6DVF: A Framework for the Development and Evaluation of Mobile Data Visualisations

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Abstract: Mobile apps, in particular tracking apps, rely heavily on data visualisations to empower end-users to make decisions about their health, sport, finance, household, and more. This has prompted app designers and developers to invest more effort in delivering quality visualisations. Many frameworks, including the Visualisation and Design Framework and Google Material Design, have been developed to guide the creation of informative and well-designed charts. However, our study reveals the need to incorporate additional aspects in the design process of such data visualisations to address user characterisation and needs, the nature of data to visualise, and the experience on small smart screens. In this paper, we introduce the Six-Dimensions Data Visualization Framework (6DVF), specifically designed for data visualisation on mobile devices. The 6DVF encompasses user characteristics and needs, data attributes, chart styling, interaction, and the mobile environment. We conducted two evaluation studies to measure the effectiveness and practicality of our 6DVF in guiding designers, pinpointing areas for improvement—especially in data completeness and usability for end-users.

1 INTRODUCTION

Data visualisation is a crucial aspect of many mobile apps. For example, in mHealth apps data visualisations enable users to communicate effectively, make informed decisions, and identify trends using their health data. With the increasing use of mobile apps and the diverse user base, there is a need for a well-designed data visualisation framework that prioritises user experience (UX) and provides accurate and consistent visualisations on mobile devices. Existing efforts, including the Data Visualisation Catalogue (Ribecca, 2019), from Data to Viz (Holtz, 2018), Data Viz project (Ferdio, 2019), IBM Design Language (IBM, 2019), the Nested Blocks Model (Meyer et al., 2015), (Kelleher and Wagener, 2011), and (Cuttone et al., 2014), have provided general guidelines for data visualisation design. While these guidelines encompass best practices for chart design, they primarily focus on desktop computers (Lee et al., 2018) and do not take into account the characteristics and context of non-expert users (i.e., people who have limited to no knowledge in data visualisation (Jena et al., 2021)). Some studies have specifically explored data visualisation for tablet devices, offering guidelines for navigating the Roambi app[1](Games and Joshi, 2015). Leading organisations such as IBM and Google have also integrated data visualisation guidelines to support chart design on mobile devices. However, these frameworks address general design elements and chart interactivity but do not consider user needs and chart functionality. In previous work, Alshehhi et al. conducted a comprehensive review of user feedback on mHealth apps, exploring app reviews (Alshehhi et al., 2022a) and conducting a user survey to identify needs and development opportunities (Alshehhi et al., 2023b). Their findings highlighted user dissatisfaction and challenges in utilising charts for health data tracking, spanning issues in functionality, data display, styling, adaptability for diverse user groups, and the overall data visualisa-

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[1]Roambi is an app used for creating business reports, dashboards, data visualisations, and charts (RoambiAnalytics, 2015)

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tion interface. Recognising these limitations, this paper introduces the 6-Dimensions Visualisation Framework (6DVF), specifically designed to address the unique challenges faced by non-expert users in mobile environments. Focused on six essential dimensions, the 6DVF offers a more intuitive and effective approach, aiming to enhance user satisfaction in mobile applications. Our contributions encompass 1) The 6DVF, a novel mobile-centric data visualisation framework that prioritises user-centric design and tackles platform-specific challenges across six dimensions. 2) A novel checklist for evaluating the framework's output based on the 3Cs: completeness, correctness, and consistency, setting a new standard for structured and efficient evaluations in the field. 3) An evaluation study providing insights into the practical benefits and potential limitations of the 6DVF, shedding light on its impact on design quality and the design process. Section 2 reviews existing frameworks, identifying gaps in current approaches. Section 3 outlines the development process of the proposed framework. Section 4 discusses the evaluation plan for assessing the framework's effectiveness. Section 4.4 presents the findings and results. Following that, Section 6 engages in a discussion of potential framework applications. Lastly, Section 7 concludes the paper.

