barriers Lerman Ginzburg et al. (2021).

Despite the widespread benefits and applications of infographics, creating high-quality infographics remains a challenging task. This complexity has led to the development of various authoring tools designed to facilitate the creation process. For instance, Wang et al. (2020) explored the general infographic design space at both the sheet and element levels and presented DataShot, which enables the automatic generation of fact sheets from tabular data. Additionally, Cui et al. (2020) developed a system capable of automatically generating proportional infographics from natural language statements. Lu et al. (2020) introduced the concept of visual information flow (VIF), elucidating the semantic structure that connects graphical data elements to convey information and stories, thereby aiding in the creation of better infographic designs and guiding the general visual organization of narratives. Zhu-Tian et al. (2020) applied deconstruction and reconstruction techniques to analyze various visual elements within bitmap timeline infographics, aiming to utilize the identified content for the automated generation of new infographics. Similarly, Matthew et al. Brehmer et al. (2017) proposed a temporal design space for narrative storytelling, deconstructing timelines into representation, scale, and layout dimensions. These tools aim to simplify the design process, making it more accessible for users with varying levels of expertise.

However, the creation process is still relatively cumbersome when it comes to geo-infographics, which integrate geographic data with infographic techniques. Geo-infographics are valuable for presenting spatially relevant information but require specialized knowledge and skills to design effectively. Current tools like Tableau and ManyEyes Viegas et al. (2007), although powerful, are not specifically designed for geo-infographics and lack comprehensive visualization methods for this purpose. While these tools can help users quickly create interactive maps or geo-infographics, they do not fully encompass all possible styles of geo-infographics. As a result, the available variety of geo-infographic styles in these systems is not as wide and comprehensive as what can be found in the market. Moreover, these tools do not list or support all design possibilities, restricting users' creativity and flexibility in creating geo-infographics. There is a significant need for dedicated authoring tools tailored specifically for geo-infographics. Such tools should support the detailed examination and categorization of geo-infographic elements, similar to how other infographics have been studied and developed. Drawing on insights from visualization grammars, which use a bottom-up approach starting from data and employing esthetic mappings to shape the visual form Wickham (2010), can inform the design of these tools. Our work addresses this gap by developing *MapCraft*, a geo-infographic authoring tool that integrates both creation and educational functionalities.

3 Methodology

Our study is founded on a systematic methodology that incorporates best practices in visualization research and design. This multifaceted strategy began with the compilation of a diverse dataset of 118 geo-infographics sourced from various platforms. Additionally, we involved eight experienced visualization practitioners who created hand-drawn geo-infographics to supplement design perspectives. The next phase involved the deconstruction of these geo-infographics to identify fundamental visual elements. This analysis led to the development of a design space encompassing four dimensions: basic map representations, encoding channels, label positions, and highlight techniques. These dimensions are mutually exclusive and provide a comprehensive framework for understanding geo-infographic design. Utilizing this design space, we developed a web-based authoring tool, *MapCraft*, allowing users to explore and apply these design principles digitally. To ensure the tool's effectiveness and usability, we conducted a user study with 12 participants who had limited or no data visualization experience. This study included usability inquiries and pre- and post-knowledge assessments to measure the educational impact of *MapCraft*. By adhering to this systematic methodology grounded in established visualization frameworks and user-centered development principles Wieczorek and Delmerico (2009), we aim to create a geo-infographic authoring tool that is a practical resource for educational and professional use.

4 Design space

To ensure comprehensive understanding of geo-infographics, we first conducted keyword searches across the two most commonly used platforms for finding infographics—Pinterest[1] and Google Images[2]—using multiple related keywords including "geo-infographics," "geographic infographics," and "map infographics." To further enrich our dataset, we supplemented these online sources with content from a visualization book dedicated entirely to high-quality infographics Rendgen (2012). From these combined sources, we selected 118 geo-infographics which meet the following 2 criteria (see examples in Fig. 2). First, the image must be of high quality, with clear text and visual design. Second, the infographic should clearly display or label the data used, ensuring the content is data-driven.

To further refine our understanding and ensure the practical applicability of our findings, we conducted reviews with eight participants who had considerable experience in data visualization. This group included 2 females and 6 males, aged between 20 and 30 (AVG=24.6, SD=2.7). Six participants were affiliated with the Human-Computer Interaction and Visualization Laboratory, comprising two doctoral students, three postgraduate students, and one undergraduate student. The remaining two participants were undergraduate students actively involved in multiple data visualization projects. All participants were majoring in computer-related programs and had hands-on experience with at least two visualization tools, including Python, Tableau, D3.js, Excel, and Figma.

The review process was structured into four stages, each lasting approximately half an hour. It began with an introduction to the review process and objectives to ensure participants understood the procedures and aims. This was followed by a pre-questionnaire to gather background information about the participants. Subsequently, participants were tasked with drawing two geo-infographics based on provided data: one depicting quantitative data related to population and the other illustrating categorical data concerning country information. We encouraged the experienced visualization practitioners to enumerate all possible methods they could think of and select what they considered the most suitable and effective approaches. Finally, participants were interviewed to explain their designs and provide suggestions for improvement.

Through this process, we collected 16 hand-drawn geo-infographics from experienced practitioners. Combined with the 118 geo-infographics gathered from various sources, this formed our corpus. To ensure consistency and accuracy in our analysis, two co-authors independently coded each geo-infographic across four key dimensions. We began by coding an initial sample of 20 geo-infographics to refine and confirm our coding scheme. After this initial phase, we applied the finalized coding scheme to the entire corpus, with both co-authors verifying each instance to ensure agreement. This process ultimately led to the development of our design space for geo-infographics, structured into four main dimensions: basic map representations, encoding channels, label design and placement, and techniques for highlighting important data points (see Fig. 1).

[1] https://www.pinterest.com/.

[2] https://images.google.com/.

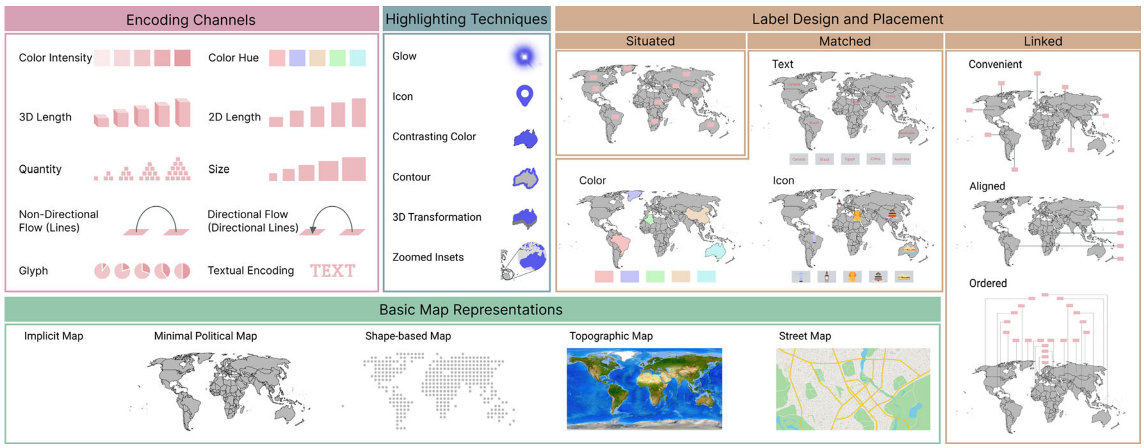


Fig. 1 The design space for geo-infographics (Note: An Implicit Map means the map itself is not visible, but further information are positioned based on map coordinates)

