TOWARDS EFFECTIVE CUSTOMER DATA VISUALIZATION: DATA-DRIVEN DOCUMENTS (D3.JS) VS. GOOGLE CHARTS

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ABSTRACT

Organizations today are in vital need of viewing, interacting, and interpreting vast amounts of data in quick easy design views. Management wants to visualize business growth, forecasting and trends in diagrams and dashboards. With an increase in data analytics, data visualization is a way to display information in a visual manner whether on paper, a computer screen, or a projector. Data-Driven Documents have become increasingly more important in the corporate world. It is becoming a new and popular way to share data in an interactive and creative way. With numerous tools designed to facilitate these data visualization needs, it becomes difficult to know and understand what users interpret as easy, useful, and/or efficient. We explore two popular freely available data visualization tools: D3.JS and Google Charts Tools for retail customer data. Thirty participants were recruited for the study. However, only 29 participants completed the task. A paired sample t-test was performed. The results indicated that D3.JS is more efficient than Google Charts, however Google Charts is more user friendly than D3.JS. Our research highlights the significance that different visualization tools may amplify users' levels of effectiveness, efficiency and preference based on its presentation and ease of use. Therefore, organizations should be mindful to their selection of data visualization tools and their audience.

Keywords: Data Visualization, Data-Driven Documents, Google Charts, D3.JS, Open Source

INTRODUCTION

Businesses collect and access more data today than they ever imagined. The challenge with large datasets is interpreting and presenting data in an easy and understandable form (Qin, Luo, Tang, & Li, 2020; Wang, Yang, Wang, Sherratt, & Zhang, 2020). Data analysis and presentation has proven to be an important aspect to every business (Jin, Wah, Cheng, & Wang, 2015), and thus creates a larger demand for better data analytic tools. One challenge that businesses have is that the results of most analyses are simply raw numbers and very difficult for the customer to interpret as is. Therefore, there is a demand for easier to read, interactive data results (Center, 2013), also known as data visualization. Data (or information) visualization is the representation or presentation of data/information in a visual and meaningful graphical form such as charts, diagrams, maps, plots, etc. Data visualization enables end-users to analyze more effectively and efficiently the relationships among the represented data.

Graphical interpretations become increasingly essential with the excessive amount of data available (Fu et al., 2014). Visual diagrams are useful at gaining the customer's attention because visuals are more likely to reach the customer, as it does not require an understanding of a language code but goes beyond specific experiences (Hariharan & Krithivasan, 2016). In addition to obtaining their attention, the diagram must accurately tell the story and express the purpose of data analysis. In order to present meaningful data visualization, it is critical to understand the needs and expectations of an end-user's sense of efficiency, effectiveness, and ease of use. We begin this process by first exploring the developer tools that aid in presenting data. By exploring different tools, we engage in preferences of users and highlight significant characteristics that represent effectiveness, efficiency, presentation layout and ease of use. Although research has shown preferences for types of visualizations (e.g., bar/line charts, colors, shapes, etc.) (Luo, Qin, Tang, & Li, 2018), there has been limited research investigating the preferred tool for presenting such characteristics. This paper attempts to address the gap by answering the questions: 1) Which visualization tool is more effective and efficient? and 2) Do user preferences influence data visualization tool choice?

In the following pages we explore the differences between data visualization tools, the effectiveness and efficiency of these tools, and the user preferences with respect to ease of use, friendliness and overall satisfaction when engaging in each of the graphical presentations. This research compares the effectiveness, efficiency, and user preference of two popular data visualization tools: D3.JS and Google Charts. We begin with a background discussion on data visualization and our two data visualization tools - Google Charts (Developers.google.com, 2019) and Data-Driven Documents (D3.JS) (Bostock, 2019). From there we present our research design and methodology. Specifically, we use AKDesigns Boutique dataset to do comparative analysis of the two data visualization tools. Finally, we share our results, discussion and conclusion.