2 RELATED WORK

Existing work on data visualisation frameworks and guidelines include various aspects of the design process. Cuttone et al.'s guidelines (Cuttone et al., 2014) emphasise reducing cognitive load during the navigation of personal information through data visualisation. They advocate for interpretable data, pattern identification, trend discovery, and enhanced interaction. Munzner's nested model (Munzner, 2009) and Meyer et al.'s nested blocks and guidelines model (Meyer et al., 2015) use a four-layered approach but are process-oriented and generic, lacking a user-centric focus. Lee et al.'s grounded theory study (Lee et al., 2018) concentrates on user comprehension but overlooks considerations for mobile devices and styling, crucial in the mHealth tracking domain. Grainger et al.'s study (Grainger et al., 2016) highlights understanding non-expert users in data visualisation but lacks a comprehensive framework. Shifting to industry practices, Google Material Design and Apple's Human Interface Guidelines provide general advice on data visualisation design, yet limitations persist in terms of user interaction on mobile devices. In summary, existing frameworks and studies have significantly contributed to the field of data visualisation but often fall short in addressing the unique challenges posed by non-expert users on mobile devices. The proposed framework (6DVF) builds upon insights from previous studies, offering a structured approach that not only characterises users but also guides the data visualisation design process on mobile devices.

3 6DVF: FRAMEWORK DEVELOPMENT

The 6DVF is derived from extensive research (Alshehhi et al., 2022a), (Alshehhi et al., 2023a), (Alshehhi et al., 2022b), the six dimensions originated from an in-depth examination of user perspectives, while identifying and categorising existing challenges. Built on user-centric concerns, the 6DVF is designed to include essential elements for best-practice mobile data visualisations. Tailored to users' observed needs and challenges, this approach enhances the framework's relevance and effectiveness, supported by a designed implementation checklist.

3.1 The 6 Dimensions

The 6DVF enhances existing guidelines by incorporating additional considerations for non-expert users and mobile app contexts. It consists of six dimensions, organized into two main parts: 1) Empathize and Needs and 2) Ideate. **Empathise & Needs Dimensions:** These dimensions focus on gaining a deep understanding of users, identifying their needs, and determining the appropriate mobile devices for the visualisation. The following dimensions are taken into account: *D1: User characterisation:* includes gaining a deeper understanding of the target audience through quantitative research methods such as market research and user surveys. The output of this process is a set of user personas that capture and characterise the target audience of the mobile app (in particular data visualisation) (Cooper et al., 2014) (Matthews et al., 2012). *D2: Users' needs and pain points:* defines the problems, emotions and experiences users encounter when using data visualisation. It is accomplished through a combination of quantitative research methods, such as surveys and market research, and qualitative research methods, such as interviews and observations which help in collecting data on how people think, feel, and interact with data visualisations. The output of this process is a user journey map that captures users' actions, thoughts, pain points, and opportunities throughout the data visualisation process (Howard, 2014). The user journey is informed by the collected data and serves as a reference for designing user-centred data visualisation experiences. *D3: Target platforms:* involves considering various mobile devices, including tablets, smartphones, and wearable devices. Factors like screen size and interactive capabilities are taken into account to ensure an optimal presentation of the visualisations and address accessibility requirements. Conducting a literature survey or market research is recommended to gain insights into the features of the current devices. The output of this process involves determining the target devices' features and operating systems (Android/iOS) that need to be taken into consideration during the design of your data visualisation. **Ideate Dimensions:** These dimensions aim to capture the details of the "what" and "how" of the data visualisations to be developed including: *D4: Data:* focuses on capturing relevant data to determine the most suitable charts and patterns for interpreting the collected information. In order to achieve this, it is essential to have a clear understanding of the desired insights based on user needs. By mapping the collected data to various chart and analysis tasks, such as identifying anomalies, correlations, and periodic summaries (Saket et al., 2018), designers can select the appropriate chart types that effectively represent the data and convey the desired insights to users. This process allows designers to make sense of the data and create meaningful visualisations. The outcome of this step is the mapping of the collected data with the corresponding charts and the creation of a list of sketched data visualisations. This ensures that the visual representations effectively communicate the insights derived from the data. *D5: Design system:* encompasses a collection of foundational user interface (UI) elements and components utilised by design and engineering teams. Guidelines and best practices govern these components (Gu et al., 2021), ensuring a consistent and cohesive approach across the chart design process. In the context of chart design, we divided it into two main aspects. Firstly, the *Look and Feel* aspect focuses on the visual design and appearance of charts. this includes considerations such as a suitable colour palette, chart layout, font sizes, labelling and types, and accessibility options symbols. Secondly, the *Interactivity* aspect addresses user interactions with the charts and the data used to build the charts. It also includes a range of interactions, limited to tap, pinch, swap, gestures, and voice notes. The outcome of this process yields a set of guidelines that are valuable in chart design. These include 1) ensuring the inclusion of essential chart elements, 2) prioritising accessibility, 3) ensuring a responsive chart layout adaptable to various screen sizes, 4) using tooltips for additional details, and 5) optimising the chart layout for specific orientations. *D6: App visualisations:* Displays the final result for data visualisation and incorporate all the elements identified in the previous steps. To ensure the best possible outcome, designers need to repeat this step for every visualisation. The result is a mobile app that presents charts tailored to the user's needs, ensuring accessibility, consistent layout, and reliable data.