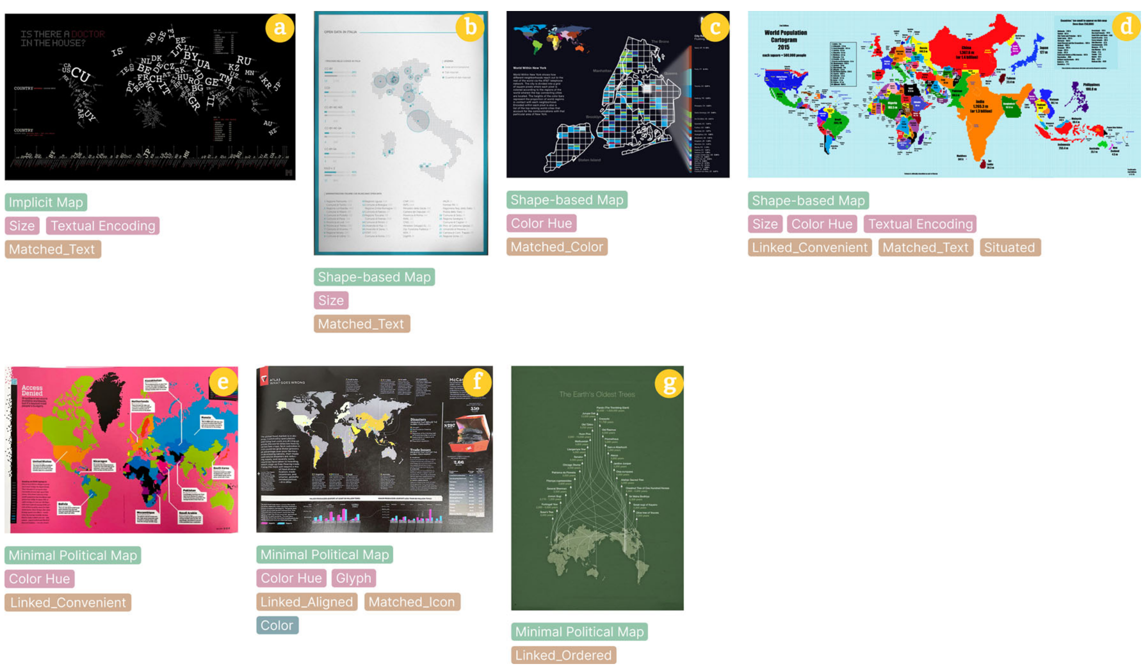


Fig. 2 Example geo-infographics in corpus

4.1 Dimension 1: basic map representations

The basic map representation refers to the depiction of geographic information alone, without any additional data overlays. It serves as the foundational visual layer in a geo-infographic, showing only the geographic context, such as borders, terrain, or locations. For instance, in a population map, the basic map would only display the geography itself—like country or region boundaries—without including population data or other thematic information. This base map anchors the rest of the infographic, ensuring that all other data elements correspond to the appropriate geographic locations.

IMPLICIT MAP. This category refers to geo-infographics where the underlying geographic information is not explicitly displayed (see Fig. 2a). Although no visible geographic elements such as borders, labels, or outlines are shown, the subsequent data is overlaid based on the hidden geographic framework. In other words, the geographic context is implied, and viewers can infer it from the placement of the data, allowing them to focus entirely on the data itself without being distracted by traditional map elements.

MINIMAL POLITICAL MAP. This type includes only the most basic geopolitical boundaries. This means that only the country's borders are shown on a world map. A national map might include just the borders between states or provinces. This minimalistic approach ensures that the geographic framework is clear without additional details that could distract from the presented main data.

SHAPE-BASED MAP. Shape-based maps utilize basic shapes, such as dots, squares, or custom icons, to form recognizable boundaries of countries, states, or regions. Unlike implicit maps, which lack visible geographic cues, shape-based maps offer a visual representation of geographic boundaries by arranging these shapes in ways that outline different areas. The shapes themselves do not encode additional data but are purely stylistic elements that help convey the geographic contours of regions.

These maps can be constructed using shapes of uniform size, creating a clear and precise boundary between areas. For instance (see Fig. 2b), a country could be depicted using an array of equally sized dots, forming a distinct and recognizable shape that accurately represents its borders. Alternatively, shape-based maps might use shapes of varying sizes to represent regions. In such cases (see Fig. 2c), while the overall geographic outline remains discernible, the boundaries between different regions may appear less precise. This approach can introduce a degree of abstraction, making the map visually engaging but potentially less accurate in depicting exact geographic boundaries.

TOPOGRAPHIC MAP. As the name implies, topographic maps illustrate topographic features like natural elevations and depressions. They provide the audience with a reference to topographic information, facilitating the display of additional details such as land use, climate zones, and natural resources.

STREET MAP. Street maps concentrate on smaller blocks within cities or countries. They depict urban features such as landmarks, roads, buildings, and traffic information.

4.2 Dimension 2: encoding channels

The encoding channel refers to the various visual variables used to convey key information on top of the basic map. In our analysis, we primarily drew on the design space of encoding channels proposed by Tamara Munzner (2016), considering both quantitative and categorical data. Based on the geo-infographics we collected and analyzed, we identified and summarized the most commonly used encoding channels employed in geo-infographics to effectively communicate the data.

COLOR (INTENSITY). Color intensity refers to the luminance or saturation of a color. This gradient is valuable for visualizing changes in quantitative data size, with low intensity denoting smaller values and high intensity signifying larger ones.

COLOR (HUE). Color hue denotes the pure spectrum of red, blue, and green colors. It is commonly employed to represent different categories or groups within the data. For instance, continents may be distinguished by assigning each a distinct hue—blue for Europe, green for Asia, yellow for Africa, red for the Americas, and orange for Oceania. Color hue can also represent quantitative data by mapping numeric variable values to distinct hues along a perceptually ordered color palette. For example, this gradation from blue to red symbolically illustrates the transition from cooler to warmer temperatures.

2D LENGTH. 2D length facilitates data representation within the geographic context by overlaying rectangles onto corresponding positions on a map. The height of each line or rectangle is directly proportional to the value of each data point.

3D LENGTH. 3D length employs three-dimensional rectangular prisms overlaid onto a basic map. Each prism's height correlates directly with the magnitude of the each data point.

SIZE. Size represents values through variations in the size of graphical elements such as different shapes, icons, or symbols. For instance, circles can represent retail stores, with their sizes indicating the number of sales at each store Peterson (2020). Another approach is to distort the geographic area of each region, such as a province or country, in proportion to a specific data value. This category can also be called "Cartogram" Gastner and Newman (2004); Tobler (2004). This method resizes the area to reflect the data magnitude (see Fig. 2d), often resulting in no longer geographically accurate shapes that effectively communicate the intended information.

QUANTITY. Quantity refers to using the number of graphical elements—such as shapes, icons, or symbols—to represent differences in numerical values across regions. For example, in a demographic map, a higher number of icons or figures in a specific area would indicate a larger population, with each icon representing a specific number of individuals. This approach visually conveys the variation in quantity between different geographic regions.

GLYPH. Glyphs are using complex icons or composite graphics for visually representing and communicating data Borgo et al. (2013). They can encapsulate multiple quantitative or categorical data points within a visual element. For example, different icons can represent various animals in different countries, or bar charts and pie charts can overlay a map to show demographic information such as age distribution or gender ratios within each country. A glyph can integrate multiple types of data; for example, available activities in the area, such as schools, offices, and restaurants, can be combined and presented together Zeng et al. (2017). This approach represents multiple variables or categories within a single glyph, maintaining visual clarity while conveying rich, layered information.

DIRECTIONAL FLOW (DIRECTIONAL LINES). Directed flow lines are used to describe sequential or directed movement or motion, such as migration patterns, trade routes, or flight paths Adrienko and Adrienko (2011). More detailed examinations of flow lines in geo-infographics can be found in Zhao et al.'s work Zhao et al. (2018).

NON-DIRECTIONAL FLOW (LINES). Non-directional flow lines represent connections between two places without implying a specific direction. These lines illustrate bidirectional or non-directional relationships, such as diplomatic relations or transportation links between cities. They can also be used to show distributions and intersections between collections, as in the case of the KelpFusion technique to show the distribution of different restaurant collections and the intersections between them on a map Meulemans et al. (2013).

