Designing Within the Lines: Practitioners' Perspectives and Visualisation Tool Evaluation in the Arabic Context

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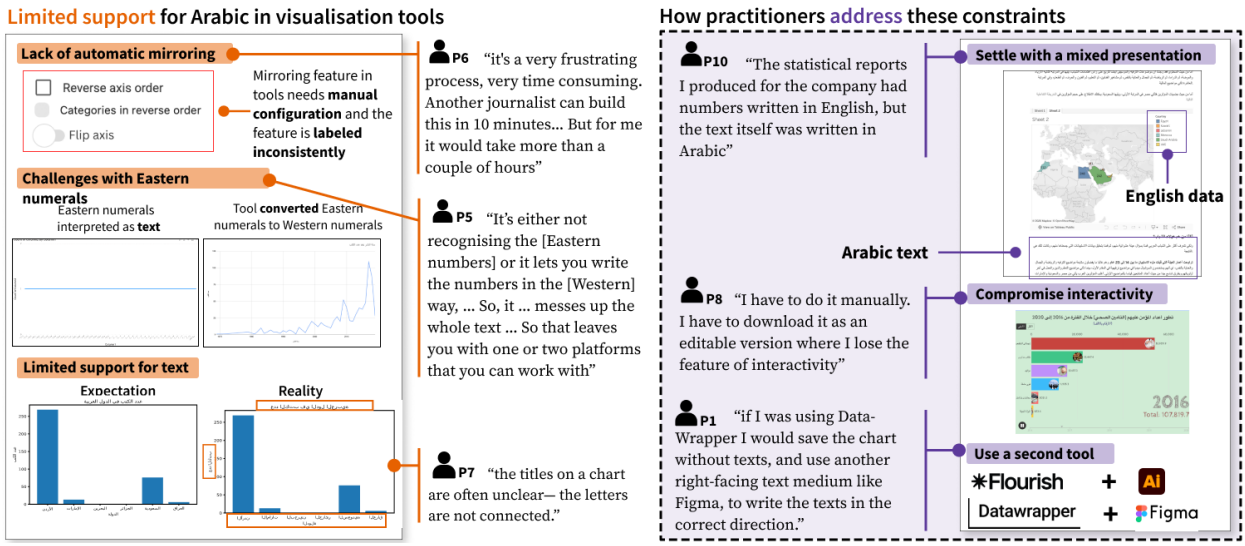

Figure 1: A snapshot of the challenges faced by practitioners using visualisation authoring tools with Arabic scripts and how they address them. These are based on an analytical evaluation of seven visualisation tools and interviews with 11 Arab practitioners.

Abstract— Design guidelines and best practices serve as references that support designers throughout the visualisation design process. While considerable effort has identified the elements that contribute to effective data visualisations, little attention has been paid to how language (scripts and reading direction), tool support, and cultural context also shape design decisions. As a result, assumptions of homogeneity persist, with visualisation practices predominantly benefiting users of English and left-to-right (LTR) scripts while overlooking the needs of over two billion Arabic script users. We investigate how Arabic-speaking visualisation practitioners design for right-to-left (RTL) scripts. We report on an analytical evaluation of seven popular GUI-based visualisation authoring tools using an Arabic dataset complemented by interviews with 11 Arabic-speaking practitioners across journalism, design, and data analysis. Our findings reveal that visualisation practitioners constantly negotiate tensions between Arabic reading conventions, "universal" LTR visual norms, and limited tool support for Arabic text, Eastern numerals, and maps. They engage in substantial labour, such as manually mirroring charts, fixing alignment issues, and stitching together multi-tool workflows, while making strategic compromises in language choice, interactivity, and chart type. Our tool analysis further reveals fragmented, inconsistent support for RTL mirroring, poor numeral rendering, and map defaults that encode geopolitical assumptions. In light of these findings, we discuss how RTL visualisation work is carried out under many constraints that affect agency and creativity. We argue that visualisation tools and defaults operationalise linguistic and geopolitical power in RTL contexts, and offer research directions and design implications that more robustly support RTL practitioners. Supplementary material: https://osf.io/8esbf.

Index Terms—Visualizations, Arabic Visualizations, Right to Left, Design Practice, Tool Comparison

1 Introduction

The widespread adoption of technology has expanded the number and diversity of users who encounter, interpret, and rely on visualisations every day. Yet, visualisation research predominantly focused on users from North America [41]. Therefore, insights from empirical research may not apply to non-WEIRD (Western, educated, industrialised, rich, and democratic) populations [35]. Considering only WEIRD populations leads to treating English as the default, reinforcing homogeneity and obscuring diversity. While English accounts for more than 60% of internet content [17], other scripts, such as Arabic, written from right-to-left (RTL), are also widely used, with over two billion users [3].

The importance of considering culture, language, and its directionality lies in fundamental differences in perception and preference. Arunkumar *et al.* [10] show that bilingual users prefer English annotations in a chart for surgical precision and Native-language annotations for holistic understanding. In colour, Gibson *et al.* [30] showed that colour names vary across cultures due to communication needs and industrialisation. Similarly, Afsari *et al.* [5] found that RTL script users varied in their viewing behaviour, while those who use left-to-right (LTR) scripts showed stability and bias to viewing from the left.

The issue extends beyond linguistic variation to encompass fundamental visuo-spatial orientations shaped by script direction [25, 28].

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Prior work [7] mapping the visualisation design space in Arabic data-driven articles has demonstrated ad-hoc adaptations, but these practices remain inconsistent and rarely grounded in empirical evidence. This inconsistency might also stem from how the visualisation tools support the designers' work. Visualisation authoring tools are powerful; prior research [61] shows that visualisation designers tend to avoid using embellishments, even when aware of their benefits for their audiences, due to a lack of appropriate tools. The lack of characterisation of the extent to which widely used visualisation authoring tools support Arabic script, Eastern numerals, bidirectional text, and RTL mirroring remains unclear, particularly on how it might drive RTL design decisions in practice. In this work, we pose the following research questions:

- RQ1: How do visualisation practitioners navigate design decisions when creating Arabic visualisations?
- RQ2: How do tool features or guidelines support them in addressing script-specific and cultural challenges during the design process?

To address these questions, we conducted two complementary investigations. First, using an Arabic dataset [8], we evaluated seven popular Graphical User Interface (GUI)-based visualisation authoring tools: Microsoft Excel, Tableau, Power BI, Flourish, Datawrapper, Google Sheets, and RAWGraphs. Given the identified limitations of the tools, we interviewed 11 Arabic-speaking visualisation practitioners across journalism, design, and data analysis. We examined how they reason about directionality, navigate tool limitations, and what are the processes behind their design decisions.

Our results reveal shortcomings and inconsistencies in the visualisation tools' support for Arabic scripts and RTL design. While some tools provide partial mirroring options, these are unevenly implemented and labelled; Eastern numerals are frequently misrecognised as text, and map defaults sometimes alter location labels and boundaries. These limitations stem partially from the lack of control granted to the practitioner and require additional time and effort on foundational design elements, thereby compromising their creativity. The tools we analysed were predominantly designed for English and follow a LTR convention. In fact, even while writing this manuscript, we encountered challenges in including Arabic text within the template, suggesting a deviation from the norm. We also observed that the interviewees themselves reinforced the stance of homogeneity by assuming their audiences' data visualisation literacy and habitual reading from their own experiences.

We reflect on our findings in light of prior work on visualisation conventions and the rhetorical use of visualisations, and argue that there is an infrastructural asymmetry, demonstrating how defaults in visualisation tools privilege LTR conventions, along with calls for action. By highlighting the interplay between cultural contexts and technical infrastructures, our work not only benefits Arab practitioners but also contributes to broader inclusivity.

2 Background

We review the literature on visualisation design practice in relation to RTL scripts, the impact of language and culture on visualisation interpretation, and the state of visualisation authoring tools.

2.1 RTL Design and Visualisations in Practice

The effectiveness of data visualisations hinges on the design practices which encompass not only the technical execution, but also the series of deliberate design decisions. These decisions help structure how data is presented, what to include or omit in the encoding, such as colour, chart type, annotations, etc. Prior work has mapped the landscape of visualisation design practices across domains, such as data-driven articles [33], anthropographics [54], thumbnail visualisations [43], and data comics [12]. Other research has also contributed to our understanding of data visualisation practices. For example, Parsons *et al.* [60] conducted a survey where they identified design principles (*e.g.*, data-ink ratio, cognitive load) that practitioners use or are familiar with. Similarly, interviews with practitioners helped understand their design process [59] and the source of their inspiration [13]. Today, modern visualisation design practices are shaped by widely adopted tools and practitioners' design guidelines (*e.g.*, [6, 21, 57]).

However, factors such as the designer's language, their culture, and the cultural contexts in which they operate are rarely considered in understanding the visualisation design process, leaving open questions about how practices translate across contexts. Research in adjacent fields like HCI and UI have extensively addressed cross-cultural adaptation through internationalisation (i18n) and localisation (l10n) [51, 69], defining adjustments for RTL contexts such as text alignment, layout mirroring, and bidirectional text support [11, 51]. Industry standards (*e.g.*, W3C [2]), and design systems (*e.g.*, Google Material Design [1]) also formalise these principles, although they primarily target user interfaces and navigation elements rather than the layout of data-driven graphs. In data visualisation, applying these principles might not be trivial for designers, and requires coordination between tool support, design processes, and an understanding of RTL audiences' expectations for visual encodings of data.

In this work, we address this gap, asking what happens when creating visualisations for RTL audiences using tools and guidance grounded in LTR conventions? Focusing on Arabic and RTL contexts, we foreground the perspective of RTL data visualisation practitioners who come from understudied geographical areas, and design for understudied languages in the field of data visualisation.