3.2 Framework Checklist

We prepared a checklist to support designers in evaluating the developed data visualisation. The checklist provides an efficient measure for evaluation, as stated in (Sawicki and Burdukiewicz, 2022). It includes the dimensions outlined in Section 3, which include User Characterisation (D1), Users' Requirements (D2), Target Platforms (D3), Data (D4), Design System (Look and feel & interactivity) (D5), and App Visualisations (D6). These dimensions are evaluated based on the Consistent, Complete, and Correct (3Cs) criteria, which are widely used for validating software requirement specifications (Kamalrudin and Sidek, 2015). In the data visualisation context, the 3Cs standards enable designers to deliver reliable charts that meet users' needs. Table 1 illustrates the six dimensions and the corresponding evaluation statements for assessing their compliance with the 3Cs criteria. The 3Cs criteria serve the following purposes: 1) Completeness guarantees the inclusion of all necessary components, 2) Consistency emphasizes uniformity in elements across the data visualization interface, and 3) Correctness ensures error-free production of components in each dimension.

4 6DVF: FRAMEWORK EVALUATION

4.1 Part A: Designer Study

In this part, we implemented the user testing approach to evaluate the framework in real-life scenarios. We conducted an evaluation involving designers in building data visualisation tasks for a specific mobile app with and without the use of our framework, followed by a survey. We split the participating data visualisation designers into two groups:

- Group 1 (Cohort 1): Participants in this group were introduced to the framework and a case study for a mobile data visualisation scenario. Each designer received a comprehensive project

Table 1: Framework Checklist.

Visualisation Dimension	Visualisation Criteria		
	Complete	Consistent	Correct
D1: User Characterisation	Do we have a complete list of the target audience's characteristics (target users) for the data visualisation?	Is there any conflict between the target audience (users) of the data visualisation?	Do we have the correct audience?
D2: Users' Requirements	Do we have a comprehensive range of users' needs and pain points?	Is there consistency in addressing user needs (functional requirements)?	Do we have the correct user needs?
D3: Target Platforms	Do we consider all the device and platform capabilities, limitations, and compatibility to present the required data visualisation	Are all the visualisations consistent with the limitations and capabilities of the underlying platform	Is the visualisation style consistent with the user profile/data/user requirements
D4: Data	Do we have all the data required to achieve the intended data visualisation	Is data consistent and can be linked – i.e. same granularity in terms of special, temporal, units of measure	Do we have the correct data for the visualisation
D5: Design system (Look and feel & interactivity)	Do we have all the look and feel (non-functional) requirements for the data visualisation	Do we have a consistent look and feel throughout all the visualisation in the app	Do we use the correct look and feel in all app visualisation
D6: App visualisations	Does a visualisation cover all (functional and non-functional) the user requirements meant for this specific visualisation	Is the visualisation style consistent with the user profile / data / functional requirements	Are these the correct data visualisation that the users need?

brief document containing project information, the goal of constructing a meal tracker prototype using Figma, a list of required features, and examples of issues identified in previous research studies on mHealth data visualisation (Alshehhi et al., 2022a), (Alshehhi et al., 2023b), (Philip et al., 2023). Subsequently, the designers were tasked with creating a set of data visualisation prototypes and completing a survey.