RELATED WORK

Data visualization is highly beneficial in data analysis as it graphically allows the user to find interesting patterns and make interpretations of the data. However, there are many challenges with huge amounts of data; one such challenge is how to capture, store, analyze, share, search, and present it in a meaningful way (Martinuzzi, 2016). Tools traditionally used to present data are far less useful with the massive rate of growth of data. Data visualization has certainly been around for many years. It is the presentation of data in the style of graphs or images that increases the worthiness of data visualization tools. Business decision makers are able to analyze data and grasp difficult concepts or identify new patterns through data visualization (Martinuzzi, 2016). The most important feature of these tools is the interactive nature with which the viewer can manipulate the presentation of the data or how quickly the visualization adapts itself at runtime. Interactive data visualization allows for efficient manipulation of data by helping people understand complex patterns and/or trends that might otherwise go unnoticed. A data visualization tool can only be effective if it is the appropriate tool for the task and used in the right way.

There are several data visualization tools. There is no one criterion for the classification of visualization tools. However, some have classified these tools as either open source or commercial/proprietary (Hariharan & Krithivasan, 2016). One difference between open source and commercial visualization tools is that the commercial tools are typically drag and drop

applications, but open source tools require more coding with Java Script being the typical language used. This is a significant difference as drag and drop tools are easier to learn and user friendly while open source tools require expertise in coding and more development time. Some of the open source options are Data-Driven Documents (D3.JS), Datawrapper, and dygraphs. Commercial (or proprietary) examples include Tableau, Qlick Sense, Spotfire or FusionCharts. Although Google Charts (Zhu, 2012) is considered a commercial tool it is free for all to use. Commercial tools tend to be part of a bundled package for users, but for additional costs may be tailored, while open-source tools are tailor made visualizations.

Another classification for data visualization tools is the required amount of coding. Many open source tools require a demanding amount of coding language skills. Java Script is the primary coding language to create visualizations. This can be challenging as Java Script requires some expertise and a good amount of development time. This increases the user's learning curve needed for these types of visualization tools. Most commercial visualization tools require little to no coding. They use drag and drop to create visualizations. This creates an easier to learn environment and reduces time invested.

Developers who have the skills to create the appropriate visual representations of the data are greatly sought after. In an effort to address the coding skills necessary for many open source data visualization tools, there are companies creating and developing ways to educate and train developers in the desired languages and tools. For example, there is a data science training program called Metis that was designed to teach professionals how to develop data visualization by using D3.JS (Metis, 2015). This program allows Metis to convene talent in one location and teach developers and designers required skillsets. These skills are complex, but in high demand. Other types of classifications for visualization tools include output types (e.g., maps, timelines, etc.) or output formats (e.g., SVG, PNG, etc.).

While knowledge drawn from these classifications and others are important to designers and developers, the end-users are an even larger and more diversified audience with a greater need to engage and comprehend the visual presentation of data. End-users include individuals in various industries with varying levels of expertise (e.g., students, customers, personnel, managers, executives, etc.). End-users desire the ability to quickly and easily access data in graphical formatthat allows for processing of complex data and a better understanding of what is happening around them. For example, consider how difficult it would be to understand weather forecasts without a graphical representation of the content. Human-computer interaction (HCI) studies highlight the many important preferences and characteristics of end-users and various technologies (Fox & Hendler, 2011). Data visualization is capable of being both aesthetically pleasing and functional (Keahey, Rope, & Wills, 2017). In fact, it should. There are many resources that discuss the importance of having a visually appealing product and this goes for data visualization as well.

Visualizations are often used to convey information, communicate key concepts, or guide attention to a particular area. Once the developers have been trained and taught to understand the importance of a good-looking product, it is also important to make sure the developers know how to conduct usability testing to ensure their clients are happy with the product being created for them (Skov & Stage, 2012). Usability testing is important to developers because they need to know how their end user thinks and interacts with the system. They need to know what kinds of improvements need to

be made and if their visualization is unclear to the customer. The more the customer is involved with feedback, the better the end results will be.

We have chosen to investigate and evaluate Data-Driven Documents (D3.JS) and Google Charts. To provide some contrast in the type of data visualization tools available as well as their accessibility, we have chosen two popular free data visualization tools where one is categorized as open source (D3.JS) and the other is commercial (Google Charts).