TEXT **TEXT**. Text refers to using words directly as an encoding channel to convey information on the map. This approach is commonly employed when the data label is straightforward and can be represented purely through textual labels, without the need for additional visual variables. For example, when displaying each country's national animal, the names of the animals themselves are used rather than icons or images (see Fig. 2a).

4.2.1 Dual encoding compatibility

From corpus, we found that single-channel encodings form the basis of information representation, and many scenarios benefit from combining multiple channels to enhance data comprehension and retention. Recognizing this, we systematically examined the identified single channels and explored their potential pairings. This analysis provides insights and guidelines for effective dual encoding strategies in geo-infographic design. Figure 3 details the viable and non-viable combinations for such encoding strategies.

Channels with inherently similar properties cannot be combined. For instance, color intensity and color hue both encode information using the color spectrum and thus cannot be paired. Similarly, 2D length and 3D length fundamentally use the concept of length to represent data, making their combination inappropriate. Directional flow and non-directional flow, which represent directional relationships through arrows and non-directional relationships through lines, respectively, are mutually exclusive and cannot be integrated. Size and 2D/3D length cannot be effectively combined due to their similar properties; length can be regarded as the size of a line.

On the other hand, text can be combined with all other encoding channels. Color is another versatile encoding channel that can be combined with most other channels. Color intensity and color hue can be paired with other encoding channels. Specifically, combining color intensity with 2D/3D length can represent quantitative data, where lower values are depicted with lighter colors and shorter rectangles or cubes and higher values with darker colors and taller rectangles or cubes. The combination of color hue with 2D/3D length operates on the same principle, substituting light colors for lower numerical values and dark colors for higher numerical values. When the data has both category and quantity attributes, color hue can be used to distinguish categories, while 2D/3D length expresses the numerical size. For instance, color hue and 2D/3D length can represent categorical and quantitative GDP attributes, respectively, with color hue distinguishing between developed (blue), emerging (green), and developing (orange) nations. The GDP values are depicted through the vertical extent of 2D rectangles or 3D bars, where a taller bar corresponds to a larger GDP and a shorter bar to a smaller GDP. Similarly, color combined with size or quantity follows the same principle as color with 2D/3D length.

In specific scenarios, Glyphs cannot be combined with color. For example, icons of famous scenic spots or national flags possess multiple colors, making overlaying colors on them visually confusing. However, glyphs like triangles or pentagrams representing different data categories can accommodate color coding. For instance, a human-shaped glyph overlaying color encoding enhances the representation of population data. Directional flow and non-directional flow, representing data flow in geo-infographics, are mutually exclusive and cannot be combined. However, each can independently use a color overlay to encode data type and direction. Glyphs can encode quantitative attributes with varied sizes or indicate data importance

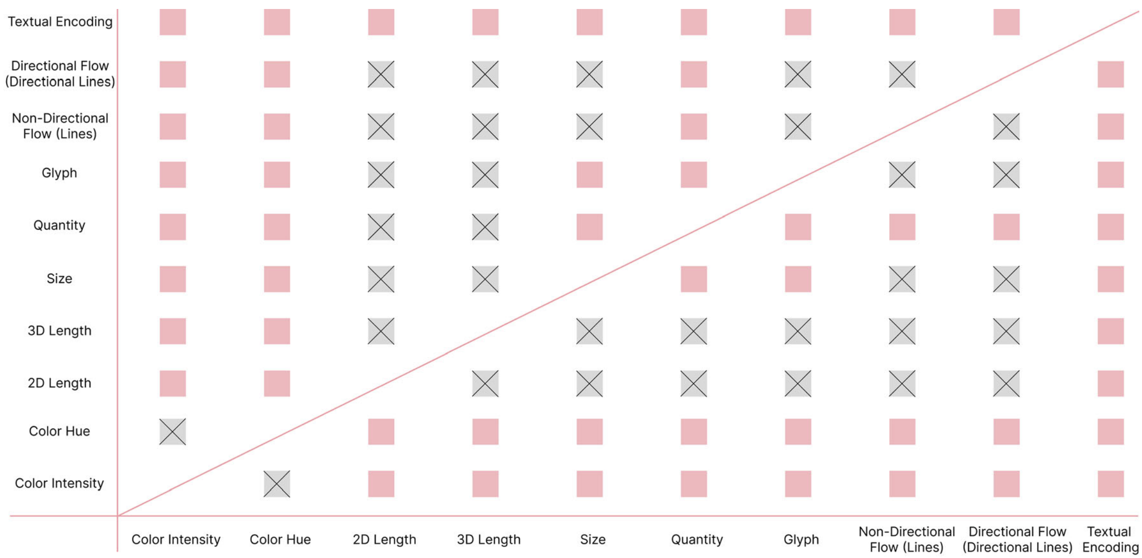


Fig. 3 Compatibility Matrix for Dual Encoding Channels. Filled squares indicate effective combinations; crosses (X) denote infeasible combinations

through glyph size. While size and quantity can theoretically be superimposed to express quantitative attributes, this may lead to audience confusion, as observed when both size and quantity equate to the same value, potentially misconstrued as multiplication. Quantity can also be used in combination with glyphs to display quantity data. It can also be combined with directional flow or non-directional flow to express the magnitude of the circulating data.

4.3 Dimension 3: label design and placement

Geo-infographics often need to convey a large amount of complex information. To fully convey the complexity and nuances of the given topic data, it is often necessary to supplement the primary visual encoding with additional annotations in a geo-infographic. The placement strategy for these labels can be categorized into three distinct approaches: situated, matched, and linked.

4.3.1 Situated

Situated labels are superimposed directly onto the map regions they represent. This direct overlay approach ensures a clear and immediate visual connection between the label and the corresponding geographic area, which is particularly useful when the map's regions are sufficiently large to accommodate the text without causing visual clutter.

4.3.2 Matched

Matched labels are used when the label information is complex or extensive, and separating the explanatory information from the map is beneficial. This approach uses visual encoding channels to establish clear and intuitive relationships between the map and the accompanying explanatory text. Common methods for creating these matches include color, icons, and text:

TEXT. This method involves placing concise, descriptive keywords or phrases (such as names of locations or addresses) directly on the map. These keywords act as prompts corresponding to more detailed explanations or annotations in a separate, often blank, infographic section. The reader can easily connect the brief text on the map with the extended information provided in the annotations by recognizing the keyword match.

ICON. Icons can also use as visual prompts on the map. These icons represent specific features or data points and are designed to correlate with larger, more detailed icons or illustrations in the explanatory section of the infographic. Icons can be particularly effective in scenarios where a visual representation is more easily recognizable than text.

COLOR. This technique involves assigning specific colors to map regions and then using the same colors for corresponding labels in the annotations. The color-coding system provides a visual link between the geographic data and the explanatory text, making it simple for viewers to identify which annotation pertains to which map feature. This method can also enhance the overall esthetic of the infographic by creating a cohesive color scheme.

4.3.3 Linked

These labels are connected to their target regions on the map as callouts through a visual link, such as a leader line or an arrow. Linked labels can be further categorized into three types based on its placements:

CONVENIENT. The labels for this type are strategically placed in open spaces near their corresponding map regions to prioritize ease of reference (see Fig. 2e). This positioning ensures that users can quickly identify the data associated with each region without cluttering the map itself.

ALIGNED. Labels of this type are arranged around the map's perimeter, creating a neat appearance (see Fig. 2f). This approach allows viewers to easily find supplementary information in a specific, consistent place rather than to search around the entire map. By placing the additional information in fixed areas, such as the top, bottom, or sides of the map where there is more space, this method enhances clarity and accessibility.

ORDERED. The deliberate arrangement of labels within the confines of a unified shape can profoundly enhance the narrative or esthetics of geo-infographic data. Specifically, when depicting forest resources, a collective label configuration can mimic the shape of a tree (see Fig. 2g). This technique not only reinforces the thematic message of the data but also organizes the labels in a visually appealing and meaningful way. As a result, these labels may enhance the viewer's understanding and retention of the data's context.