- Group 2 (Cohort 2): Participants in this group were not familiarised with the framework at the start of the designing process. However, they were presented with the same case study and asked to create a set of data visualisation prototypes without the use of the framework. After completing the task, we introduced them to the framework and asked them to complete a survey that investigates how likely they would be willing to use our framework for their future projects.

Although this approach might introduce a bias in the design approaches taken by the two cohorts, our goal in following this approach was to compare the effectiveness of having the 6DVF versus not having it during the design process. Additionally, we aimed to evaluate the practical impact of 6DVF from the designers' perspectives.

4.2 Part B: End User Study

In this section, we utilised the A/B testing approach, providing users the opportunity to explore two random prototypes, one from Group 1 and another from Group 2. (The links to access the prototypes can be found here). This approach is widely recognised as a robust method for evaluating different iterations of products or services (Johari et al., 2017). It holds significant relevance in UX research, utilising user evaluations to refine products or services, aligning them with user expectations and needs (Young, 2014) (King et al., 2017). The experiment's flow is outlined as follows: First, each end user is tasked with exploring a randomly assigned prototype from set A and subsequently providing their evaluation. Subsequently, they navigate to a randomly assigned prototype from set B and proceed to complete their evaluation. Finally, the end users are prompted to respond to a comparison question. They share their opinions, contributing valuable qualitative insights

4.3 Survey Development

Regarding part A survey questions, we developed the survey questions based on the checklist provided earlier (Table 1) in addition to a usability evaluation questionnaire inspired by the System Usability Scale (SUS) (Lewis, 2018). The survey questions are structured as follows:

- Demographic information: Participants provide age, gender, professional experience, and familiarity with data visualisation tools.
- Perceived effectiveness: Participants rate the framework's effectiveness in various design aspects, including data visualisation functionality, accessibility, creation, interaction design, visual aesthetics, and overall efficiency, using a scale from 1 to 10 where 1 indicates "Strongly Disagree" to "Strongly Agree".
- Framework usability: Participants rate the usabil-

ity of the framework using nine statements covering user satisfaction, acceptance, confidence, and recognition of limitations on a scale from "Strongly Disagree" to "Strongly Agree". In addition to the quantitative assessment, open-ended questions are included, allowing participants to provide qualitative feedback on their experiences.

In terms of part B, we developed the evaluation questions taking inspiration from two established instruments: the SUS (Lewis, 2018) and the UEQ (Schrepp et al., 2014) and they are structured as follows:

- Demographic Information: Participants provide details such as age, gender, education level, familiarity with mHealth tracking apps, number of mHealth apps used, and operating system.
- Prototype Evaluation: Participants randomly explore a Figma link assigned with predefined tasks and evaluate the prototype using a scale from "Strongly Disagree" to "Strongly Agree" for eight statements. Additionally, participants provide qualitative feedback through open-ended questions, sharing their experiences with the prototypes.
- Comparison of Sets A & B: Participants express their preferences among prototypes based on various metrics through single-choice questions inspired by the UEQ.

Before the study, ethical approvals were obtained from the university's research ethics committee. Informed consent was secured from participants through the Qualtrics platform, ensuring their awareness of the study's purpose, data collection methods, and their rights to withdraw without consequences.

4.4 Participant Recruitment

A detailed flyer was created to attract individuals with relevant expertise based on specific criteria. The requirements outlined in the flyer included participants being above 18 years old, having a minimum of one year of experience in health tracking apps, familiarity with data visualisation techniques and mobile design principles, proficiency in using Figma or Adobe XD, and a commitment of 8 hours over a week. Strategic distribution channels, including professional networks (e.g., Data Visualization community, LinkedIn), industry forums (e.g., Freelancer, Upwork), and social media platforms, were utilised to circulate the study flyer. Interested individuals meeting the criteria were encouraged to express interest and undergo a preliminary screening. Of the initial 16 participants, two did not pass the screening. Participants were also required to share links to their design projects or portfolios for further assessment. Fourteen eligible participants were randomly assigned to two cohorts of seven each, receiving compensation upon study completion. For part B recruitment, we utilized platforms such as Prolific and various social media channels, chosen for their broad reach across diverse demographics. Recruiting 30 participants, each received a $50 AUD incentive upon completing the survey and validating their randomly assigned survey ID.