D3.JS

D3.JS is a JavaScript visualization tool that offers efficient data manipulation with no extra installation processes. It supports large data sets and interactivity, such as zooming and panning. D3.JS is an example of a web-based visualization tool. This tool is more advantageous because D3.JS offers a larger and easier availability of opportunities since all it needs is a web browser to access it. D3.JS uses HTML (Hypertext Markup Language) for page content, CSS (Cascading Style Sheets) for aesthetics, JavaScript for interaction, and SVG (Scalable Vector Graphics) for vector graphics enabled by a shared representation of the page called the document object model (DOM) (Bostock, 2019; Bostock, Ogievetsky, & Heer, 2011; Jiang, Fang, Ge, & Zhou, 2007). It also offers the possibility of creating almost any type of visualization from the ground up. However, the learning curve is high for developers because there are no built-in charts and it requires a good understanding of SVG and DOM elements to take advantage of its capabilities (Bostock, 2019).

D3.JS uses the data from arrays to create HTML tables or to create different SVG charts. HTML is the standard language for developing web sites and integrates well with JavaScript, CSS, and other languages. Scalable Vector Graphics (SVG) is a format that is used in many areas such as animation, user interfaces, Web graphics and mobile applications (Jiang et al., 2007). SVG is a vector-based image format for handling two-dimensional graphics. The format consists of an XML-based file format as well as programming API for graphical applications. An XML-based file format uses the Document Object Model (DOM), which is a programming API which defines the way documents are accessed and manipulated. DOM is also used in HTML which makes it easy for SVG format and HTML format to work together. This makes the SVG format very relevant when developing web sites that are using interactive graphics (W3.org, 2017). D3.JS allows for data to be created into an HTML table or into different SVG charts.

Google Charts

Google Charts is not open sourced but is a free tool for personal and commercial use. It is a Java library running on HTML5 and SVG and aims at Android, iOS and total cross-browser compatibility, including older Internet Explorer versions supported via VML. All the charts created are interactive and some are even zoomable. Google Charts is very user friendly and their site features a really nice and comprehensive gallery where users can see the kind of visualizations and interactions they need (Developers.google.com, 2019). Google Charts does have an easier learning curve as it provides an extensive list of built-in charts but learning the variations among them would take a longer period of time. Google Charts tends to be preferred by developers who have the JavaScript experience, but novices may be troubled by the SQL syntax needed for data retrieval (Supaartagorn, 2016). According to

Suppaartagorn (2016), a solution would be to use a framework that is designed to connect with Google Charts API.

A descriptive comparison table highlights the main differences in Table 1.

Table 1. Comparison table of JavaScript Visualization Tools

Tool	Commercial/ Open Source	Cost	Coding Requirement	Learning Curve	Built in Charts
D3.JS	Open Source	Free	Heavy coding	Difficult	None
Google Charts	Commercial	Free	Drag and drop	Gradual	25+ variations

D3.JS is the most preferred data visualization tool among developers (Rodden, 2014). It is widely used for generating dynamic and interactive data visualization in a web browser. D3.JS runs fast with minimal overhead in almost any modern web browser (Bostock et al., 2011; Sack, Donohue, & Roth, 2015). Google Charts is the most widely used data visualization tool, as it is powerful, simple to use, and free of charge (Zhu, 2012). There are great resources that help to explain how to use Google Charts with R to make interactive charts that have been famous for appearing in TED talks (Gesmann & de Castillo, 2011). R is a programming language which is a freely available software environment for statistical computing and graphics supported by the R Foundation for Statistical Computing (r-project.org). These interactive charts make it possible for the customer to view the actual changes in the data and to not have to imagine it for him or herself. Additionally, both D3.JS and Google Charts renders charts with Scalable Vector Graphics (SVG); although, Google Charts adds Vector Markup Language (VML). D3.JS is powerful Java Script library for manipulating documents based on data, charts rendered in SVG, and has nine chart types; Google Charts displays live data on your site, charts rendered in HTML 5 using SVG and VML, and has nine chart types. Both tools are described further in the next sections.

RESEARCH METHODOLOGY

As the field of information technology matures, understanding the effectiveness, efficiency, and user preferences of data visualization tools and frameworks become more important. This research compares the effectiveness, efficiency, and user preference of two popular data visualization tools: D3.JS and Google Charts. The data was captured through the development of an interface representing each data visualization tool including a task survey.

Interface Development

The two data visualization tools were chosen to interact with a dataset appropriate to develop a task for our participants. Both D3.JS and Google Charts have maps that are available for the public. However before the sample data can be connected and displayed, both maps must be adjusted and altered. The Google Charts Map is produced using free code provided by Google and allowed for the adjustment of features such as color, range of data, size. The D3.JS map required more detailed coding using JavaScript. Once the maps were altered, they were added to the overall design of the interface.