4.4 Dimension 4: highlighting techniques

A range of highlighting techniques have also been identified to guide viewers' attention toward specific sections of the geo-infographic.

 **GLOW**. This method uses a luminous point to signify a location, drawing the viewer's attention to a particular area as a focal point. For example, a glowing dot might highlight a city's location on a nighttime map.

 **ICON**. This method involves placing an icon like a map pin at the exact location of interest, directly drawing the viewer's attention to that point. For instance, this icon can highlight a tourist spot on a city map, making it easy for tourists to navigate.

 **CONTRASTING COLOR**. This method applies a color that contrasts with the rest of the map to a specific region, highlighting the area of interest. For example, a specific country might be shaded in a bright color to distinguish it from its neighbors on a geopolitical map.

 **3D TRANSFORMATION**. This method enhances the base map with three-dimensional effects, such as shadows or extrusions, creating a visual illusion of height and prominence.

 **CONTOUR**. This method outlines a region on the base map, helping to distinguish areas that are significant.

 **ZOOMED INSETS**. This method involved magnifying a specific map area that is too small to be represented adequately at its actual size. This technique is particularly useful for highlighting areas of great importance that are geographically small, such as an island. The enlarged section can be displayed in an adjacent blank space to avoid obstructing the view of the rest of the map. Alternatively, it can be overlaid directly on its original location, which may partially obscure surrounding areas and reduce the distraction of the viewer's attention.

5 Geo-infographic authoring tool: *MapCraft*

5.1 System design

Based on the proposed design space, we developed *MapCraft*, a tool designed to streamline the creation of geo-infographics (see Fig. 4). Users can upload their map-related data, select appropriate encoding channels, choose highlighting techniques, and design and place labels. The tool then allows users to export a customized geo-infographic.

Data Upload Interface. At the beginning, users are presented with the Data Upload Interface (see Fig. 4.1), where they can import JSON files. The JSON file should contain an array of objects, with each object including key-value pairs for the country name, the data to be visualized, and an optional label. An example of this format is shown in Fig. 5.

Authoring Interface. The *MapCraft* authoring interface (see Fig. 4.2) is consisting with two components: the Components Panel (see Fig. 4.2A) and the Canvas Panel (see Fig. 4.2B).

- **Components Panel**: Located on the left side, this panel allows users to select visual elements from four key dimensions of geo-infographic design: basic map representations, encoding channels, label design and placement, and highlighting techniques. Users can explore different design choices for each dimension, enhancing their understanding of how various encoding channels and design options affect the effectiveness and esthetics of the geo-infographic. The "dual encoding" feature within the Components Panel allows users to apply multiple encoding channels simultaneously. Based on the type of data to be encoded, the system will have a popup alert to remind users of inapplicable encoding channels and suggest alternative compatible options. This feature helps avoid conflicting encoding channels and assists in creating reasonable geo-infographics, especially for users with limited experience.
- **Canvas Panel**: Serving as the central workspace, this panel displays real-time updates based on the user's selections from the Components Panel. Users can see immediate visual feedback, enabling them to refine their designs for both effectiveness and visual appeal iteratively. Upon finalizing their design, users can export the geo-infographic as an SVG file using the "print" button, capturing the final design from the Canvas Panel.

Gallery and About Interfaces. The gallery interface (see Fig. 6) showcases examples created by experienced designers to inspire users, while the about interface (see Fig. 9 in Appendix) provides a brief overview and guidance on using the tool effectively.

5.2 Implementation

MapCraft was implemented using D3.js, Vue.js, and Node.js, ensuring a responsive and dynamic user experience.

6 Evaluation

To evaluate the value of *MapCraft*, we recruited 12 participants with an interest in visualization but no prior design experience. The goal was twofold: first, to assess whether users could effectively design geo-infographics using the tool, and second, to evaluate their overall experience and understanding of geo-infographics. Participants were tasked with creating geo-infographics in three stages: before using the system, while using the system, and after using the system. We collected both quantitative and qualitative data to assess how well *MapCraft* supported the design process and improved participants' knowledge of geo-infographics.

6.1 Participants and apparatus

Participants consisted of 12 undergraduate students (6 females and 6 males) aged between 18 and 22, with an average age of 19.5 years (SD = 1.02). All participants were computer science majors from the local university but lacked prior experience in visualization. These participants were specifically chosen as they represent our target user group—individuals who are challenged to create geo-infographics using existing visualization tools.

The tests were conducted in a school computer laboratory, utilizing AOC CU34G2X monitors, which are 34-inch LCD displays with a resolution of 3440 $\times$ 1440 pixels. This setting ensured a consistent and controlled environment for the participants to perform the required tasks.

6.2 Procedure

This study was conducted with ethical approval from the university. As Fig. 7 shows, the experimental procedure was structured into seven stages, lasting approximately one hour. It began with a brief overview of the experimental process and objectives, ensuring participants understood the procedures and aims. This stage also included obtaining consent and informing participants of their rights, including the ability to withdraw at any time, take breaks, and have their personal information protected. Next, participants completed a pre-questionnaire to gather background information (see Sect. 11.1 in Appendix) and assess their initial knowledge of designing geo-infographics. Following this, participants were tasked with drawing two geo-infographics based on provided data: one depicting quantitative population data and the other illustrating categorical country information. Participants then used *MapCraft* to create geo-infographics. After using the tool, participants modified their initial drawings independently. Subsequently, participants completed a post-questionnaire, which included the System Usability Scale (SUS) and the same knowledge assessment as in the pre-questionnaire. Finally, participants were interviewed to discuss their experience using *MapCraft*, provide comments on the design space and usability, and share their intentions for future use.

6.3 Data collection and analysis

We collected a rich set of data to assess the effectiveness and usability of *MapCraft*. Firstly, we gathered the original and modified drafts of geo-infographics created by hand and the graphics designed using *MapCraft* (see Figs. 10 and 11 in Appendix), recording the frequency of usage for each encoding channels, label design and placement, and highlighting techniques (see Fig. 8). Secondly, we assessed participants' initial and post-usage knowledge of geo-infographic visualization, including their understanding of encoding channels, label design and placement, highlighting techniques, and dual encoding implementation (see Sect. 11.2 in Appendix). Thirdly, we evaluated the System Usability Scale (SUS). Lastly, we conducted interviews to gather qualitative feedback, exploring participants' perceptions of the design space, challenges encountered during use, and their intentions for future use (see Sect. 11.3 in Appendix).

7 Results and discussion

7.1 Results

7.1.1 System Usability Scale (SUS)

The SUS yielded an overall score of 78.33, indicating a "Good" level of usability and placing *MapCraft* within the B grade category.

7.1.2 Geo-infographics design

As depicted in Fig. 8, we compared the frequency of visual element selection across three stages: hand-drawn geo-infographics prior to *MapCraft* use, geo-infographics created using *MapCraft*, and hand-drawn modifications post-*MapCraft* use.

First Drawings. In the initial hand-drawn stage, most participants struggled to visualize quantitative and categorical data effectively, preferring single encoding channels. Color was predominantly used for presenting information, and Linked Convenient was the most frequently used label design technique. Highlighting techniques were limited, with users primarily employing Icon and Contour.

Using *MapCraft*. During the use of *MapCraft*, users demonstrated increased diversity in encoding methods, with all provided methods being utilized. Dual encoding became more prevalent, and Linked Convenient and Matched Icon were the most frequently used label design techniques. Highlighting techniques became more varied with Enlarged Portions and Glow, indicating users' exploration of new methods. Additionally, all participants took an average of 10 minutes from their first encounter with the system to successfully produce two beautiful geo-infographics, with the longest adaptation time being only 16 minutes.