2.2 Reading direction and visualisation interpretation

Reading direction is closely embedded in the perceptual process of how individuals scan and interpret data visualisation. Research in cognitive and cross-cultural psychology shows that habitual reading/writing directions (*e.g.* RTL, LTR) bias how people attend to, scan, and organise visual information [4, 25, 28]. For example, Arabic and Hebrew readers tend to prefer rightward directions when judging motion, sequences, or temporal progress, compared to English readers [50, 78]. These effects or directional biases can be dynamic and learned. Göbel *et al.* found that pre-literate children from LTR and RTL cultures exhibit different default counting directions, which can temporarily reverse after short shared-reading experiences [31]. This suggests that reading-direction conventions are culturally acquired and shaped by the context in which the materials are consumed. For data visualisations in RTL context, this challenges the universality of LTR assumptions in visualisation design and highlights the impact of layout direction on interpretation.

In data visualisation, reading direction habits and biases have been linked to how people interpret visual encodings. Directional biases influence where viewers attend first when scanning a visualisation [72], and common charts such as bar charts, timelines, and scatterplots tend to align with habitual reading flow, such that orientation and axis placement can impact both comprehension and perceived naturalness [39]. Cross-cultural research further shows that spatial metaphors such as "progress", "increase", or "future" are interpreted differently across reading traditions [28], suggesting a broader role of directionality in shaping how visual information is understood.

Our knowledge about human perception in visualisation is mostly based on LTR script users, with English as the dominant language of research and pedagogy [65]. Cross-cultural data visualisation research on Arabic or RTL contexts show that Arabic-speaking users have different interpretation and preferences with basic chart styles [10, 32, 66], and designers rely on ad hoc strategies like mirroring, axis reversal, mixed directions to reconcile linguistic and graphical conventions [7]. We investigate how creators of RTL data visualisation reason about these adaptations. Because visual elements and the language through text are interrelated, complementary channels that readers integrate together [34, 75], we approach these adaptations holistically. Understanding when creators align or separate linguistic and visual directions is key to advancing culturally inclusive visualisation practices.

2.3 Evaluating Data Visualisation Authoring Tools

Data visualisation tools are central to the design process, motivating their evaluation across domains [15, 37, 68, 73]. As mainstream tools such as Tableau, Power BI, Microsoft Excel, and Google Sheets

are widely used beyond scientific communication and among non-programmers [20], examining their capabilities is key to understanding how they enable or constrain design practice. Prior work has evaluated these tools by comparing their usability, functionality, and support for designers' workflows. Common approaches involve applying a reference dataset across tools and analysing the resulting outputs or user processes. For instance, Negi *et al.* [55] compared Tableau, Power BI, Looker Studio, and Qlik Sense for rendering large-scale and real-time data; Huang *et al.* [37] examined how dashboard developers used Tableau, Spotfire, Power BI, and R Shiny for presenting scientific data in the health domain. Other studies have also assessed usability [55], support for interactivity and other visualisation techniques [71], scalability [58], and workflow integration [49].

These evaluations provide valuable insights into tool capabilities and inform practitioners' choices based on organisational needs, data scale, and desired design outcomes [15, 37, 47]. However, they largely foreground datasets and defaults aligned with LTR scripts, and thus rarely examine how popular tools support RTL visualisation design. Because tool defaults shape what is easy or difficult to produce, the limited visibility of Arabic-script and RTL support in features and settings remains a critical gap. In this work, we address this gap and explore the relationship between the technical and functional affordances of tools and practitioners' experiences in RTL contexts.

3 Analytical Evaluation of Visualisation Tools

To understand how existing visualisation authoring tools support RTL visualisations, we performed an analytical evaluation. This step is necessary not only to understand the tool's limitations, but also to comprehend the design decision process practitioners follow when designing Arabic visualisations. In the following sections, we describe our method for testing visualisation tools' support for Arabic scripts.

3.1 Visualisation authoring tools

We evaluated seven visualisation authoring tools on their support for Arabic scripts. We utilised the dataset published by Alebri *et al.* [7] where they identified that Flourish, Highcharts, and D3 have been used in generating some of the visualisations found in Arabic data-driven articles. We also based our selection on the most used tools identified through the state of the industry survey (which included designers, journalists, and data analysts) conducted by the Data Visualisation Society in 2024 [20]: Microsoft Excel, Tableau, Google Sheets, Python, Figma, R, Power BI, Adobe Illustrator, D3, Datawrapper, Flourish, and RAWGraphs. We focused on GUI-based tools and excluded code-based tools (e.g., Python libraries, R), tools that require plugins to generate charts (e.g., Figma), and tools primarily used for editing (e.g., Illustrator). Therefore, we evaluated: *Microsoft Excel, Tableau, Power BI, Flourish, Datawrapper, Google Sheets, and RAWGraphs*.

3.2 Dataset

We used the Jamloon Arabic Book dataset [8] to evaluate the visualisation tools' support for RTL scripts. We selected this dataset as it contained time-series, numerical, and categorical data, and the textual data was in Arabic. For geographical data, we extracted the country publication from the publisher column.We later selected only the books that had an entry for the country column. The original dataset contained Western numbers (e.g., 1, 2, 3); therefore, the native Arabic-speaking authors manually created a version with Eastern numbers ٣ ،٢ ،١.

The dataset is available in the supplementary material. The aim of preparing this dataset was to create a **line chart** which displays the number of publications in each year, a **bar chart**, which displays the number of publications in each country, and a **map chart** displaying the number of publications in a selection of Arab countries. An example of these charts is shown in Fig. 1 (all charts are in supplementary material).

3.3 Coding Process

We did not find existing evaluation criteria of visualisation authoring tools in terms of language and direction support; our coding was informed by prior work evaluating visualisation authoring tools generally. Using a deductive approach, we annotated each tool based on three categories: tool characteristics, community support, and default charts. The tool characteristic category was drawn from related work ([15,36]), which included chart type support, interactivity, and tool usability. Next, the community support category was informed by the compatibility support criteria of Huang *et al.*'s for visualisation authoring tools regarding language and direction support [36]. Finally, the default chart category was drawn from Behrisch *et al.*'s [15] and Alebri *et al.*'s work [7], where the data type support (e.g., text and numerical rendering) and the visual element's positions and directions in a chart were evaluated. The first and third authors, who carried out the coding process, are native Arabic speakers, which is important for exploring the tools in Arabic. Each of these coders carried out the coding process independently and met afterwards to resolve disagreements by either recreating the default chart or testing a feature. The visualisations (bar, line, map) were generated using the default settings, without any modifications, to ensure consistency in our analysis. Each coder captured a screenshot of the output for comparison and conducted the coding during the same period to minimise discrepancies caused by potential tool updates.

3.4 Evaluation Criteria

We considered the tool's characteristics, community support, and the default chart type (bar, line, map). See Tab. 1 for a detailed codebook definition. First, tool characteristics included the following elements: *Tool support for Arabic language, UI support for RTL, platform access, license, primary user group, chart types supported, RTL mirroring support, interactivity, calendar format supported, and font support*. Second, community support consisted of *Arabic documentation availability and community support for RTL issues*. Third, default chart coded the directionality, position, textual, and numerical rendering of bar, line, and map charts generated using the default setting. For maps, we restricted our evaluation to choropleth maps as they are widely supported by most visualisation tools. The default chart evaluation was performed twice for each tool, using Eastern and Western numerals.

3.5 Results and Analysis

We assessed the tools' characteristics and capabilities for supporting Arabic scripts by rendering our Arabic datasets to each tool to evaluate their default configurations. *Overall, we observed a lack of support for Arabic scripts, particularly for Eastern numerals as shown in Tab. 3*. Microsoft Excel performed best among the tools, particularly for its characteristics (see Tab. 2), and for its consistency in generating default charts for both datasets. Due to space constraints, we only report the most important results in Tab. 2 and Tab. 3. We also assign binary values to features. For instance, for the RTL mirroring support feature, we consider a tool to possess this feature if it provides any form of mirroring support (*e.g.* text, only X-axis or offer it only on the browser version). For full details, refer to the supplementary material. Next, we report our key results based on our evaluation criteria.

3.5.1 Tool characteristics and community support

The majority of the tools (above 71%) offer some kind of RTL mirroring support to reverse any elements of the chart (see Tab. 2). For instance, Flourish allowed customising the reading direction for text elements and icons only. Google Sheets allowed reversing the X-axis only. Power BI allowed mirroring only the Y-axis position. On the other hand, Excel and Datawrapper allowed reversing both axes. We also observed an inconsistency in the label for the RTL mirroring feature. For instance, Excel labelled it as "Categories in reverse order", Datawrapper required specifying the output locale under layout, Flourish used "Reading direction", Power BI used "switch axis position", and Google Sheets used "Reverse axis order".

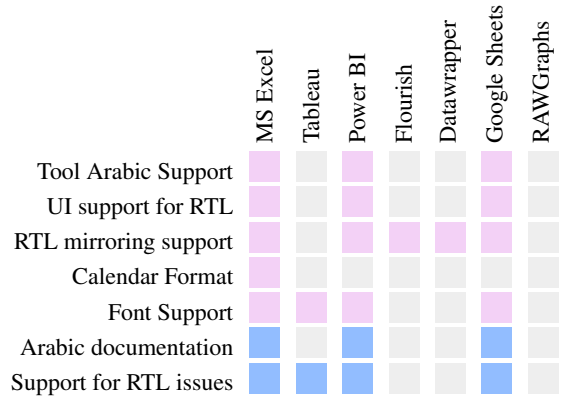
Calendar format was poorly supported by most tools where alternative calendars to the Gregorian calendar were not offered. On the other hand, Microsoft Excel offered Hijri and Um Al Qura, which are common in Arab countries. Most tools (above 57%) provided Arabic font support and had active community support for RTL issues. We found that most of these tools offered one or two default Arabic fonts. Yet, we did not investigate the level of support.