The tasked survey interface design is arranged in an accordian bootstrap layout. There are five sections in the accordion (See Figure 1). The bootstrap and JavaScript code allows the sections to

toggle between showing and hiding sections. If one section is showing, the other sections are hidden. To capture participant's related information, inputs are saved even when the sections are hidden.

Section 1 is a simplified consent form approved by IRB and informing the participant of the purpose, procedures, risks/benefits, and confidentiality of the study. Section 2 collects basic information about the participant (age and student status). Figure 1 show the survey user interface used to capture basic information. Section 3 labeled "Chart A Task" includes the Google Charts Map, the task survey, and a timer. The timer will stop when the accordion section is closed and remain paused until the tasked survey is complete. Section 4 labeled "Chart B Task" functions similarly to Section 3 with the exception that it uses the D3.JS visualization tool. There are differences in the appearance of the hover technique and data presentation between Google Charts and D3.JS. Finally, Section 5 addresses the user preferences about the two visualization tools in a series of three multiple-choice questions and two short answer questions.

Figure 1. Survey Interface to Capture Basic Information: Data Visualization Survey

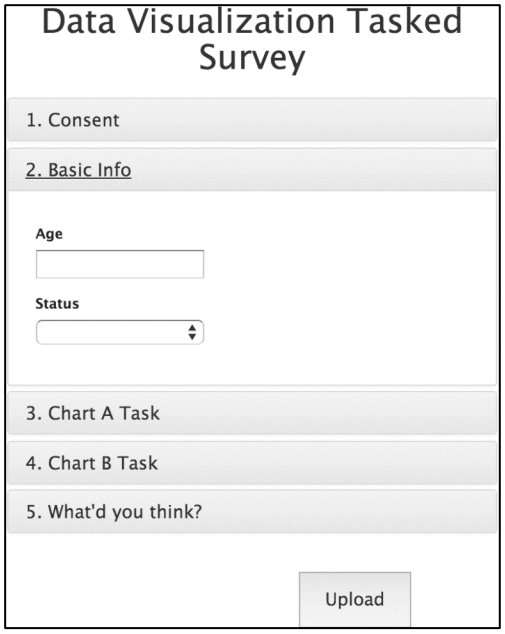


Figure 2. Chart A Task for Google Charts map

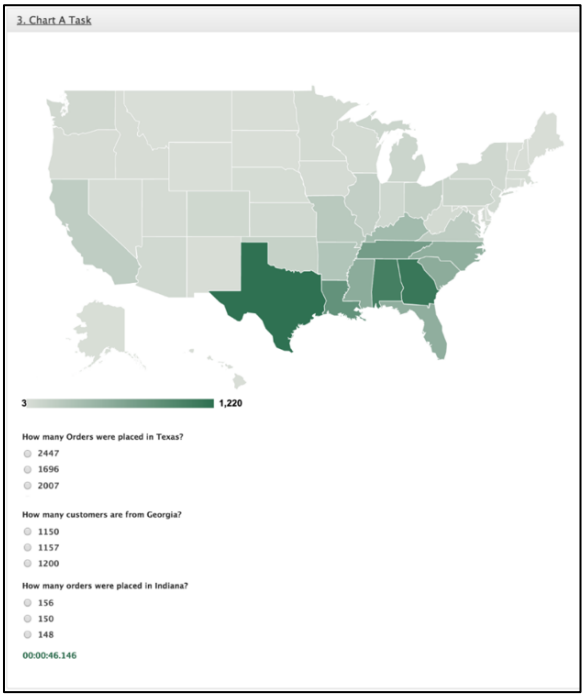
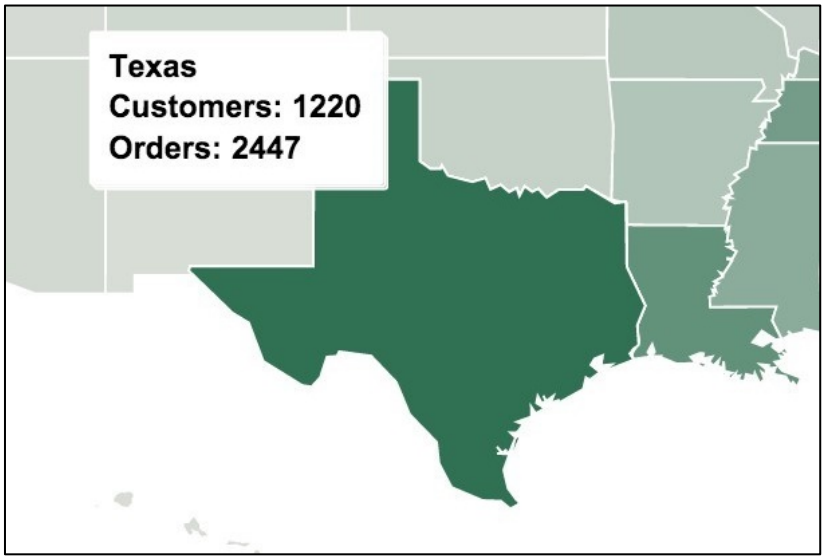