Modified Drawings. After using *MapCraft*, participants modified their initial drawings, showing significant improvement in their ability to encode data correctly. Dual encoding usage increased, and users paid greater attention to diverse encoding methods, with Linked Convenient remaining the most popular label design technique. Highlighting techniques became more balanced across different methods, indicating a deeper understanding of possible design choices.

Overall, users demonstrated improved performance on designing geo-infographics after using *MapCraft*. This improvement was reflected in their ability to handle conflicts, utilize dual encoding, and diversify visualization methods.

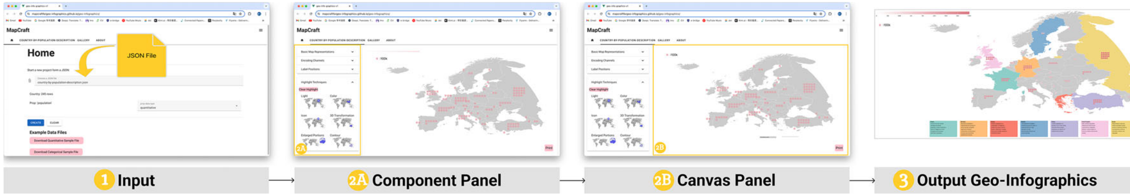
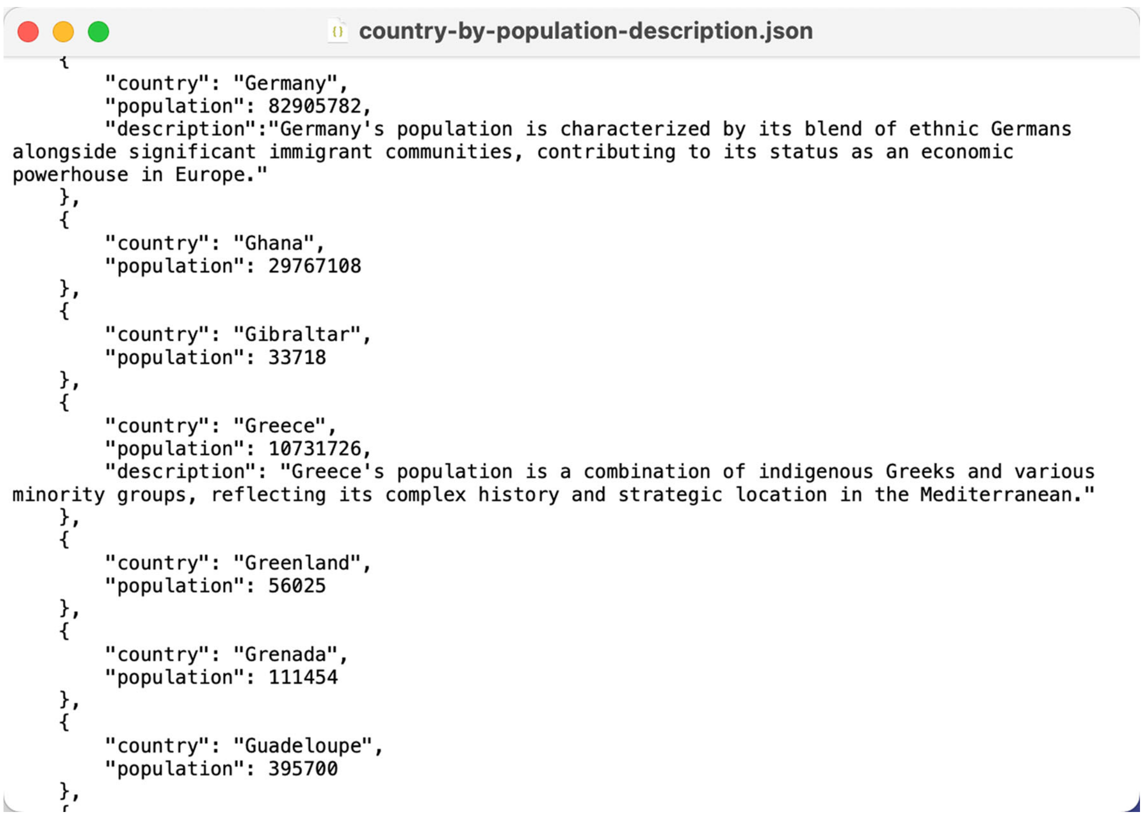


Fig. 4 The process of creating geo-infographics using *MapCraft*

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```


Fig. 5 Example of supported JSON file

7.1.3 Knowledge assessment

We analyzed the knowledge level from pre- and post-questionnaires, focusing on the methods users employ to design geo-infographics.

Before Using *MapCraft* Five participants struggled with encoding channels in the pre-questionnaire, and none could apply dual encoding methods correctly. Method selection in label design, placement, and highlighting techniques were very limited. Most users could present labels and add highlights, but often, their methods were inappropriate, such as using color for both encoding and highlighting simultaneously. Overall, users relied on basic methods, frequently using color for highlighting and simply filling the map with color rather than exploring various applications.

After Using *MapCraft* After using *MapCraft*, all participants could select at least one appropriate and correct method in these dimensions, with only one participant still confused about dual encoding. Participants began demonstrating creativity in highlighting techniques and combining various methods.

The comparison of knowledge before and after using *MapCraft* indicates that users showed enhanced competence in selecting and utilizing methods. Their design thoughts became more mature and feasible. The

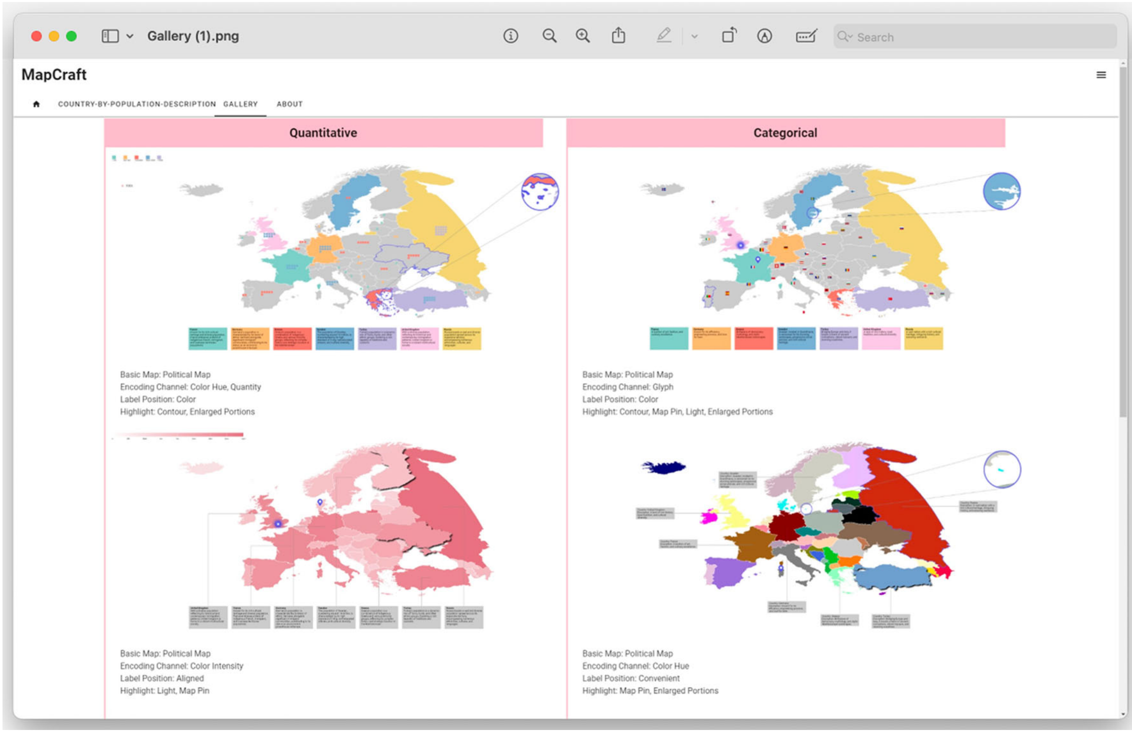

Fig. 6 Gallery interface

findings suggested users enriched their knowledge of geographic visualization methods after using our system. Participants were eager to explore and apply newly acquired, novel, and visually appealing techniques, leading to increased diversity in design method choices in the post-questionnaire responses.

