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A Comparative Review of Evaluation in Visualization Literacy Studies

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Abstract

Data visualization is a powerful tool that simplifies complex datasets into easily comprehensible visual representations, making it easier to identify patterns and relationships within the data. To fully understand data visualization, individuals must develop visual literacy skills, which entails effectively understanding, interpreting, and creating visualizations. Assessing visualization literacy skills through literacy tests is crucial, and educational tools play a significant role in advancing these skills by providing guidance and resources. However, determining the suitable settings for data collection in literacy tests and evaluating educational tools is a complex and demanding task. This paper presents a comparative analysis based on two literacy studies introducing literacy tests and evaluating the effectiveness of pedagogical tools for Treemap and Parallel Coordinates Plot (PCP) through classroom and crowdsourcing experiments. The analysis focuses on key factors, including data collection, study time and resources, data quality, data validity, and challenges encountered during experiments. The findings underscore the significance of considering specific research questions and target populations when selecting experimental settings for visualization literacy and educational purposes.

Keywords: Data visualization, Visualization literacy, Classroom-based evaluation, Crowdsourcing evaluation

Görselleştirme Okuryazarlığı Çalışmalarında Değerlendirmenin Karşılaştırmalı Bir İncelemesi

Öz

Veri görselleştirme, karmaşık veri kümelerini kolayca anlaşılır görsel temsillere basitleştirerek veriler içindeki kalıpları ve ilişkileri belirlemeyi kolaylaştıran güçlü bir araçtır. Veri görselleştirmeyi tam olarak anlamak için bireylerin, görselleştirmeleri etkili bir şekilde anlama, yorumlama ve oluşturmayı içeren görsel okuryazarlık becerilerini geliştirmesi gerekir. Görselleştirme okuryazarlık becerilerini okuryazarlık testleri aracılığıyla değerlendirmek çok önemlidir ve eğitim araçları, rehberlik ve kaynaklar sağlayarak bu becerilerin geliştirilmesinde önemli bir rol oynar. Ancak okuryazarlık testlerinde veri toplama için uygun ortamların belirlenmesi ve eğitim araçlarının değerlendirilmesi karmaşık ve zahmetli bir iştir. Bu makale, okuryazarlık testlerini tanıtan, sınıf ve kitle kaynak deneyleri yoluyla Ağaç Haritası ve Paralel Koordinatlar Grafiği için pedagojik araçların etkinliğini değerlendiren iki okuryazarlık çalışmasına dayanan karşılaştırmalı bir analiz sunar. Analiz, veri toplama, çalışma süresi ve kaynakları, veri kalitesi, veri

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geçerliliği ve deneyler sırasında karşılaşılan zorluklar gibi temel faktörlere odaklanır. Bulgular, görselleştirme okuryazarlığı ve eğitim amaçları için deneysel ortamları seçerken belirli araştırma sorularını ve hedef popülasyonları dikkate almanın önemini vurgulamaktadır.

Anahtar Kelimeler: Veri görselleştirme, Görselleştirme okuryazarlığı, Sınıf tabanlı değerlendirme, Kitle kaynak kullanımlı değerlendirme

1. INTRODUCTION

Data visualization is the graphical representation of data and information and enables transforming complex datasets into visual representations that are easily understandable and interpretable [1]. Visual designs allow for identifying trends, outliers, and correlations, helping to uncover hidden patterns and derive meaningful insights from complex datasets. However, to make the most of data visualization, people need to learn how to understand, interpret, and create visualizations effectively [2,3]. By developing these skills, individuals can become better readers and visualization creators, enabling them to communicate their insights effectively and avoid potential pitfalls such as misleading or misinterpreted visual representations.

Educational tools are essential for promoting visualization literacy and are specifically designed to help learners gain practical experience and engage in iterative processes of creating, refining, and critically evaluating visualizations. Evaluating the effectiveness of educational tools in enhancing visualization literacy can be done through different methods, such as classroom experiments and crowdsourcing. Classroom experiments involve incorporating visualization literacy training and measuring its impact on a group of individuals' understanding and comprehension of visualizations. On the other hand, crowdsourcing experiments provide an alternative approach by involving a diverse group of individuals to evaluate visualization literacy and educational tools due to its low cost and scalability [4]. Both experimental settings facilitate the assessment of users' literacy skills and the effectiveness of educational tools through visualization literacy tests. Additionally, they offer valuable insights for identifying areas that require improvement and refining pedagogical approaches to enhance visualization literacy.