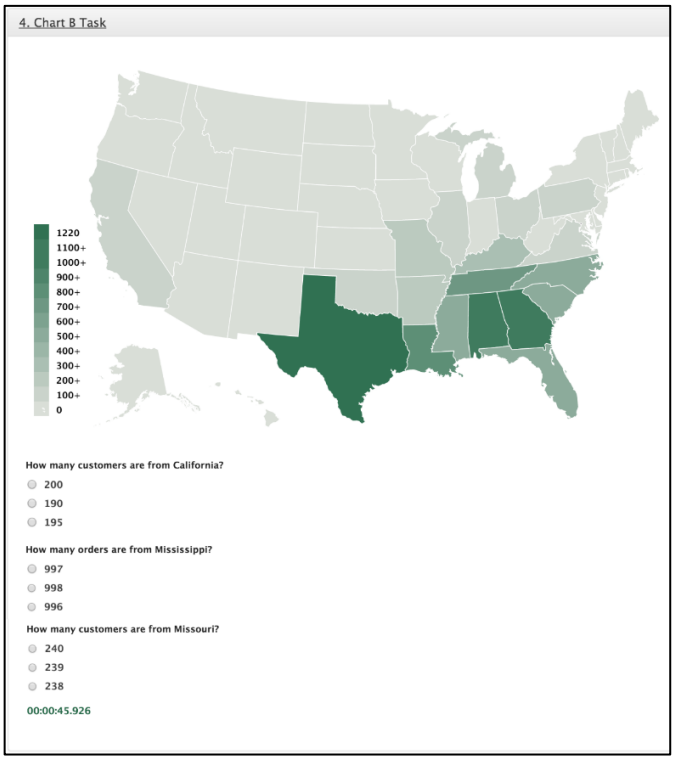
Figure 2 shows the Google Charts Map data visualization instance. The Google Charts Map is produced using the commercial but free code provided by Google. The maps allow the user to hover over each state to see how many customers and orders there have been in each state (see Figure 3).

Figure 3. The Google Charts Map's Hovered Result.



Similarly, Figure 4 shows the D3.JS map data visualization instance. The D3.JS has the capability to toggle along with its assigned region.

Figure 4. Chart B Task for D3.JS map



To provide a different look, the maps allow the user to hover over each state to see how many customers and orders there have been in each state (see Figure 5).