7.1.4 Interview

Participants (P) endorsed the four-dimensional framework of our proposed design space for geo-infographic creation, describing it as logical, clear, and intuitive. For instance, P5 remarked that “dividing the creation of a geo-infographic into these four parts is logically sound,” and P2 noted, “You start with a map and then add elements one by one.” This feedback highlights the framework’s accessibility and ease of use, even for individuals lacking prior experience in data visualization. Several participants emphasized *MapCraft*’s ability to integrate various visual elements seamlessly. P3 mentioned the tool’s capacity to “combine a variety of visual elements, to arrange and piece them together,” while P9 appreciated how it allows users to “draw a map that can convey different pieces of information, integrating them seamlessly.” Participants agreed that *MapCraft* is highly user-friendly, convenient, and efficient. Participants such as P2 and P3 found it “much more convenient than hand-drawing or searching for other tools,” and P5 praised its ability to “quickly represent the information of countries and create a visually appealing map.” P12 and P13 highlighted its convenience and practical functionality, with P14 describing it as “quite practical.” However, P5 and P6 noted the need for extra instruction when prompts appear to avoid illegal operations. Additionally, some users require more exploration time and effort before they can appropriately apply the features. Regarding the dual encoding function, most users were attracted by its sophistication and were surprised by this novel visualization method. However, this new approach also introduced some learning costs. As P8 mentioned, the feature requires only “limited understanding” to get started, and as P14 stated, “It’s a little challenging but quite fun.”

Overall, the positive feedback suggests that the four-dimensional design space effectively guides users through the geo-infographic creation process, making it accessible and straightforward. *MapCraft* enables even novice users to produce esthetically pleasing and informative geo-infographics efficiently. Participants expressed strong intentions to utilize *MapCraft* for future geo-infographic creation, underscoring its practical value and usability.

7.2 Discussion

7.2.1 Limitation

Following Tullis's research Tullis and Stetson (2006), the SUS is a widely recognized method for assessing usability, providing a reliable score even with smaller sample sizes, such as 12 to 14 participants. Our participant pool of 12 lends credibility to our findings. However, 12 samples may not be sufficient for a comprehensive evaluation in other aspects, such as the knowledge test. While we maintained gender balance in our participant group of 6 males and 6 females, the age range was narrowly defined from 18 to 30, excluding participants from other age groups. Additionally, all participants were university-educated, either as undergraduates or postgraduates. This focus may have excluded perspectives from a broader, potentially less educated user base. However, considering our tool is for creating geo-infographics, it is arguable whether lower education levels are within our target demographic.

Furthermore, we reflect on our data analysis methodology, which focused on the diversity of participants' designs and creative ideas. We did not rigorously measure their accuracy in understanding various encoding channels. As an educational tool, future iterations may benefit from more serious assessments of educational outcomes. This could involve pre- and post-tests designed to evaluate the effectiveness of different encoding channels, ensuring a more thorough evaluation of the tool's educational impact.

7.2.2 Geo-infographics versus interactive map visualization

While utilizing geographic information, interactive map applications and geo-infographics serve different purposes and have distinct design requirements. We explored whether our design space for geo-infographics could be applied to interactive map visualizations. Interactive map applications like Google Maps[3] are dynamic platforms designed for real-time interaction and navigation, prioritizing accuracy over esthetics. Conversely, geo-infographics are static visual representations focused on clarity, visual appeal, and storytelling. Both formats share similarities in basic maps, encoding channels, and highlighting techniques. In geo-infographics, encoding channels and basic maps are chosen for esthetic appeal and accuracy, whereas in interactive maps, accuracy tends to be prioritized. As a result, while the same basic maps, encoding channels and highlighting techniques may be used in both formats, their selection and frequency can differ based on these priorities. Another significant difference lies in label design and placement. Geo-infographics often use various label types, including linked labels, to ensure all information is visible within the static layout. In contrast, interactive maps typically use interactive labels that appear upon user action, such as clicks or hovers, reducing the need for complex label arrangements and allowing for a cleaner interface.

7.2.3 Authoring and education

In evaluating *MapCraft*, we assessed the changes in participants' knowledge about geo-infographics and their ability to generate them. From positive results, we can define our tool as both an educational and an authoring tool, breaking traditional boundaries between these two categories.

1) *Comparison with Purely Educational and Purely Authoring Tools.*

- **Purely Educational Tools**: These tools are typically designed to convey information and educate users about specific topics. They often use demonstrations, tutorials, or static examples to illustrate concepts. In a geo-infographics context, a purely educational tool might display various dimensions of geo-infographic design—such as encoding channels, map types, and labeling techniques—without providing an interactive or hands-on component. The primary limitation of these tools is the lack of user engagement. Users may understand theoretical aspects but lack the opportunity to apply this knowledge in a practical setting, which can hinder deeper learning and retention.
- **Purely Authoring Tools**: These tools are designed to automate the creation process, often providing users with a set of inputs and generating visualizations automatically. They prioritize efficiency and ease of use. For geo-infographics, a purely authoring tool might allow users to input data and automatically generate a geo-infographic without requiring any design decisions from the user. The main drawback of these tools is their limited educational value. While they can produce visualizations quickly, users do not gain an understanding of the underlying design principles or improve their visualization skills through

[3] https://maps.google.com/.

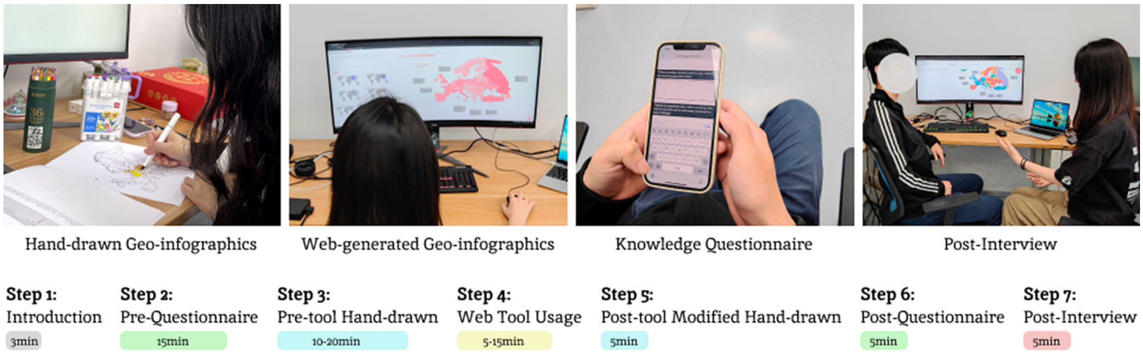

Fig. 7 The user study process

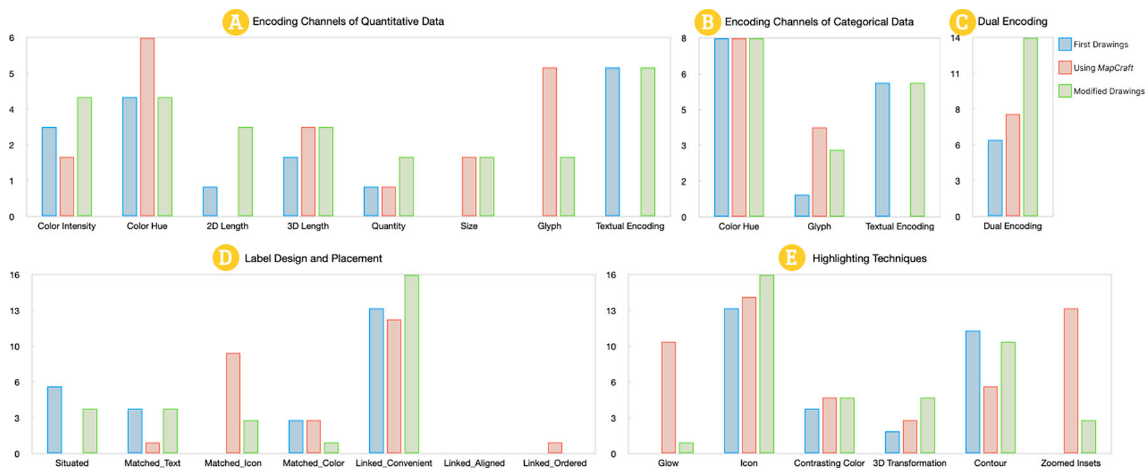

Fig. 8 Summary of the frequencies of various design techniques used by participants during the geo-infographic creation process

the process. For example, a powerful map visualization tool, Flourish[4], is often employed for map visualization and storytelling. It provides powerful creation tools but does not allow users to learn how to design geo-infographics. Inexperienced users may struggle to gain visualization knowledge and improve their design skills while using this tool.