5 RESULTS

5.1 Part A: Participant Profile

The age distribution was as follows: the majority, 7 participants (78.57%), fell within the 18-30 age range, while 2 participants (14.28%) were aged between 31-40, and 1 participant (7.14%) was aged between 41-50. In terms of gender, 8 participants (57.42%) identified as male, and 6 participants (42.85%) identified as female. This section details participant profiles, focusing on their UX design experiences and preferred guidelines or frameworks for crafting data visualisations. The majority of participants, 7 participants (78.57%) were aged 18-30, while 2 participants (14.28%) were aged between 31-40, and 1 participant (7.14%) was aged between 41-50, with gender distribution being 8 participants (57.42%) male and 6 participants (42.85%) female. Regarding education, 7 participants (50%) held Master's degrees, 6 participants (42.88%) held Bachelor's degrees, and 1 participant (7.14%) completed post-secondary education. Experience levels varied, with 6 participants (42.85%) having 1-3 years of experience, 6 participants (42.85%) having 3-5 years, and 1 participant (14.28%) having more than 7 years. Regarding the tools used, Figma was mentioned by 42.85% (6 participants), Adobe XD by 14.2% (2 participants), Double Diamond process by 14.2% (2 participants), Draw.io by 7.14% (1 participant), Material Design by 7.14% (1 participant), and Tableau by 7.14% (1 participant). This question was optional, and one participant did not provide an answer.

5.2 Part A: 6DVF Evaluation

Both groups provided ratings for 19 statements, and notably, Group 2 exhibited a stronger inclination to incorporate the 6DVF in future projects. Specifically, the mean comparison for the "User Characterisation" dimension was 7.57 for Group 1 and 7.71 for Group 2. Further comparisons across dimensions are illus-

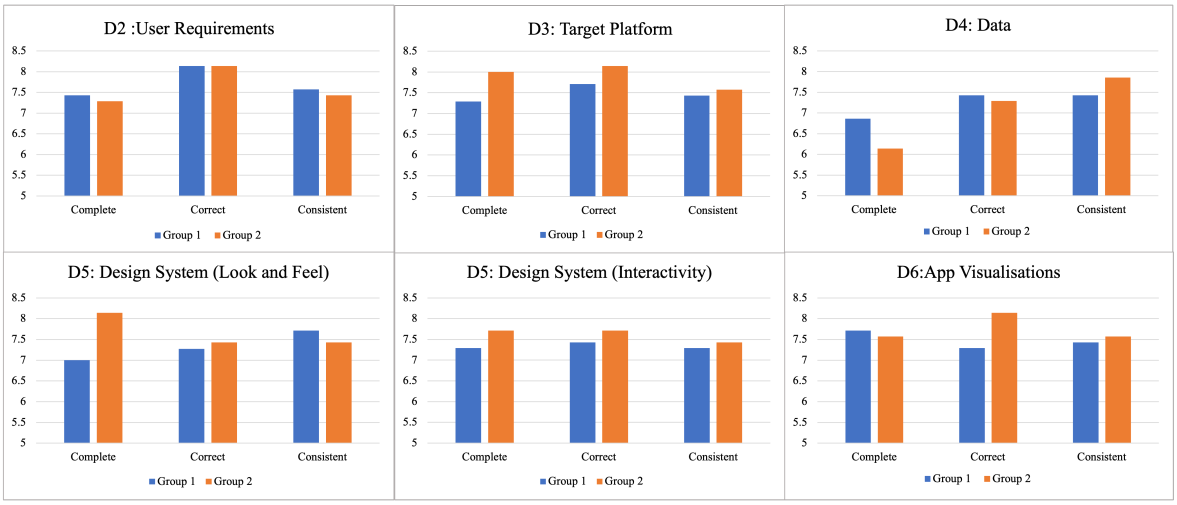

Figure 1: The chart displays mean scores for two groups of designers: Group 1, provided with the framework during prototype design, and Group 2, given the framework after completing their designs. Scores indicate designers' willingness to use the framework in future projects.