Table 1: Codebook guide for evaluating the support for Arabic scripts in the analysed visualisation authoring tools.

Name	Description
Tool characteristics	
Tool Arabic support	Does the tool exist in a version in Arabic? (y, n,y in premium)
UI support for RTL	How does the UI switch to a RTL layout if the language is set to Arabic (*e.g.* All mirrored, labels translated)
Platform access	How can the tool be accessed (Desktop, web-based, both)
License	What are the available plans for the tool? (*e.g.* Commercial, Freemium, Open source, Free)
Primary user group	Who are the primary users for the tool? (*e.g.* Data Analysts, Developers, General Public, Researchers, Others)
Chart types supported	The chart types that can be generated (*e.g.* BarChart, LineChart)
RTL mirroring support	Can chart be mirrored? (y-one step, y-multiple steps, n)
Interactivity	Does the tool allow creating interactive visualisations? (y/n)
Calendar format	Does the tool support calendars other than the Gregorian calendar (e.g., Hijri, Hebrew)? (y/n)
Font support	Fonts available for Arabic script (Included in defaults, Configurable, No support)
Community support	
Arabic documentation availability	Does the tool provide documentation in Arabic? (y/n)
Community support for RTL issues	Is there a community support for RTL issues? (Active, Somewhat active, Inactive, Does not exist)
Default charts (barchart, linechart, map using Eastern numerals (٣ ،٢ ،١) and Western numerals (1, 2, 3))	
Arabic text rendering	Correctly render axis Arabic text? (y/n)
Bi-directional text handling	Can it handle AR text with EN text or numerals? tested with writing a title (y/n)
Eastern number rendering	Does the tool correctly render axis Eastern numbers? (y/n)
Legend alignment	Where's the legend placed in maps? (*e.g.* Left-aligned, Right-aligned, Configurable, couldn't display (C/D))
X-axis direction	What is the X-axis direction for the numerical axis? (LTR, RTL, Configurable, C/D, N/A)
Y-axis position	What is the Y-axis position in bar and linecharts?(Left, Right, Configurable, C/D, N/A)
Tooltip and annotation position	Where is the position of the tooltip? (*e.g.* Left-to-pointer, Right-to-pointer, Dynamic, Configurable, C/D, N/A)

RAWGraphs showed the weakest support for Arabic content (see Tab. 2), which is unsurprising given its origin as an open-source academic project built for research rather than commercial deployment. Surprisingly, mainstream tools such as Tableau, Flourish, and Datawrapper did not perform substantially better, indicating that even mature industry products have not prioritised Arabic language integration.

Table 2: The analysed visualisation authoring tools and their support for Arabic. Purple indicate the availability of the tool characteristic, blue denote the availability of community support, and refers to no support. The full analysis in the supplementary material.



3.5.2 Default charts

We evaluated the default charts generated by the seven visualisation tools using the same dataset. We considered the tool successful, unless it rendered a chart where the numbers treated as text or converted them from Eastern to Western. Overall, as Tab. 3 shows, Microsoft Excel most consistently supported Arabic for generating the three chart types, regardless of the numeral type. None of the tools generated a mirrored chart (i.e., RTL X-axis and Right Y-axis) by default. All the axis-based charts we rendered with default settings applied the LTR convention (*e.g.* RTL X-axis and Left-aligned Y-axis). Next, we report our findings based on the *chart type, numerical handling, and textual support*.

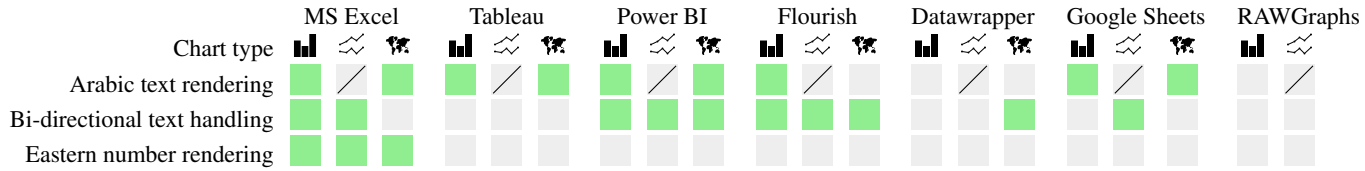
Chart type Bar and line charts were generally well supported with Western numerals. Three tools failed to render maps properly, with RAWGraphs lacking map support altogether. In contrast, charts using Eastern numerals were poorly supported. Only Microsoft Excel successfully rendered bar, line, and map charts using Arabic text and Eastern numbers. Several tools were not able to render the charts properly. For instance, Tableau and Power BI treated numbers as text (see Fig. 1). In some cases (*e.g.* Flourish and Datawrapper), the output included axes but lacked marks and channels; in others (*e.g.* RAWGraphs and Datawrapper), no output was generated. Additionally, some tools (*e.g.*, Google Sheets) rendered the charts by automatically converting the Eastern numbers to Western, indicating a lack of native support for Eastern numeral rendering. The rendering of visualisations depended on the chart type and the numeral system (see Tab. 3). Regarding maps, they were consistently the least reliable across both numeral systems.

Numerical handling Eastern numerals were poorly supported in most tools as shown in Tab. 3. For instance, Power BI misrecognised the data type for the bar chart. Manual attempts to change the data type (*e.g.* in Tableau) were rejected by the tool, indicating limited flexibility in handling Arabic inputs. On the other hand, we successfully rendered all chart types in the seven tools when using Western numerals, except in three cases, due to text handling for maps in Flourish and Datawrapper, and because maps are not supported in RAWGraphs. Furthermore, we observed that Google Sheets automatically converted Eastern numerals to Western numerals without notifying the user. Although this conversion enabled chart creation, it reduces user control and raises concerns about the visualisation's integrity.

Text support Overall, the seven visualisation tools had better Arabic text rendering than Eastern numerals rendering. Labels, headers, and other Arabic rendered correctly in most cases. Datawrapper and Flourish were the only tools that did not render Arabic text properly in maps, either causing an error or returned null values. Given the results presented above and the findings on text handling, there is a systematic mismatch between the two processes, resulting in a mixed presentation where Arabic text coexisted with Western numerals—highlighting the tools' partial and inconsistent localisation support.

Our analysis revealed that generating maps with default settings produced inconsistent region names and boundaries. While this reflects "prevailing geopolitical realities", it also suggests that "different

Table 3: Arabic and RTL support in generating basic charts: barchart, linechart, map, using default settings in seven visualisation authoring tools. RAWGraphs do not support maps. Criteria with binary values are presented in this table; the rest are in the supplementary material, along with the analysis using Western numerals. The tools collectively demonstrate insufficient support for Eastern numerals.



and indicate the presence and absence of tool support, respectively.

indicates that the default line chart did not include textual data for evaluation.

perspectives are not equally embedded in tool defaults". For instance, Tableau and Google Sheets recognised the country entry "Palestine" whereas Datawrapper and Microsoft Excel converted it to "West Bank and Gaza" without notification. A similar inconsistency emerged with the representation of Western Sahara: while Microsoft Excel considered it as part of Morocco, others (*e.g.* Tableau, Google Sheets, Datawrapper, Flourish) displayed it as an independent territory.

4 Interview Study

To further understand how the limitations of visualisation authoring tools impact the design process, we ran a follow-up qualitative study. We also explore design strategies specific to Arabic scripts, along with the methods that visualisation creators use to address these limitations.

4.1 Method

Our study was approved by the United Arab Emirates University's Social Sciences Ethics Committee (ERSC-2024-5388). We obtained informed consent from all interviewees, who filled in and signed a consent form (see supplementary material). The interview addresses Alebri *et al.* [7]'s open research question about how designers reason about RTL adaptations in Arabic data-driven articles. Accordingly, we expand our recruitment to visualisation practitioners who describe their work across design, journalism, and data analysis (see Tab. 4).

We recruited our participants between December 2024 and May 2025. Potential participants completed a screening survey (offered in English and Arabic) and, if eligible, were contacted to schedule an interview via Calendly. Participants were eligible if they were *native Arabic speakers* and *designed Arabic data visualisations* as part of their work. We did not specify the level of expertise required to create visualisations. Our participants were recruited via a study poster on social media platforms (LinkedIn, X), mailing lists (ArabHCI, Data Visualisation Society), and snowball sampling. We also contacted the journalists who produced the visualisations included in Alebri *et al.*'s [7] dataset, other journalism agencies in the Arab world, along with academic and research institutions, commercial organisations that provide visualisation services to Arab clients (*e.g.* Prezlab, Datawrapper), and journalists and data visualisation designers from our professional networks. Of 72 potential participants, 24 signed up for our screening survey; however, six of these were ineligible. We invited the rest ($n = 18$) for an interview, 11 of whom responded and attended the interview. Recruitment was conducted alongside data analysis, with the study being advertised while interview transcripts were being coded.

Interviews were conducted on Microsoft Teams by a native Arabic speaker fluent in English. Participants could choose between Arabic and English to express their experiences without a language barrier. Eight participants chose to interview in Arabic. After introducing the participant to the purpose of the interview and their rights, participants discussed: (a) their background, (b) visualisation guidelines and design strategies followed, and (c) visualisation tools used. Participants were invited to walk the interviewer through a visualisation example they designed or share samples of their data-driven articles. The average interview length was 35 minutes, and participants were compensated with an Amazon gift voucher or equivalent, worth £20. Our participants resided in five Arab countries, all reported having lived in one for at least 10 years, and nine reported fluency in at least one additional language. Table 4 shows an overview of the participants. As demonstrated, there is overlap between the visualisation tools reported by participants and those analysed in Sec. 3.