Figure 5. The D3.JS Map's Hovered Result

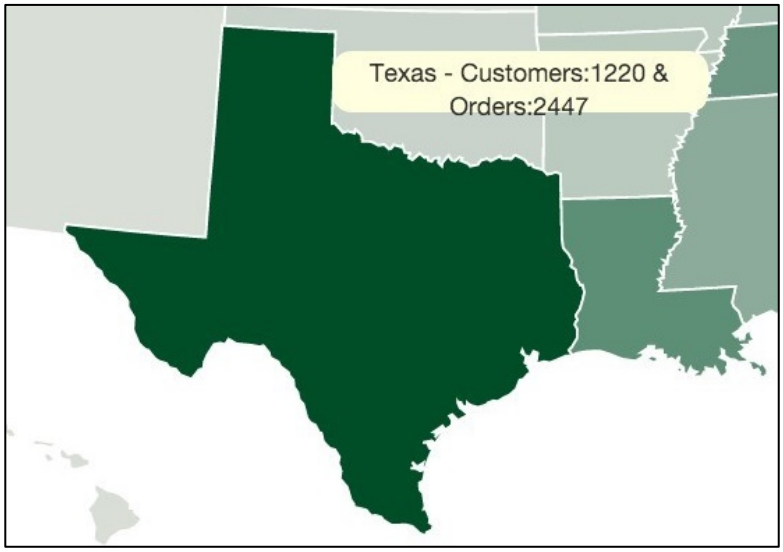
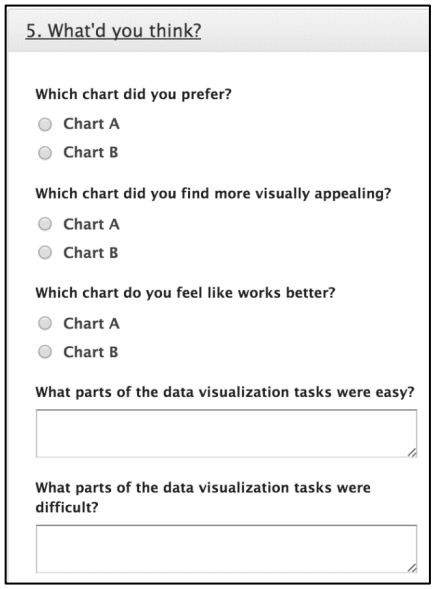


Figure 6 shows the survey used to capture the user preference information. As stated, this study attempts to evaluate the user interfaces of the two alternative visualization tools.

Figure 6. Survey for User Preference



Once the tasked survey responses are complete, the participant clicks a submit button located at the bottom of the accordion. All answers and timers are submitted to a MySQL database and a JavaScript pop-up window displays a thank you for participating message to the participant.

Experimental Procedures

Upon arrival, each participant was greeted and provided with an informed consent form. The informed consent form explained the purpose of the study, risks, benefits, and states that participation was voluntary and could be ended at any time. After completing the consent form, the participants were escorted to the computer that contained the visualizing system and provided with a copy of the task instructions. A researcher provided instructions on what to do to begin the task. The tasks were presented to the participants using pseudo random fashion across the subjects to minimize learning. For instance, if participant one received Condition 1 followed by Condition 2, then participant 2 received Condition 2 followed by 1. This pseudo random order was applied to all participants. Once the participant started, the researcher observed and recorded task completion time and number of errors.

To capture the user preference, the participants were asked three multiple-choice questions stating which chart they prefer more, which chart is more visually appealing to them, and which chart do they feel works better to them. In addition, the participants were asked to explain what parts of the data visualization tasks were easy or difficult for them. Once the participants clicked the submit button, their responses were stored in a custom database designed for this study. Later, the responses and the timestamps were imported into a MySQL table through PHP. Once the tasked survey has been submitted, a JavaScript pop-up window appeared to signal task completion. After completing the visualization task, each participant was then asked to choose their preferred subjective preference of the user interfaces. Afterward, the participant was thanked for their participation in the study.

Research Design

Participants. Participant recruitment was conducted by using telephone, email (through a class roster's emails), via Google + shared friends, using flyers, through the messaging system on the Desire2Learn (D2L) learning management system, and through verbal (word of mouth) recruitment. The target population were college students, faculty, and staff members. In total, thirty participants were recruited for this study. However, one participant was excluded from data analysis since the participant did not meet the criteria needed to be included in the research. In other words, the reason why one participant was excluded from data analysis is due to data screening (cleaning stage) as they were outliers from the rest of the groups. All the participants are young adults with ages ranging between 20 and 25. Therefore, the final results include data analysis of 29 participants.

Dataset. For this research, AKDesigns Boutique's dataset was used. This data was imported into the D3.JS and Google Charts maps. AKDesigns Boutique's data was used within the maps in the tasked survey. There are two different methods used to import the data into the maps. For the Google Charts Map, it was simpler to hard code the data into the map. AKDesigns Boutique's databases are not set-up to implement a live feed for the data to update as orders were made and customers joined. The D3.JS map used JavaScript Object Notation (JSON) to import the United States map information and a Common Separated Values (CSV) file to implement the AKDesigns Boutique data. JSON is used to allow for more customization of data visualizations (Kipp, Laa, & Cook, 2019). The CSV file was created in Excel.