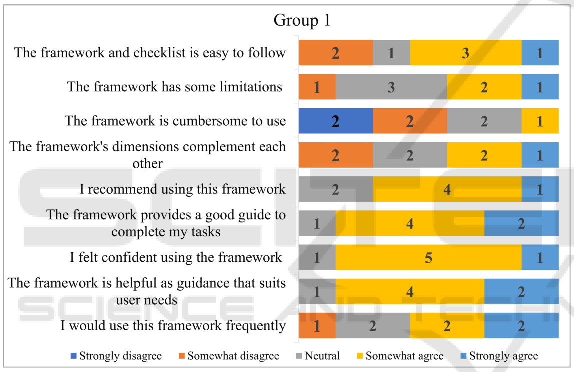

Figure 2: Participant Ratings and Opinions on 6DVF: Group 1.

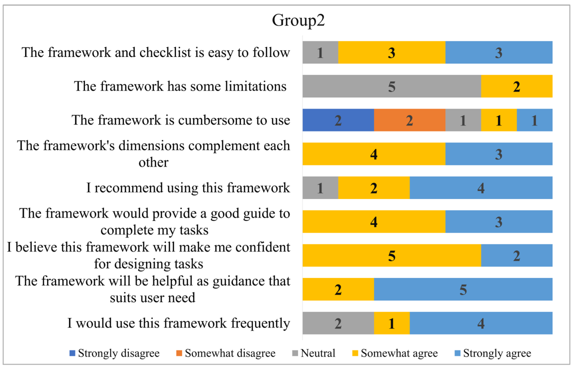

Figure 3: Participant Ratings and Opinions on 6DVF: Group 2.

trated in Figure 1. Regarding the usability evaluation of 6DVF, Group 1 and Group 2 had mean ratings of 3.71 and 4.29, respectively. For a detailed breakdown of participant responses for specific statements, refer to Figures 2 and 3. In Group 2, 85.71% (6 out of 7) designers followed other frameworks. When asked to compare the guidelines they followed with our guidelines, we received 5 valid answers, all providing positive feedback.

5.3 Part B: Participant Profile

Participant demographics included: 17 (56.76%) aged 18-30, 5 (16.67%) aged 31-40, 3 (10.00%) aged 41-50, and 5 (16.67%) aged 50 and above. Gender distribution comprised 20 males (66.67%) and 10 females (33.33%). Educational levels varied: 1 (3.33%) completed primary education, 1 (3.33%) had lower secondary qualifications, 9 (30.00%) had upper secondary education, 5 completed post-secondary studies, 12 (40.00%) held master's degrees, and 2 (6.67%) had doctoral degrees. In mHealth app experience, 43.33% (13) were basic users, 6 were intermediate, and 11 (36.67%) were advanced users with over a year's experience. Concerning installed apps, 11 (36.67%) had one, 18 (60.00%) had 2-5, and one participant had more than 5 apps. Operating system preferences were evenly split between Android and iOS, each favoured by 50.00% of participants.

5.4 Part B: Prototypes Evaluation and Preferences

While set A received positive feedback, set B showed mixed results, as depicted in Figures 4 & 5. Set A was preferred by 66.6% of participants for enjoyment, look and feel completeness, and as their overall preference. Additionally, 70% found set A more userfriendly than set B. Despite positive feedback for set A, participants identified areas for improvement, particularly within the D4 (Data) and D5 (Look & Feel) dimensions, based on open-ended suggestions.