The first, fifth, and sixth authors (native Arabic speakers) edited the Arabic interview transcripts, and the second author edited the English ones. Editing the Arabic interviews required first standardising the colloquial dialect to Modern Standard Arabic to ensure consistency across the Arabic dialects and maximise the quality of the English translations by Google Translate [70]. The first author then revised these translations against the original to ensure their validity. All transcripts were anonymised before translation and their flow enhanced with any visualisations that the participant discussed.

The transcripts were analysed using thematic analysis [16]. The first and second authors began with independent coding and developed their own codes and interpretations. After completing every one or two transcripts, they met to discuss their codes. Overlapping codes were renamed when needed and merged. For conflicting assignments, the coders discussed their rationale and interpretations in relation to the research questions: consensus resulted in applying one or both codes, or a new code combining both ideas, and disagreements were tracked. We held regular group meetings with the other authors to discuss codes, update the codebook, and resolve disagreements. We decided to stop recruitment when the transcripts showed significant repetition and reached saturation. The group's meetings also led to identifying and refining the themes to those supporting our research thesis. For instance, a theme on the field of data journalism was discarded: though recurring across participants, it mainly covered codes such as workflow that reflected high-level organisational structure without a clear link to design decisions. Whenever new codes emerged, we revised the coding process for the previous transcripts. Our process yielded 26 codes clustered into four final themes (see Supplementary Material).

4.2 Results

We identified four themes to explore practitioners' visualisation literacy, design strategies, challenges, and tools used during the design process for Arabic visualisations.

4.2.1 Designing Within Constraints

This theme presents the key tool limitations shared by participants, followed by the strategies they employed to address these challenges in practice. Participants explained that the tools lacked features that enable automatic mirroring. Mirroring is a design strategy used to flip the direction and position of UI elements based on the reading direction. As prior work suggests, this is a common strategy found in Arabic visualisations [7]. P8 reflected on their experience with Excel and explained: *"not everything is flipped actually. It can read the data ... but it doesn't flip. The legend at the top stays as is, so it stays from LTR...that is time-consuming because I have to do it manually. I have to download it as an editable version where I lose the feature of interactivity"*. In parallel, P5-6 also found the manual labour to edit the visualisation due to the lack of the mirroring feature

Table 4: Overview of our interview participants' demographic data

P#	Profession	Visualisation Tools/ Frameworks Used	Years of Experience	Age Range	Sex
P1	Journalist	Flourish, Datawrapper, Power BI, Tableau	+16	35-44	M
P2	Journalist	Flourish, Datawrapper	8-15	35-44	M
P3	Journalist	Flourish, Datawrapper, Excel	1	35-44	M
P4	Data Analyst	Flourish, Datawrapper, Power BI, Tableau	1-3	25-34	M
P5	Journalist	Flourish, Datawrapper, Tableau	8-15	25-34	F
P6	Journalist	Flourish, Infogram	8-15	35-44	M
P7	Journalist	Flourish, Datawrapper, Python	8-15	35-44	M
P8	Designer	Datawrapper, Excel, RAWGraphs	4-7	25-34	M
P9	Designer	Flourish, Datawrapper, Cables, D3, R	8-15	35-44	M
P10	Journalist	Tableau, Excel, R	+16	45-54	M
P11	Journalist & Student	Canva	1-3	25-34	F

to be time-consuming and frustrating, as P6, who is a freelancer and manually mirrors chart components using a photo editor, stated *"it's a very frustrating process, very time-consuming. Another journalist can build this in 10 minutes... But for me it would take more than a couple of hours"(P6).* P2, P5, and P8 expressed willingness to use the mirroring feature if integrated into visualisation tools.

Our analysis revealed a *tension between aligning the language and visual interpretation and separating the two*. While some participants aimed to preserve the Arabic reading flow by aligning text and chart direction (P2-3, P5-6, P9), others deliberately separated the two (P1, P4, P8) to maintain visual clarity and avoid distortion. On the one hand, some participants saw that the entire chart needs to align with the Arabic script. For instance, P9 stated that it is not enough to simply translate the text and stop there without mirroring and justified this position by stating *"It is normal when I open an Arabic book, I open it from the right"*. Similarly, P2 expressed that they would choose mirroring a chart for the following reason *"If my story was written in Arabic, why don't I make the chart more Arabic, as we learned, so that it starts from RTL?"*. Also, P3 who chooses only to translate the text in a chart stated *"I think it's best to display it from RTL since we're writing the axes in Arabic. It's better to be consistent"*.

On the other hand, some participants saw that the language direction should be viewed in isolation from the chart direction. For instance, we heard from P1 *"Some people tend to think that the direction of everything in Arabic is from the right, and this is actually confusing"* and commented that mirroring is only for the textual elements in the chart. Similarly, P8 expressed *"chart is a chart, right? you just need to translate the text, not the way that we show the information"*.

While the tools lacked automatic mirroring features, participants (P1, P4, P6, P8-9) expressed that they mirror their charts when designing for Arabic content and use the following strategies to address this shortcoming in visualisation tools. One of these strategies was using a second tool, whether it was a photo editing tool or custom coding to modify the chart. Our participants reported using the following tools to edit their visualisations: Adobe Photoshop ($n = 3$), Canva ($n = 2$), Adobe Illustrator ($n = 2$), Adobe After Effects ($n = 1$), Figma ($n = 1$), and Microsoft PowerPoint ($n = 1$). Removing the axes was another strategy participants practiced (P1, P4, P9) while mirroring visualisations. Participants highlighted that removing the axes entirely reduces confusion. *"If the bars are directly labeled ...sometimes we get rid of this confusion by not having an axis at all"* as P1 stated.

P4 also suggested a temporary guiding solution: *"to highlight the axis to clarify its beginning"* until readers are used to the direction. The absence of automated mirroring features pushed participants to resort to data-driven and context-sensitive reasoning. For instance, P4 remarked *"I think that if the x-axis contains qualitative data and not quantitative data, then I think that there might not be a problem in reversing the axis because ...it doesn't logically conflict with the direction of the Cartesian axis"*. On the other hand, P6 stated that reversing shouldn't be implemented on all *axis-based charts*, but can be safely applied to *flowcharts*.

Participants expressed challenges with Eastern numerals when designing Arabic visualisations. P6 asserted this difficulty, which they addressed by opting for a simple or basic chart. P5 had a similar remark: *"It's either not recognising the [Eastern numbers] or it lets you write the numbers in the [Western] way... it kind of messes up the whole text you are trying to write...So this leaves you with one or two platforms that you can work with"*. Furthermore, P4 expressed great difficulty when adding Eastern or Western numerals to Arabic text (*e.g.*, titles or annotations) as the order gets "messy". Thus, participants were forced to use a mixed language presentation in their produced visualisations. For instance, P10 expressed *"the statistical reports I produced for the company had numbers written in English, but the text itself was written in Arabic"*. Similarly, P7 stated *"in Arabic, this is how the visualisation looks [refers to a LTR scatter plot with Arabic textual annotation], and the numbers themselves are Western numbers"*.

Participants described multiple text-related limitations, demonstrating a lack of infrastructural support for Arabic scripts. The most common issue that participants (P4-7, P11) faced when designing Arabic visualisations was the *text alignment problem*. *"Even at the writing level, there is anxiety . . . Sometimes even when you enter the address in Arabic, it basically puts the letters together and does not write the words as you want them (see Fig. 1)"(P11).* P7 also stated that Python creates Arabic visualisations with disconnected letters (see Fig. 1). Yet, even some mainstream visualisation tools do not support Arabic script properly. *"A platform like Tableau, with its size and presence in the Arab world, still has alignment issues in Arabic text . . . especially when you put numbers in the middle of the text (P4)"*.

Beyond text rendering issues, participants were challenged because of the *absence of Arabic interface options and unreliable data entry for Arabic text*. For instance, P7 reflected on their interaction with Power BI and stated: *"the app's interface is completely unhelpful to Arabic readers. The interface requires knowledge of English or languages that use Latin script, and Arabic isn't supported"*. Similarly, P8 noted that these tools do not automatically recognise Arabic: *"in most of the programs that I use, they do not read Arabic until you do it manually"*. P11 also suggested that data entry is not as simple as it is for Latin languages: *"these tools are, even at the logistical level are always in French or English. It is true that someone who designs a chart in Arabic faces some difficulties even at the level of data entry."*

Furthermore, participants also described *poor font rendering*. For example, P9 explained the absence of control with Arabic fonts: *"there aren't options to change fonts, there might be only one Arabic font available"*. P4 also explained that the nature of the Arabic language is not considered with the font options available in these tools: *"most Arabic fonts, when we try to add diacritics, such as shadda ّ and damma ُ, for example, the letters break (see Fig. 1). There aren't many fonts, or many open fonts available, except for one or two, as far as I know, that have good design by Arabic standards"*.

In response to these issues, participants (P1, P5–P9, P11) responded by opting for a simple or basic chart or avoiding certain charts. *"in Arabic, the features that you can control are pretty limited. So, when I design a visualisation in Arabic, I usually tend to keep it nice and as simple as possible (P5)"*. Similarly, participants rely on other strategies

such as producing the chart in a Latin language: *"most organisations in Tunisia, even large organisations which are affiliated with the state ... use data in French and produce visual presentations in French because it takes a lot of time when writing even a title in Arabic (P11)."* P7 even shared that they end up producing the chart in simple English to avoid the difficulty of producing Arabic charts in Python.

4.2.2 Practitioners' visualisation literacies and design decisions

Participants positioned themselves in relation to different forms of literacy, such as graphical and English language literacy and to their awareness of tool mirroring features that shaped their design practices. Participants were divided on mirroring visualisations for Arabic scripts because of their *graphical literacy* (P1, P4, P6, P8-9). Their reflections on the topic highlight the influence of their educational background.