2) *Balancing Automation and User Involvement.* The choice between purely automated tools and those requiring significant user involvement often depends on the target users and their needs:

- **Automated Tools**: These are ideal for users who need quick results without deep engagement in the design process. They are suitable for scenarios where efficiency is paramount, such as in business environments where time constraints are critical, or for users with limited visualization expertise who need to generate professional-looking results with minimal effort. In the system developed like DataShot Cui et al. (2020), infographics are generated by the system with pre-designed styles, sparing users the need to spend a significant amount of time learning or possessing visualization design experience. Users only need to make simple edits to obtain a professional infographic.
- **User-Involved Tools**: These tools benefit users who seek to understand and learn from the visualization process. They are suited for educational settings, training programs, and scenarios where the quality and customization of the final product are more important than the creation speed. Users in these contexts benefit from the hands-on experience and the opportunity to apply theoretical knowledge in practice.

[4] https://app.flourish.studio/projects.

Experienced users can create highly personalized and professional geo-infographics, while inexperienced users can also gain design experience with guidance from official documentation.

However, achieving the right balance between automation and user involvement is crucial. More automated tools might be preferable for professional environments where quick turnaround and consistency are essential. In contrast, educational tools benefit from greater user involvement, which fosters a deeper understanding of the subject matter.

8 Conclusion

This research started with an extensive analysis of 118 geo-infographics found online and design ideas from eight visualization practitioners. From these efforts, we developed a comprehensive design space for geo-infographic design. Based on the design space, we created *MapCraft*, a web-based authoring tool designed to simplify geo-infographics creation. Our user study with 12 potential users demonstrated that *MapCraft* effectively assists users in creating high-quality geo-infographics while enhancing their understanding of diverse geo-infographic design choices. The tool was found to be user-friendly, straightforward, and valuable for users. Additionally, future advancements could focus on increasing automation and intelligence within the tool, thereby reducing the need for extensive user education and enabling faster infographic creation.

Appendix A: Complementary user interfaces

ABOUT interface

Figure 9 shows the interface of ABOUT.

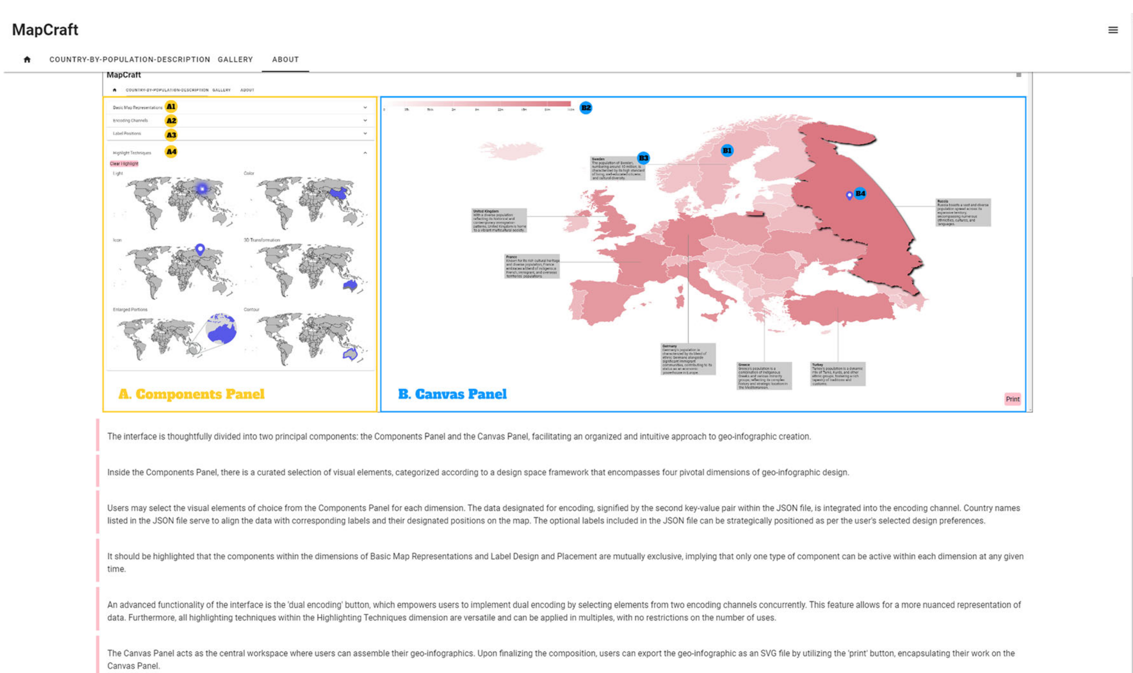

Fig. 9 About interface

Appendix B: Collected geo-infographics created by users

Figures 10 and 11 show the geo-infographics created by users.