RESULTS

We have conducted an IRB (institutional research board) approved usability study on the effectiveness, efficiency, and user preference of two popular data visualization tools: Google Charts and D3.JS. The performance result of one participant is an outlier because it is outside of the expected standard deviation from the mean. In other words, as stated in the research design section, one participant was excluded from data analysis is due to data screening (cleaning stage) as they were outliers from the rest of the groups. Therefore, the analysis result was conducted on 29 participants. The result is presented in terms of effectiveness, efficiency, and user satisfaction.

Effectiveness

As stated in the 'research methodology' section, the effectiveness was measured discretely as the number of successes and failures in task completion. A task was deemed successful if the participant completed the data visualization task without error. We measured the total number of errors committed as the measure for effectiveness of the data visualization tool. As stated, one of the expected outcomes of the experiment was that the participants would be able to accurately complete the data visualization task given tasks using both Google Charts (Condition-1) and D3.JS (Condition-2). The overall effectiveness result indicated that using Google Charts or D3.JS was effective. All the participants completed the task. End-users of Google Charts produced relatively more number of errors than end-users of D3.JS, 7 versus 6 respectively. However, the analysis result indicated that there is no statistical difference between the two conditions.

Efficiency

Task completion time was measured for efficiency. Since the design was a repeated measure (each participant performed both tasks), a paired sample t-test was used. The descriptive statistics and analysis are shown in Table 2 and Table 3. The mean scores for Condition-1 and Condition-2 are 43.28 and 34.66, respectively. The mean difference was approximately 8.6. Considering the p-value is less than .005, we can conclude there is significant difference in efficiency at Condition-1 and Condition-2. The descriptive statistics suggest data visualization condition could impact performance. It also suggests that Condition-2 performed better than Condition-1. However, further data analysis was required to find out the statistical significance of each of the conditions. For data visualization, Table 3 shows that there was a statistically significant difference between the two conditions ($p=0.01$, $p < 0.05$). The mean decrease in data visualization scores was 8.62 with a 95% confidence interval ranging from 3.95 to 13.30. The eta squared statistic (0.58; Cohen's $d = (34.6552 - 43.2759) / 14.92382 = 0.577647$) indicated a medium effect. The result suggests that Condition-1, took significantly longer on average to complete than Condition-2.

Table 2: Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Condition-1	43.2759	29	16.32679	3.03181
	Condition-2	34.6552	29	13.37448	2.48358

Table 3: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Condition1 - Condition2	8.62069E0	1.22894E1	2.28209	3.94605	13.29533	3.778	28	.001

User Satisfaction

The purpose of this user preference study was used to gain knowledge of the participants' opinion of the user interface design of the visualization tools. We found that 26 of the participants expressed Google Charts was easier to use than D3.JS. In addition, they also fournd it to be more visually appealing. Hence, the final expected outcome was that, on average, the participants were more satisfied using Google Charts than D3.JS.

DISCUSSION

Key Findings and Implications

A key goal of data visualization is to enable end-users to analyze the relationships among the represented data more effectively and efficiently. Examining data visualization tools for characteristics that represent effectiveness, efficiency, and ease of use based on user preferences will highlight the significances between which tool to use when a particular characteristic is preferred. This study explores two developer tools – Google Charts and D3.JS to determine end-user preferences with respect to the presentation and representation of the data. Specifically, we address a gap in the literature for specific tool preference as well as actual user input on the preferred visual layout.

Effectiveness of a data visualization tool allows end-users to accomplish their tasks. In general, we anticipate most tools to provide effectiviness for user tasks, however we asked the question if among two data visualization tools is one more effective than the other. Our first results demonstrate that both Google Charts and D3.JS are effective. However, Google Charts is considered more effective than D3.JS. We measured the total number of errors committed by the end-users and although no statistical difference was found between the tools, participants still had fewer errors when using Google Charts. This was confirmed in a number of the comments made by participants stating things such as *"... the hover boxes in Chart A [Google Charts] were much easier to read"* and it was *"...easy to scroll over a state"*. Essentially the large text and intuitive nature of the charts, made it more effective for end-users to accomplish their task. The more clear and consistent the data visualization tool is able to present, the more effective the tool is to its end-users.