"we did not reverse the axis from RTL for positive values . . . Therefore, it has never happened in our culture in general or in our knowledge, to see the axes in reverse. Therefore, we have always relied on maintaining the direction of the chart as it is, from LTR." (P4)

"I mean, the X or Y axis starts from LTR based on maybe my education, I don't remember that we used to flip anything." (P8)

"The Coordinate System, . . . we learned it in school . . . we got used to it this way . . . The segment of society that studied Arabic . . . Their direction was from RTL, the opposite of ours." (P9)

The above quotations also suggest the importance of language literacy. While *English language literacy* was not a major issue for most of our participants based on their educational background, some (P3, P7) expressed language difficulties. P7 took an Arabic Journalism Diploma where the teaching language was Arabic, described: *"the diploma helped me overcome the language barrier, as most of these tools are [in] English"*. P3 expressed concerns about not using the full capacity of visualisation authoring tools because of language barrier:

"there's a lack of understanding of English terminology. When we translate it into Arabic, we face difficulties. It might be a statistical term, and even if we understand the term after translation, it's difficult to understand the identity of the term, its meaning, or how to employ it. ...We may need more... explanations in Arabic about design... we're only using a small portion of what's available." (P3)

This strengthens the importance of efforts like The Data Visualisation Glossary [76] that translate technical terms in visualisation design into Arabic. Regarding awareness of mirroring features, P3 and P8 were not aware of them in some visualisation tools, although both of them use tools that provide those features (*e.g.* Datawrapper, Excel) *"I haven't looked into this feature, this is the first time I've heard of it"*.

4.2.3 Practitioners' assumptions about audiences

Extending the previous theme, participants revealed how their assumptions about the audience shaped their designs, reinforcing universality. In particular, many participants (P1, P3-6) assumed a certain *graphical literacy* about Arab audiences. For instance, P5 stated *"there are charts that I will not use in an Arabic article because I don't really believe that the Arab audience would understand"*. We also heard a generalisation of how Arab audiences read graphs from P3 *"I think most Arab readers are used to reading charts from LTR"*. Similarly, P6 opted to use simple charts because they assumed the Arab audience's graphical literacy *"I would say since most of the Arabic audience are not used to seeing this kind of data visualisation, we need to make sure that when we are using them, they have to be clear and self-explanatory"*. P1 also implicitly suggested an assumption about the audience's graphical literacy *"I personally think that changing the direction of the curves based on the language is a huge mistake and creates a state of misunderstanding among the audience who are used to reading curves and graphs in their precise statistical concept from the left."*

Participants also highlighted assumptions about the *audience habituation* (P1-3, P9) to LTR charts in Arabic scripts. P2 stated *"because most platforms currently publish charts on social media, the reader's eye and the viewer's eye began to get used to the idea that the chart starts from LTR"*. P9, who designs mainly in English, made the following assumption *"I know that due to the lack of Arabic content specific to graphs, we are accustomed to English content, and thus we are accustomed to the direction from LTR"*.

Furthermore, participants (P1, P6) also assumed the *reading expectations* of the Arab audience. P6 generalised their personal experience to all Arab audiences *"even when I read something in English, by default my eyes go from RTL. When I look at a picture or any kind of visual I assume that this should be the case . . . for our Arabic readers."* P1, who stated views against mirroring, indirectly expressed a generalisation of what the audience's expectation are: *"Usually, there is a visual culture among people, and violating it is an obstacle."*

Participants also made assumptions about *the audiences' ability to understand the statistical language* used in their stories. For instance, P6 anticipated the following *"I feel like for one of the statistics [I] used, People are not familiar with it, I have to explain it"*. We also heard from P9 who justified this assumption by the fact that statistical terms are not used in colloquial Arabic *"when I was addressing the Arab audience, I was concerned not to give them a difficult word that they could not understand from the chart itself, such as a difficult definition or a difficult word used"*.

4.2.4 Embedded power in visualisation defaults

Participants' reflections revealed how the design decision process is restricted by political, economic, and epistemic control. Many participants (P1, P3-11) brought up issues with the design process, which hinted towards what we interpret as a *colonial legacy* [23]. In particular, this was in the shape of perceiving the content produced in Latin languages as superior (P3, P9-11).

"I have to produce the rest of the projects in English due to its popularity, because projects that are only produced in Arabic do not receive the expected or anticipated response and engagement from the Arab world." (P9)

"producing any content in English is more elegant,... we [Arabs] lack an aesthetic sense in producing statistical reports." (P10)

Yet, this perspective was also propagated in contemporary tool design, where *English is treated as the default* while other languages are silenced (P4-8, P11). P8 asserted *"Of course it [data file] will be in English!"*. In another example, P5 reported their experience using Flourish, Datawrapper, and Tableau that limited their agency in making design decisions *"It [visualisation tool] messed up the design pretty much because the design template is designed for English speakers and language. . . I avoid writing a complex text or complex headline"*. Because English was the default, developing with it is a more convenient option as P10 elaborated *"Any data I used was originally in English, and then I Arabized it. It's easier and faster to use English."*

The systems of power were not only visible in the privileging of English, but also in *the ways tools enforce LTR defaults* (P2-3, P6-7), compelling participants to adapt their work to the tool's assumptions. For instance, P2 shared their thinking process with the design team whenever they are borrowing an English visualisation: *"let's stay on the same basis as Flourish itself, which forces you to start from LTR"*. P6 also made a generalisation of the visualisation tools by noting *"if you're using any tool, by default all the effects are from LTR"*. Beyond visualisation tools, P7 extended this concern to libraries *"Python, for example, does not ask about the direction. It assumes that the graph has the correct direction"* and ended up producing the chart in English.

The framing of English defaults as universal quietly reinforces LTR conventions in Arabic visualisations, revealing how technical settings can embody power. *"because most platforms currently publish charts on social media, the viewer's eye gets used to the idea that the chart starts from LTR. (P2)"*

"I think we've gotten used to the idea during our studies that charts are read from LTR, because it's more compatible and easier, even in Excel... It's easy to standardise, to the point that I think most Arab readers are used to reading charts from LTR." (P3)

The lack of guidelines for Arabic visualisation design (P1, P3-10) reinforces the dominance of LTR conventions in Arabic scripts. In some instances, our interviewees think that violating the normalised conventions would harm the reader: *"even if it is a mistake, sticking to it*

will facilitate the purpose of simplifying the conveyance of information to people and not confusing them (P1)".

This normalisation extended beyond language and direction to spatial representation. Participants (P1, P6-7) expressed that local realities are replaced by treating the Western geopolitical framings as universal, just as visualisation tools treat English and LTR direction as universal. For instance, P1 and P6 expressed concerns about the misrepresentation of the Arab world, where certain areas are not even displayed on the map or enforced different labelling. P7 also highlighted the lack of recognition of country or city names in Arabic in these tools: *"Because the names of Arabic cities and governorates in Python are not available in Arabic, they must be entered in English for the map data to be understood."* This not only lengthens the design process but also prevents practitioners from depicting uncertainty in areas of conflict.

Participants also discussed *access issues*, noting that creating Arabic visualisations often required additional effort to mirror designs, while some necessary features were further restricted by paywalls: *"most of these tools give you some control when you're a free user. But, they give you more control if you are a premium . . . and the problem is that most of these platforms are not really affordable."(P5)*

5 Discussion

We combined analytical evaluation of visualisation tools with semi-structured interviews to understand how practitioners navigate design decisions when creating Arabic visualisations and how tools support them. Next, we map our results to relevant literature and outline a research agenda with recommendations for visualisation design practice.

5.1 Constrained Work: Effort, Agency, and Creativity

Our results suggest that Arabic visualisation practitioners experience limited agency over the fundamental elements of their produced visualisations. For instance, they feel compelled to use a basic chart, avoid specific charts, or even present it in English to work around the tool's limitations for RTL scripts (Sec. 4.2.1). Given that our analysed tool selection overlaps with the tools reported by participants, our tool analysis also confirmed this finding, in which we observed instances (see Sec. 3.5.2) where the tool converted Eastern numerals to Western and forced a mixed presentation (see Fig. 1) - a task that should be very basic in generating a visualisation in these tools. Although such sense of low agency is not exclusive to Arab practitioners, as previous work suggests that automated visualisation tools often induce low authorship [52], we demonstrate that this is even more pronounced when designing in Arabic, where the language itself is overridden.

The low agency pushes the design process of Arabic data visualisation toward fragmented workflows, resulting in increased friction and effort over trivial issues (*e.g.*, text alignment, the legend and the source position). Participants reported that they often need to use multiple tools to achieve their desired final design (see Sec. 4.2.1) or spend a considerable time translating each Arab city name (see Sec. 4.2.4). Using multiple tools may result in the loss of some capabilities, as our participants reported resorting to static visualisations because they must fix charts using other tools. Although extending the tool's capabilities through add-ons or custom plugins could mitigate the problem, it does so at the cost of increasing the user's workload. The time-consuming nature of this process places Arabic visualisation practitioners at a structural disadvantage in benefiting from the efficiency of mainstream visualisation tools as reported by Méndez *et al.* [52].

Due to the aforementioned constraints, creativity in Arabic data visualisation is compromised. Participants reported frequently settling for simpler text and representations (*e.g.*, basic charts) due to tool limitations, suggesting that the effort and time required to manage foundational elements—such as Eastern numerals and text alignment—discourages exploration of more complex or expressive designs. While Baigelenov *et al.* [13] has shown that practitioners often draw inspiration from presets and system recommendations, this inspiration can be limiting rather than generative, particularly when alternatives require substantial effort. Over time, the repeated circulation of such constrained outputs risks reinforcing "design fixation" [40]- a cognitive barrier in which designers adhere to familiar solutions rather than exploring alternatives. Our findings extend Parsons *et al.*'s [62] account of fixation attributed to presets, visualisation corpora, effort, and habitual practices by showing how these mechanisms are amplified in the context of Arabic-script visualisation.