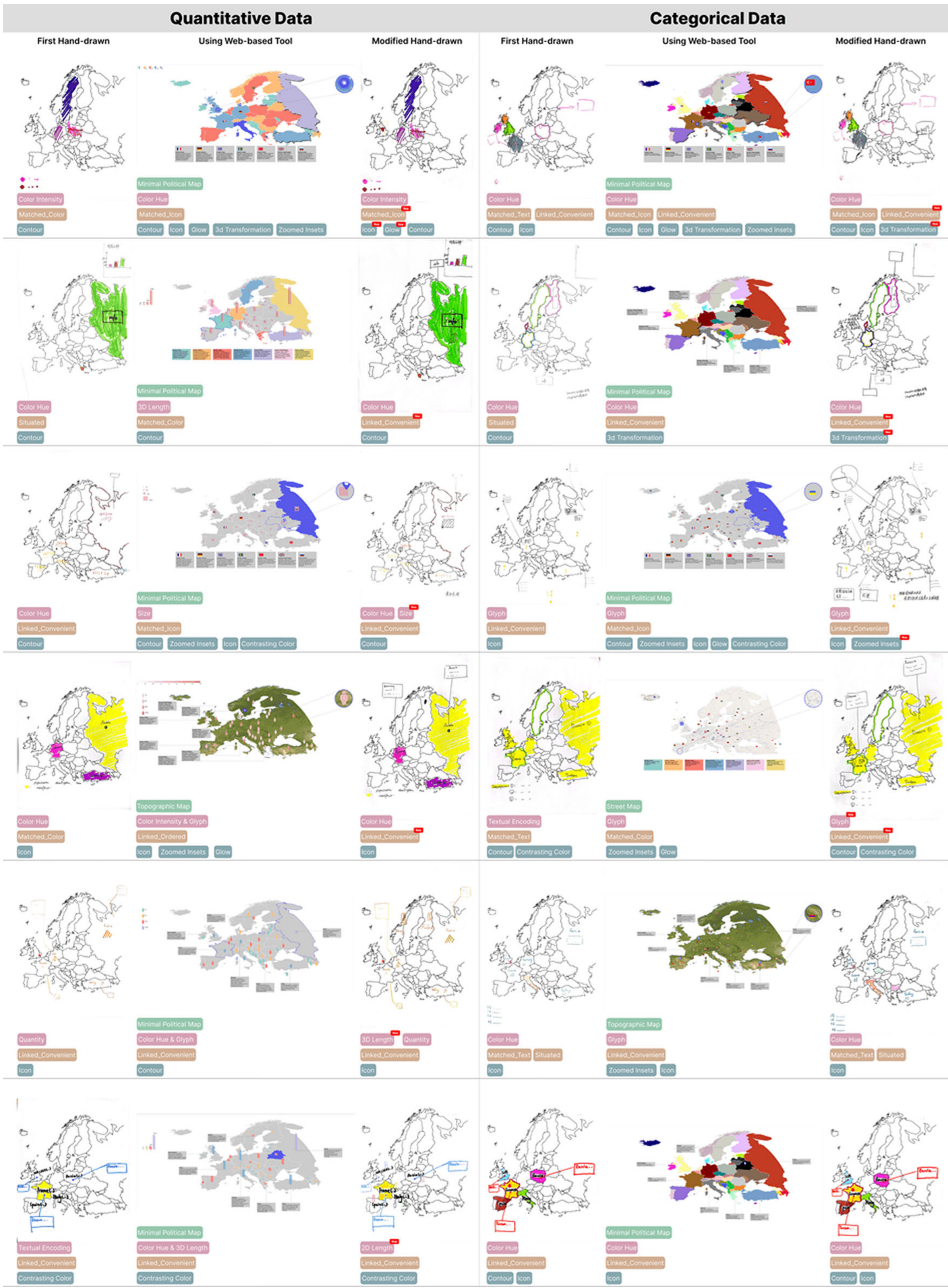

Fig. 10 Geo-infographics created by users

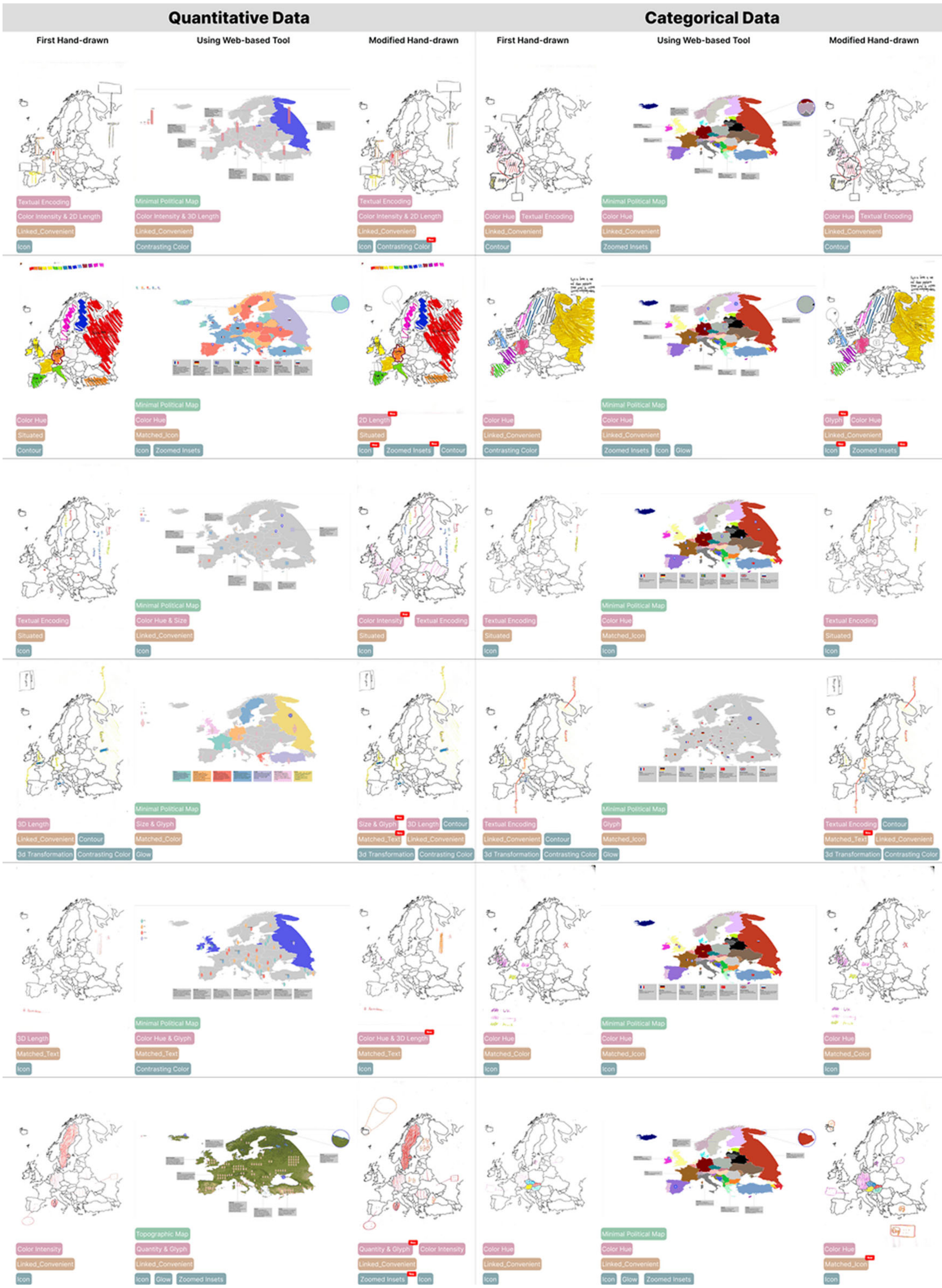

Fig. 11 Geo-infographics created by users

Appendix C: User study questionnaire

Demographic background

Here are the contents of the demographic background questionnaire in the pre-questionnaire, consisting of six short answer questions and a multiple choice question.

- **Question 1:** Age.
- **Question 2:** Gender
- **Question 3:** Filed of Study or Profession.
- **Question 4:** Have you had any experience with data visualization?
- **Question 5 (multiple choice question):** Which of the following tools have you used for data visualization?
  - Microsoft Excel
  - Tableau
  - Google Charts
  - D3.js
  - R (ggplot2, Plotly)
  - Python (Matplotlib, Seaborn, Plotly)
  - Figma
  - Other
- **Question 6:** Have you had any experience with geo-infographics or interactive maps websites?
- **Question 7:** Self-assessment of confidence level in design geo-infographic.

Geo-infographics designing knowledge

Here are the contents of the geo-infographics designing knowledge assessment in the pre- and post-questionnaire, consisting of eight short answer questions.

- **Question 1:** What encoding channels come to your mind for representing population data?
- **Question 2:** What encoding channels come to your mind for representing country information data?
- **Question 3:** Based on population data, which encoding channels do you think can be effectively combined for dual encoding?
- **Question 4:** Trying to add annotation in geo-infographic, what placement or match method can you think of?
- **Question 5:** What methods can you think of for highlighting within a geo-infographic?
- **Question 6:** Which encoding channels within the design space do you think are appropriate for population data?
- **Question 7:** Which encoding channels within the design space do you think are appropriate for country information data?
- **Question 8:** Which encoding channels within the design space do you think can be effectively combined for dual encoding based on population data?

Interview

Here are the questions in the interview.

- **Question 1:** What tool features are particularly useful for you to complete tasks? Please explain the reason.
- **Question 2:** What difficulties or challenges did you encounter while using *MapCraft*?
- **Question 3:** Do you think it is reasonable to categorize visual elements into basic map representations, encoding channels, label design and placement, and highlighting techniques? Is it easy to understand? Has it caused you any trouble?
- **Question 4:** Do you plan to continue using this tool in future projects? Why or why not? What factors will influence your decision?

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