Similarly, the efficiency of a data visualization allows users to experience the quickness and speed of transforming multiple data points into a visually appealing representation. Our study found statistical significance between the two conditions ($p < 0.05$). Thus, the null hypothesis was rejected. To provide additional support, the effect size shows there is indication of a medium to large effect, with a substantial difference in the data visualization tools efficiency scores.
Finally, we found that users do have preferences towards the data visualization tool in relation to the task. In general, end-users preferred Google Charts over D3.JS because of the ease of use and aesthetic design. The font was viewed as easier to read and visibly larger. This continues to support the argument that customers not only prefer visibly appealing data representation, but have a quicker comprehension of the data. Our study continues to support the research and practical needs that key features of data visualization tools are quick adaptation of the data, useful and aestetic presentation of the data, and the end-user has preferred characteristics when engaging with the tool.

Limitations and Future Directions

This exploratory study investigated the effectiveness, efficiency, and user preference of Google Charts and D3.JS. Participants answered a series of questions based on requested tasks. As noted by Jin (2017), user's characteristics may have differing effects with respect to visualization tools. Moreover, these characteristics may direct us to understanding why certain features are preferred

over others. Hence, future research should collect and explore additional personal characteristics such as gender, race, technical expertise, and level of education.

Much of the data visualization research focuses on the comparison of specific features or the number of data points manageable by the visualization tools. Our study contributes to the literature by providing a study that explores the user view of the visualization tools and their preferred choices based on effectiveness, efficiency, and user friendliness.

Overall, while the main objective of this study was to find out whether D3.JS or Google Charts is effective in data visualization. The result indicated, on average, it took longer time for the participants to complete the task using the D3.JS option. In addition, about 90% of the participants preferred Google Charts for ease of use over D3.JS. Even though this result provides an insight for data visualization, it has several limitations. The limitation is generalizability since only thirty participants were used for the study. Diverse samples that represent the general population will be beneficial for accurate prediction.

CONCLUSION

More and more people are using data visualization tools. Google Charts and D3.JS are popular tools found to be effective and efficient. However, there is a need of user-driven reports stating the efficiency and user preference of these popular data visualization tools. This is important because it can help us understand which visualization tool could be effective under certain circumstances, as well as what characteristics are important to ease of use and user satisfaction.

We conducted a usability study on the effectiveness, efficiency, and user preferences of two popular data visualization tools. Participants were able to accurately complete the given tasks using both Google Charts and D3.JS. The research results indicated that there is a difference in ease of use between Google Charts and D3.JS. Participants believe Google Charts to be faster, more efficient, and more aesthetically pleasing than the D3.JS map even though their average times on each chart contradicts these opinions. Overall, this research highlights the significance that different visualization tools may amplify users' levels of effectiveness, efficiency and preference based on its presentation and ease of use.

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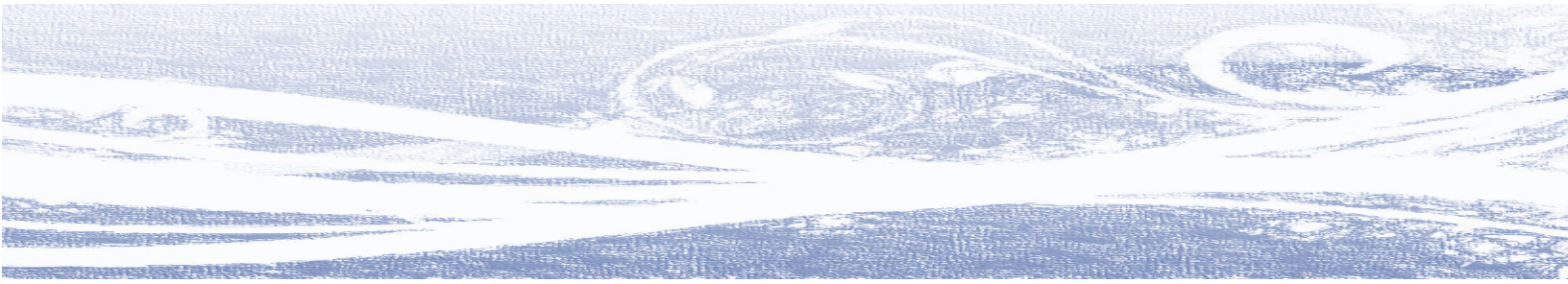

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