An implication of these findings is that visualisation tools offering automated design should critically revisit the level of control afforded to their users across scripts, ensuring a unified set of design elements that remain user-controllable and are not compromised by script direction, such as numeral systems or the set of recommended chart types. Tools can also be more transparent about the limitations imposed due to script language by notifying the user of any overridden changes. Furthermore, visualisation tools should be designed to preserve continuous design flow by reducing interruptions not only for practitioners working with Arabic but for all practitioners, particularly at the level of foundational elements, and by supporting bottom-up creative processes rather than enforcing fixed layouts or script-dependent presets.

5.2 Exercises of Power in Visualisation Practice

Our findings show that power in Arabic data visualisation design operates through a structurally reinforcing chain that is difficult to interrupt, in which cultural beliefs, such as the perceived universality and dominance of English, become embedded in conventions, materialised through tool defaults, and normalised as standard practice. As reported in Sec. 4.2.3, some participants expressed concern that violating LTR conventions could cause confusion and disrupt message delivery. Importantly, this concern appears to stem not only from perceptions of the reader's familiarity with LTR conventions but also from the absence of RTL conventions, thereby positioning deviation as a risk rather than a legitimate design choice. While prior work critiqued conventions for the power they extend to visualisations, making them render as clinical and impartial [42], their absence is also problematic. To illustrate, readers might think something is increasing when it is actually decreasing, simply due to the axis position or orientation. Alebri *et al.* [7] found inconsistent design patterns when depicting numerical data in Arabic script, even within the same article, suggesting a lack of standards. This is similar to the case of depicting uncertainty, where practitioners may avoid representing uncertainty when guidance is lacking [38].

Our work presents a case study of how cultural dominance shapes the visualisation practice through defaults. Participants repeatedly described how the design process in the visualisation tool, from uploading data to editing chart titles, was consistently governed by LTR defaults. This was further confirmed by our tool analysis, which showed that Eastern numerals were rendered as text, while Western numerals were treated as numerical values, reinforcing asymmetric support at a foundational level. Despite substantial attention to the rhetorical power of visualisations (*e.g.* [22, 39]), our findings highlight that, in the case of RTL scripts, this rhetorical power lies not with the authors but with the tool. We also demonstrate how visualisation authoring tools have political dimensions. Costanza-Chock argues [19] that defaults are shaped around an "unmarked" imagined user defined by dominant cultural and linguistic norms, which are then internalised and reproduced through design systems rather than explicitly chosen by designers, demonstrating the artefact's power. Defaults matter particularly in visualisation, as the field serves users with diverse backgrounds and levels of expertise. Moreover, defaults are often trusted, especially by novices who may feel unqualified to question them and accept them as given [46].

A single worldview is embedded in most visualisation authoring tools when depicting maps of the Arab world, demonstrating a power structure. Country borders and their names change over time, and the current settings of these tools implicitly assume stability and reject alternative framings or ongoing conflicts. Our interview participants commented that the tools misrepresent the Arab World by not recognising Arabic names and enforcing labels without notification (see Sec. 4.2.4). Our tool analysis affirms this, showing that Arabic country names were not even recognised by the tool (*e.g.* Flourish). As Monmonier [53] and Winner [79] demonstrate, map design elements such as heavy lines and area names contribute to sovereignty rather than a scientific representation of geographic reality. Although some of the vi-

sualisation tools allow users to upload their own map, non-experts with limited time may opt for the default map, leading to further exercise of that perspective. Displaying maps that omit or re-label some countries may lead readers to distrust or feel detached [44].

While practitioners are constrained by external sources of power, such as tool defaults, our results indicate that they simultaneously mediate power over readers through assumption-driven visualisation design choices. Section 4.2.3 demonstrates how our interview participants avoided a certain visualisation or selected a particular language based on their assumptions about the reader. This finding further confirms the work of Hullman and Diakopoulos [39], who argue that editorial design choices (*e.g.* visual representation, annotation, omission, emphasis) are made and that visualisations therefore hold rhetorical power over certain interpretations. Readers are treated as passive recipients through these assumptions, amplifying the "banking model" critiqued by Freire [27], in which he argues that knowledge should be co-constructed.

The influence of power in the form of defaults extends beyond individual design outcomes: visualisations generated using defaults are frequently employed in evaluations of Large Language Models (LLMs) (*e.g.* [67]), thereby shaping our understanding of model capabilities. Furthermore, we cannot yet rely on generative AI to produce Arabic visualisations. For instance, ChatGPT currently generates charts using Python libraries like Matplotlib, which renders Arabic text incorrectly with disconnected letters (see Fig. 1) unless additional Arabic text-shaping libraries (*e.g.*, arabic-reshaper) are explicitly used. We therefore invite the community to reconsider the weight afforded to defaults in the design process. Framing a configuration as the "default" implicitly positions alternatives as deviations from the norm, reinforcing dominant perspectives; supporting multiple contextualised defaults may offer a more equitable starting point for visualisation design. Including Arab practitioners in the design process for these tools is also essential. Another implication of our work is to adopt Dörk *et al.*'s [22] principles of critical visualisation, where creators could use the tooltip to show alternative place names, provide a disclosure describing the map's limitations, and hold the map's constructor accountable.

5.3 Research Agenda and Future Directions

While altering deeply rooted linguistic beliefs (*e.g.*, "designs in English are more elegant") is difficult, interrupting this chain by developing empirically grounded design guidance for RTL scripts is more attainable. Doing so requires empirical investigations that replicate core visualisation perception, interpretation and comprehension studies (*e.g.*, [18, 64, 77]) in RTL settings, and examine whether violating LTR conventions necessarily impairs comprehension, or whether such assumptions are themselves a product of normalised defaults.

This opens the door to many research opportunities. Mapping the visualisation literacy within audiences who consume Arabic script will provide an evidence-based understanding of their capabilities and strategies. Although robust measurements for data visualisation literacy exist (*e.g.*, [26, 29, 48]), the empirical studies that ground them were often not designed with RTL scripts and their users in mind [74]. Additionally, while data visualisation literacy at scale likely depends on other factors such as educational curricula, prior adaptation of visualisation literacy assessments [9, 56] provide concrete pathways for culturally and linguistically grounded measurement. Contextualising, adapting and validating existing visualisation literacy instruments would enable more precise claims about visualisation skill distributions and help derive methods for teaching or improving data visualisation globally.

Our understanding of the Arabic visualisation ecosystem, particularly through its users, remains limited. Our interview analysis shows that practitioners routinely make design choices based on assumptions about their audience's expectations for directionality rather than established guidelines or empirical evidence. Some even presume readers are accustomed to LTR charts. The lack of empirically tested guidelines for RTL data visualisation was surfaced in Alebri *et al.*'s work which revealed inconsistencies in how authors approach RTL designs and adaptations [7]. Because *guidelines* and *tools* are largely shaped and evaluated through empirical observations [14, 24], the lack of investigation for RTL contexts leaves practitioners without contextualised references. Future research with Arabic visualisation audiences can address this gap by replicating core perception and interpretation studies to assess how mirroring affects visualisation comprehensions across chart types and user backgrounds. Beyond directionality, future studies could also investigate how visualisation elements such as legends, annotations, title, and framing, interact with cultural conventions and shape people's attitude towards data visualisation [45,63,66]. Overall, moving practitioner beliefs toward direct empirical evidence would allow researchers to determine when RTL adaptations improve comprehension, when they are neutral, and when they introduce new challenges.

We provide actionable recommendations for visualisation authoring tools on how to benefit from our findings, particularly in restoring the creator's agency: (1) *consistent design controls*: text formatting and layout options should remain available through discoverable controls with consistent terminology across tools, regardless of script direction, so that authoring in Arabic does not remove capabilities and interactivity that creators retain in LTR contexts; (2) *recognition of foundational elements*: Eastern numerals and Arabic city names should be handled as native data types rather than worked around; (3) *transparency over silent overrides*: automatic transformation should be surfaced with option to revert. Together, these requirements would let RTL practitioners work within a unified, user-controllable set of design elements rather than continually negotiating around defaults.

As with all studies, some limitations should be noted. First, generalisation to other RTL scripts. Generalisation is problematic in itself, as it contributes to the constraints mentioned in Sec. 5.1. Therefore, our work may not apply to all RTL scripts; it uses Arabic as a case study, with a base of over two billion users [3], so there is a pressing need to consider them in the visualisation community [41]. Focusing on a single script enables the development of tools for that script rather than adapting an existing tool. Therefore, we encourage explorations of other RTL scripts, such as Persian and Urdu. Second, the sample of participants. Some might argue that our pool is small, but given that data visualisation practice continues to flourish in the Arab world and that our participants are experienced and influential, we believe that quantity should be balanced by quality. We also recognise the underrepresentation of women in our sample. As described in Sec. 4.1, we have made a substantial effort to recruit a gender-balanced sample; this may be due to economic and cultural factors. Third, while there is a major intersection between the GUI-based tools analysed and the tools used by our interviewed participants, we recognise that some tools and other chart types need further assessment. Future work could inspect code-based tools more closely or evaluate the tools with more complex charts. Lastly, our findings reflect the perspectives of native Arabic-speaking practitioners. However, non-Arabic-speaking practitioners also create visualisations for Arabic-script contexts, and their perspectives should therefore be considered in future research.

6 Conclusion

Through an analytical evaluation of seven visualisation authoring tools with Arabic datasets and interviews with Arab practitioners, we explore the visualisation design practice for Arabic scripts. Our results suggest limited support for Arabic scripts in these tools, particularly in the recognition of Eastern numerals, requiring massive efforts from practitioners over foundational elements. Other observed issues related to text alignment, font options, Arabic country names on maps, and the lack of automatic mirroring features push creators to work under constraints, requiring them to adapt by using additional tools or settling for a basic chart or compromising interactivity. We argue that these limitations stem from a lack of agency, thereby disadvantaging creators of Arabic visualisations of the benefits of these tools. This also compromises their creativity. We contribute a reflection on infrastructure disproportion, by showing how defaults in visualisation tools are biased to LTR conventions, along with calls for action.