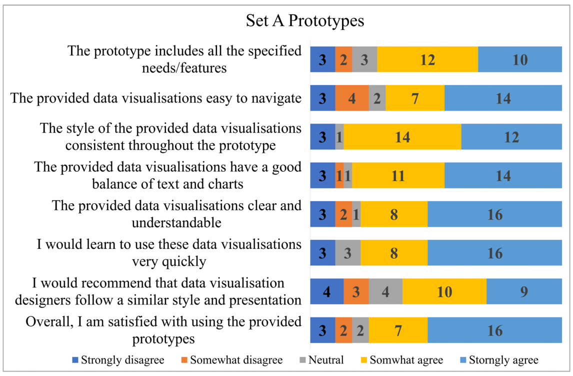

Figure 4: Set A Prototype Evaluation.

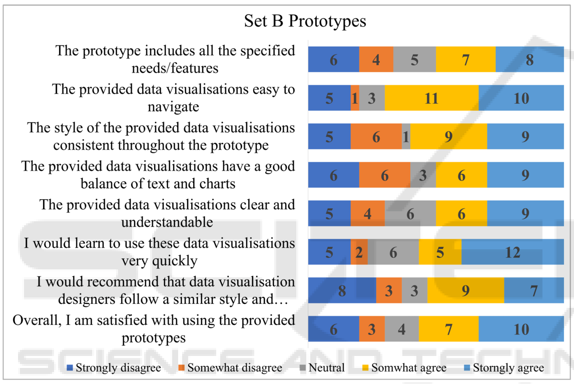

Figure 5: Set B Prototype Evaluation.

6 DISCUSSION

6.1 Part A: DVF's Effectiveness and Usability

Comparing ratings between active users (Group 1) and informed non-users (Group 2) of the 6DVF framework reveals consistent positive feedback across several dimensions. Both groups found the framework effective in guiding user characterisation and specifying target audience characteristics, as well as in fulfilling functional requirements in data visualisations. While the framework adequately addresses considerations for mobile platforms, there is room for improvement in ensuring consistency. Group 2 consistently rated the "Data" and "Look and Feel" dimensions higher, indicating potential enhancements for completeness and consistency in data presentation. However, positive ratings for "Look and Feel" demonstrate the framework's effectiveness in guiding designers to create visually engaging and consistent visualisations. Participants noted the assistance of the 6DVF in incorporating interactive elements and creating accurate visualisations, although slight variations were observed in perceived completeness and correctness. Overall, the results offer valuable insights into the effectiveness of the 6DVF across various aspects of data visualisation, highlighting strengths and areas for improvement in data completeness, correctness, and consistency. The usability and acceptance of the 6DVF were analysed, with both groups expressing overall satisfaction and ease of use. Designers from Group 2, who had experience with other frameworks, showed higher satisfaction and confidence in the 6DVF. Despite positive feedback, perceived usability limitations were noted, prompting a commitment to refinement. Feedback highlighted the effectiveness of guidelines, clarity of instructions, and the framework's ability to meet client requirements. Designers expressed confidence in using the 6DVF, emphasising its potential to build trust and competence. The absence of specific improvement recommendations suggests overall satisfaction or may indicate a need for further investigation.

6.2 Part B: Prototype Evaluation and Preferences

Participants consistently praised Set A, which incorporated the 6DVF, while Set B, lacking structured design principles, received diverse feedback, suggesting potential shortcomings in meeting user expectations. Although most participants preferred Set A, further analysis revealed factors contributing to Set B preference, offering valuable insights for framework enhancement. The initial evaluation study highlights areas for improvement, particularly in Data and Look & Feel. Plans include refining the framework before conducting an expanded study to assess its broader impact.

7 CONCLUSION

Addressing gaps in existing frameworks regarding end users' needs, we conducted a comprehensive exploration of designers' perspectives on mobile data visualisation challenges and expectations. The proposed 6DVF, grounded in these insights, serves as a foundational guide for implementing best practices, with a focus on customisation, accessibility, and scalability for mobile devices. Experiment results highlighted successful framework implementation and identified areas for improvement, particularly in the data dimension. To further validate observed UI design differences and assess the checklist's effectiveness, we are planning a study involving UI design experts. This aims to provide a detailed understanding of how the checklist can effectively evaluate and differentiate UI designs. Additionally, to enhance usability, we intend to develop a Figma plug-in, seamlessly integrating key aspects of our framework into designers' workflows.

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