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REFERENCES

[1] Material Design: Layout Basics, Bidirectionality & RTL. https://m3.material.io/foundations/layout/understanding-layout/bidirectionality-rtl Accessed on 2023-04-18. 2

[2] Structural markup and right-to-left text in HTML, 2021. https://www.w3.org/International/questions/qa-html-dir Accessed: Mar. 20, 2026. 2

[3] Languages using Right-to-Left Scripts, 2023. https://www.w3.org/International/questions/qa-scripts Accessed: Jan. 30, 2026. 1, 9

[4] F. Abed. Cultural influences on visual scanning patterns. *Journal of Cross-Cultural Psychology*, 22(4):525–534, 1991. doi: 10.1177/0022022191224006 2

[5] Z. Afsari, A. Keshava, J. P. Ossandón, and P. König. Interindividual differences among native right-to-left readers and native left-to-right readers during free viewing task. *Visual Cognition*, 26(6):430–441, 2018. doi: 10.1080/13506285.2018.1473542 1

[6] K. Ajani, E. Lee, C. Xiong, C. Nussbaumer Knaflic, W. Kemper, and S. Franconeri. Declutter and Focus: Empirically Evaluating Design Guidelines for Effective Data Communication. *IEEE Transactions on Visualization and Computer Graphics*, 28(10):3351–3364, 2021. doi: 10.1109/TVCG.2021.3068337 2

[7] M. Alebri, N. Rakotondravony, and L. Harrison. Design patterns in right-to-left visualizations: the case of arabic content. In *2024 IEEE (VIS)*, pp. 251–255. IEEE, 2024. doi: 10.1109/VIS55277.2024.00058 2, 3, 5, 8, 9

[8] D. Alharthi. Jamalon arabic books dataset. Kaggle, 2021. [Online]. Available: https://www.kaggle.com/datasets/dareenalharthi/jamalon-arabic-books-dataset. 2, 3

[9] H. S. Andrianarivony, T. D. Raharison, I. T. Rakotoniaina, M. T. Ramarokoto, N. Rakotondravony, and L. Harrison. Investigating the Use of Native and Secondary Language with Data Visualization in Madagascar. *IEEE VIS Posters. Oklahoma City*, 2022. 9

[10] A. Arunkumar, L. M. Padilla, and C. Bryan. Lost in translation: How does bilingualism shape reader preferences for annotated charts? In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*, pp. 1–22, 2025. doi: 10.1145/3706598.3713380 1, 2

[11] N. Aykin. *Usability and internationalization of information technology*. CRC press, 2004. doi: 10.1201/b12471 2

[12] B. Bach, Z. Wang, M. Farinella, D. Murray-Rust, and N. H. Riche. Design patterns for data comics. *Conference on Human Factors in Computing Systems - Proceedings*, 2018-April:1–12, 2018. doi: 10.1145/3173574.3173612 2

[13] A. Baigelenov, P. Shukla, and P. Parsons. *How Visualization Designers Perceive and Use Inspiration*, vol. 1. Association for Computing Machinery, 2025. doi: 10.1145/3706598.3714191 2, 8

[14] K. Batziakoudi, F. Cabric, S. Rey, and J.-D. Fekete. Lost in magnitudes: Exploring visualization designs for large value ranges. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pp. 1–18, 2025. doi: 10.1145/3706598.3713487 9

[15] M. Behrisch, D. Streeb, F. Stoffel, D. Seebacher, B. Matejek, S. H. Weber, S. Mittelstädt, H. Pfister, and D. Keim. Commercial visual analytics systems–advances in the big data analytics field. *IEEE transactions on visualization and computer graphics*, 25(10):3011–3031, 2018. doi: 10.1109/TVCG.2018.2859973 2, 3

[16] V. Braun and V. Clarke. Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2):77–101, 2006. doi: 10.1191/1478088706qp063oa 5

[17] A. Chua. How the English Language Conquered the World, 2022. 1

[18] W. S. Cleveland and R. McGill. Graphical perception: Theory, experimentation, and application to the development of graphical methods. *The American Statistical Association*, 79(387):531–554, 1984. doi: 10.2307/2288400 9

[19] S. Costanza-Chock. Design Justice: towards an intersectional feminist framework for design theory and practice. *DRS2018: Design as a catalyst for change*, pp. 25–28, 2019. doi: 10.21606/drs.2018.679 8

[20] T. Data and V. Society. Data Visualization State of the Industry Survey. Technical report, The Data Visualization Society, 2024. 3

[21] A. Diehl, A. Abdul-Rahman, M. El-Assady, B. Bach, D. A. Keim, and M. Chen. VisGuides: A Forum for Discussing Visualization Guidelines. In *Proc. of Eurographics Conf. on Visualization, EuroVis Short Papers*, pp. 61–65, 2018. doi: 10.2312/eurovisshort.20181079 2

[22] M. Dörk, C. Collins, P. Feng, and S. Carpendale. Critical InfoVis: Exploring the Politics of Visualization. *Conference on Human Factors in Computing Systems - Proceedings*, 2013-April:2189–2198, 2013. doi: 10.1145/2468356.2468739 8, 9

[23] P. Dourish and S. D. Mainwaring. Ubicomp's colonial impulse. *UbiComp'12 - Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, (March):133–142, 2012. doi: 10.1145/2370216.2370238 7

[24] U. Engelke, A. Abdul-Rahman, and M. Chen. Visupply: A supply-chain process model for visualization guidelines. In *2018 International Symposium on Big Data Visual and Immersive Analytics (BDVA)*, pp. 1–9, 2018. doi: 10.1109/BDVA.2018.8534029 9

[25] J. Fagard and R. Dahmen. The effects of reading-writing direction on the asymmetry of space perception and directional tendencies: A comparison between French and Tunisian children. *Laterality: y: Asymmetries of Body, Brain and Cognition ISSN:*, 8(1):39–52, 2003. doi: 10.1080/713754473 1, 2

[26] E. E. Firat, A. Joshi, and R. S. Laramee. Interactive visualization literacy: The state-of-the-art. *Information Visualization*, 21(3):285–310, 2022. doi: 10.1177/14738716221081818 9

[27] P. Freire. *Pedagogy of the Oppressed*. 30 ed., 2005. 9

[28] O. Fuhrman and L. Boroditsky. Cross-cultural differences in mental representations of time: Evidence from an implicit nonlinguistic task. *Cognitive science*, 34 8:1430–51, 2010. doi: 10.1111/j.1551-6709.2010.01105.x 1, 2

[29] L. W. Ge, Y. Cui, and M. Kay. CALVI: Critical Thinking Assessment for Literacy in Visualizations. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, 2023. doi: 10.1145/3544548.3581406 9

[30] E. Gibson, R. Futrell, J. Jara-Ettinger, K. Mahowald, L. Bergen, S. Ratnasingam, M. Gibson, S. T. Piantadosi, and B. R. Conway. Color naming across languages reflects color use. *Proceedings of the National Academy of Sciences of the United States of America*, 114(40):10785–10790, 2017. doi: 10.1073/pnas.1619666114 1

[31] S. M. Göbel, K. McCrink, M. H. Fischer, and S. Shaki. Observation of directional storybook reading influences young children's counting direction. *Journal of experimental child psychology*, 166:49–66, 2018. doi: 10.1016/j.jecp.2017.08.001 2

[32] B. Gorelik and N. Sulieman. Reading direction shapes data visualization perception: Insights from right-to-left and left-to-right user studies. *ACM Trans. Appl. Percept.*, 23(1), article no. 3, 13 pages, Oct. 2025. doi: 10.1145/3759155 2

[33] S. Hao, Z. Wang, B. Bach, and L. Pschetz. Design Patterns for Data-Driven News Articles. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems*. ACM, Honolulu, HI, USA, 2024. doi: 10.1145/3613904.3641916 2

[34] M. A. Hearst. Show it or tell it? text, visualization, and their combination. *Commun. ACM*, 66(10):68–75, 8 pages, Sept. 2023. doi: 10.1145/3593580 2

[35] J. Henrich, S. J. Heine, and A. Norenzayan. Most people are not WEIRD. *Nature*, 466(1):29, 2010. doi: 10.1017/S0140525X0999152X 1

[36] H. Huang, S. Ravi, T. Warrington, H. Cui, C. Wang, M. McCreary, B. Lauffer, and C. Lu. A comparison of data visualization tools: a case study in health-related research. 24(1):62–78, 2022. doi: 10.1177/14738716241270206 3

[37] H. Huang, S. Ravi, T. Warrington, H. Cui, C. Wang, M. McCreary, B. Lauffer, and C. Lu. A comparison of data visualization tools: A case study in health-related research. *Inf. Vis.*, 24(1):62–78, 2025. doi: 10.1177/14738716241270206 2, 3

[38] J. Hullman. Why Authors Don't Visualize Uncertainty. *IEEE Transactions on Visualization and Computer Graphics*, 26(1):130–139, 2020. doi: 10.1109/TVCG.2019.2934287 8

[39] J. Hullman and N. Diakopoulos. Visualization rhetoric: Framing effects in narrative visualization. *IEEE transactions on visualization and computer graphics*, 17(12):2231–2240, 2011. doi: 10.1109/TVCG.2011.255 2, 8, 9

[40] D. G. Jansson and S. M. Smith. Design fixation. *Design Studies*, 12(1):3–11, 1991. doi: 10.1016/0142-694X(91)90003-F 8

[41] A. Jena, M. Butler, T. Dwyer, K. Ellis, U. Engelke, R. Kirkham, K. Marriott, C. Paris, and V. Rajamanickam. The Next Billion Users of Visualization. *IEEE Computer Graphics and Applications*, 41(2):8–16, 2021. doi: 10.1109/MCG.2020.3044071 1, 9

[42] H. Kennedy, R. L. Hill, G. Aiello, and W. Allen. The Work That Visualisation Conventions Do. *Information Communication and Society*, 19(6):715–735, 2016. doi: 10.1080/1369118X.2016.1153126 8

[43] H. Kim, J. Oh, Y. Han, S. Ko, M. Brehmer, and B. C. Kwon. Thumbnails

for Data Stories: A Survey of Current Practices. *2019 IEEE Visualization Conference, VIS 2019*, pp. 116–120, 2019. doi: 10.1109/VISUAL.2019.8933773 2

[44] L. Koesten, A. Saske, S. M. Starchenko, and K. Gregory. Encountering Friction, Understanding Crises: How Do Digital Natives Make Sense of Crisis Maps? *Conference on Human Factors in Computing Systems - Proceedings*, 2025. doi: 10.1145/3706598.3713520 9

[45] H.-K. Kong, Z. Liu, and K. Karahalios. Frames and Slants in Titles of Visualizations on Controversial Topics. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pp. 1–12. ACM, Montreal QC Canada, Apr. 2018. doi: 10.1145/3173574.3174012 9

[46] C. Lauer and S. O'Brien. How People Are Influenced by Deceptive Tactics in Everyday Charts and Graphs. *IEEE Transactions on Professional Communication*, 63(4):327–340, 2020. doi: 10.1109/TPC.2020.3032053 8

[47] A. Lavanya, S. Sindhuja, L. Gaurav, and W. Ali. A comprehensive review of data visualization tools: features, strengths, and weaknesses. *Int. J. Comput. Eng. Res. Trends*, 10(01):10–20, 2023. doi: 10.22362/ijcert/2023/v10/i01/v10i0102 3

[48] S. Lee, S. H. Kim, and B. C. Kwon. VLAT: Development of a Visualization Literacy Assessment Test. *IEEE Transactions on Visualization and Computer Graphics*, 23(1):551–560, 2017. doi: 10.1109/TVCG.2016.2598920 9

[49] A. Lousa, I. Pedrosa, and J. Bernardino. Evaluation and analysis of business intelligence data visualization tools. In *2019 14th Iberian Conference on Information Systems and Technologies (CISTI)*, pp. 1–6. IEEE, 2019. doi: 10.23919/CISTI.2019.8760677 3

[50] A. Maass and A. Russo. Directional bias in the mental representation of spatial events: Nature or culture? *Psychological science*, 14(4):296–301, 2003. doi: 10.1111/1467-9280.14421 2

[51] A. Marcus. Global/intercultural user interface design. In *Human-Computer Interaction*, pp. 45–70. CRC Press, 2009. 2

[52] G. G. Méndez, U. Hinrichs, and M. A. Nacenta. Bottom-up vs. Top-down: Trade-offs in efficiency, understanding, freedom and creativity with infovis tools. *Conference on Human Factors in Computing Systems - Proceedings*, 2017-May:841–852, 2017. doi: 10.1145/3025453.3025942 8

[53] M. Monmonier. *How to Lie with Maps*. 1991. 8

[54] L. Morais, Y. Jansen, N. Andrade, and P. Dragicevic. Showing Data about People: A Design Space of Anthropographics. *IEEE Transactions on Visualization and Computer Graphics*, 28(3):1661 – 1679, 2020. doi: 10.1109/tvcg.2020.3023013 2

[55] A. Negi, L. Tripathi, S. Prabha, and C. Azad. Charting the future: an in-depth review of cuttingedge big data visualization tools for 2025. In *2025 12th International Conference on Computing for Sustainable Global Development (INDIACom)*, pp. 01–06. IEEE, 2025. doi: 10.23919/INDIACom66777.2025.11115697 3

[56] O. Omelchenko, O. Konopatska, P. Khomenko, and T. Kharin. Cross-linguistic and cultural adaptation of the mini-vlat: A study on visualization literacy assessment in ukrainian. 2025. doi: 10.2312/evs.20251079 9

[57] A. Ottley. Consensus and contradictions: A cross-organizational analysis of visualization style guides. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems*, CHI '26, article no. 442, 21 pages. Association for Computing Machinery, New York, NY, USA, 2026. doi: 10.1145/3772318.3791628 2

[58] A. Pandey, I. Sharma, A. Sachan, and D. P. Madhavan. Comparative study of data visualization tools in big data analysis for business intelligence. *IJRASET*, 10:2592–2600, 2022. doi: 10.22214/ijraset.2022.44400 3

[59] P. Parsons. Understanding Data Visualization Design Practice. *IEEE Transactions on Visualization and Computer Graphics*, 28(1):665–675, 2022. doi: 10.1109/TVCG.2021.3114959 2

[60] P. Parsons, Y.-H. Hung, A. Baigelenov, and C. Schrank. What Design Methods do DataVis Practitioners Know and Use? In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems-Late Breaking Work*, pp. 1–8. Honolulu, HI, USA, 2020. doi: 10.1145/3334480.3383048 2

[61] P. Parsons and P. Shukla. Data Visualization Practitioners' Perspectives on Chartjunk. In *Proceeding of IEEE VIS - short paper*, pp. 1–5. IEEE, Utah, 2020. doi: 10.1109/VIS47514.2020.00049 2

[62] P. Parsons, P. Shukla, and C. Park. Fixation and creativity in data visualization design: Experiences and perspectives of practitioners. In *2021 IEEE Visualization Conference (VIS)*, pp. 76–80, 2021. doi: 10.1109/VIS49827.2021.9623297 8

[63] E. M. Peck, S. E. Ayuso, and O. El-Etr. Data is Personal: Attitudes and Perceptions of Data Visualization in Rural Pennsylvania. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pp. 1–12. ACM, Glasgow Scotland Uk, May 2019. doi: 10.1145/3290605.3300474 9

[64] G. J. Quadri and P. Rosen. A survey of perception-based visualization studies by task. *IEEE Transactions on Visualization and Computer Graphics*, 28(12):5026–5048, 2022. doi: 10.1109/TVCG.2021.3098240 9

[65] N. Rakotondravony, P. Dhawka, and M. Bancilhon. Beyond english: Centering multilingualism in data visualization. *Workshop on Visualization for Social Good*, 2023. doi: 10.48550/arXiv.2309.06659 2

[66] N. Rakotondravony, Y. Ding, and L. Harrison. Probablement, wahrscheinlich, likely? a cross-language study of how people verbalize probabilities in icon array visualizations. *IEEE Transactions on Visualization and Computer Graphics*, 29(1):1189–1199, 2023. doi: 10.1109/TVCG.2022.3209367 2, 9

[67] S. Rauf, K. Vinit, and C. Sougata. Evaluating LLMs for visualization generation and understanding. *Discover Data*, (April), 2025. doi: 10.1007/s44248-025-00036-4 9

[68] L. Ravi, Q. Yan, S. M. Dascalu, and F. C. Harris Jr. A survey of visualization techniques and tools for environmental data. In *Proceedings of the 2013 Intl. Conference on Computers and their Applications (CATA 2013)*, 2013. doi: 10.4236/ti.2023.143009 2

[69] K. Reinecke and A. Bernstein. Improving performance, perceived usability, and aesthetics with culturally adaptive user interfaces. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 18(2):1–29, 2011. doi: 10.1145/1970378.1970382 2

[70] Y. M. N. Sabtan, M. S. M. Hussein, H. Ethelb, and A. Omar. An evaluation of the accuracy of the machine translation systems of social media language. *International Journal of Advanced Computer Science and Applications*, 12(7), 2021. doi: 10.14569/IJACSA.2021.0120746 5

[71] J. Schmidt. Usage of visualization techniques in data science workflows. In A. Kerren, C. Hurter, and J. Braz, eds., *Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications, VISIGRAPP 2020, Volume 3: IVAPP, Valletta, Malta, February 27-29, 2020*, pp. 309–316. SCITEPRESS, 2020. doi: 10.5220/0009181903090316 3

[72] E. Segel and J. Heer. Narrative visualization: Telling stories with data. *IEEE transactions on visualization and computer graphics*, 16(6):1139–1148, 2010. doi: 10.1109/TVCG.2010.179 2

[73] H. M. Shakeel, S. Iram, H. Al-Aqrabi, T. Alsboui, and R. Hill. A comprehensive state-of-the-art survey on data visualization tools: Research developments, challenges and future domain specific visualization framework. *IEEE Access*, 10:96581–96601, 2022. doi: 10.1109/ACCESS.2022.3205115 2

[74] M. Solen. Scoping the future of visualization literacy: A review. In *Proceedings of the Fifth Workshop on Visualization for Communication (VisComm), IEEE VIS 2022*. Oklahoma City, OK, USA, 2022. doi: 10.31219/osf.io/eypgm 9

[75] C. Stokes, V. Setlur, B. Cogley, A. Satyanarayan, and M. A. Hearst. Striking a balance: Reader takeaways and preferences when integrating text and charts. *IEEE Transactions on Visualization and Computer Graphics*, 29(1):1233–1243, 2023. doi: 10.1109/TVCG.2022.3209383 2

[76] The KPI Institute. Data Visualization Glossary, 2024. Accessed: Mar. 17, 2026. 7

[77] M. Tory and T. Möller. Human factors in visualization research. *IEEE Trans. Vis. Comput. Graph.*, 10(1):72–84, 2004. doi: 10.1109/TVCG.2004.1260759 9

[78] B. Tversky, S. Kugelmass, and A. Winter. Cross-cultural and developmental trends in graphic productions. *Cognitive psychology*, 23(4):515–557, 1991. doi: 10.1016/0010-0285(91)90005-9 2

[79] L. Winner. Do artifacts have politics? *Computer Ethics*, pp. 177–192, 2017. doi: 10.5040/9798216385448.ch-17 8