This paper analyses empirical studies conducted in a classroom and crowdsourcing environments. We draw upon two prior studies on visualization literacy, which assessed educational tools for Treemap and Parallel Coordinates Plot (PCP), to determine the appropriate settings for data collection in visualization literacy. We propose a comparative analysis that highlights the impact of factors such as data collection, study time and resources, data quality, data validity, and challenges in conducting experiments, emphasizing the need to consider specific research questions, target populations, and trade-offs for researchers.

The rest of the paper is organized as follows: Section 2 reviews the previous work on different experimental settings chosen in visualization literacy research. Section 3 summarises the treemap literacy paper that presents results from a classroom experiment. Section 4 summarises the parallel coordinates literacy paper that presents a crowdsourcing experiment. Section 5 provides factors influencing study results of visualization literacy studies in the classroom and crowdsourcing settings. Section 6 wraps up with conclusions and future work.

2. RELATED WORKS

In this section we describe related research that focus on visualization literacy user studies with classroom and crowdsourcing studies. A survey [5] categorized a selection of related research papers to explore the visualization systems for educational purposes while another survey [6] providing an overview of the visualization literacy literature with the evaluation technique.

2.1. Classroom Studies

In an educational environment, the researchers create assessments for both pre-experiments and post-experiments to examine the visualization literacy abilities of users, relying on participants' responses to questions. Within this context, a group of participants, typically in a classroom setting, engage in a collective experiment together e.g. studies by [7,8,9,10,11].

Baker et. al. [12] present a study with middle school students to explore their ability to understand and use different types of graphs. The researchers carried out an experiment in a classroom setting to observe how novice learners performed in interpreting, creating, and selecting visual representations. The study involved 52 students from grades 8 and 9, who completed 3-4 exercises. Alper et. al. [9] conducted a study to explore teaching methods for enhancing visualization literacy among elementary school children. They introduced an online platform called C'est La Vis, which allows students to create and engage with visual representations of data. The researchers conducted a field study to evaluate the effectiveness of the tool, as well as to gauge students' interest and comprehension during the exercises. The study involved 15 students who were divided into small groups and observed in two different classrooms. Similarly, Wang et. al. [13] introduced the concept of "cheat sheets" which are a compilation of visual illustrations and textual explanations, such as data comics, designed to aid in data visualization education. They conducted a user study in a classroom setting with 11 participants from a nearby university. The participants were presented with a visualization example using a specific technique and then asked to complete a brief quiz to assess their comprehension.

2.2. Crowdsourcing Studies

Certain studies choose to utilize online platforms for their experiments, allowing them to recruit a significant number of participants from various geographical locations [14]. Crowdsourcing platforms like Amazon's Mechanical Turk (MTurk, https://www.mturk.com) provide access to a large pool of participants at affordable rates, enabling researchers to collect data within a relatively short timeframe in some studies [2,15,16].

Boy et. al. [17] presents a systematic approach for evaluating visualization literacy. The experimental setting involved 144 participants from MTurk. They were provided with a series of visualizations and assessed on their ability to interpret and analyze the data accurately. Kwon and Lee [3] presents a study that compares different online learning approaches using parallel coordinate visualization. The experimental setting involved 120 participants from MTurk, who were randomly assigned to different learning approaches. The study examined the effectiveness of these approaches in terms of learning outcomes, user satisfaction, and engagement. Simiarly, Lee et. al. [18] conducted a research study to explore the relationship between visual literacy and three cognitive characteristics. The experiment involved 178 participants recruited from MTurk. The participants were required to complete four assessments, including a Visualization Literacy Assessment Test (VLAT). The purpose of the study was to examine how these cognitive factors relate to individuals' visual literacy skills as measured by the VLAT.

3. TREEMAP LITERACY: A CLASSROOM-BASED EVALUATION

Treemaps are a type of hierarchical data visualization method that can effectively represent complex data structures. This advanced visual design is not easily perceived by untrained eyes, making enhancing treemap literacy skills an important topic. The study by Firat et. al. [19] focuses on identifying potential obstacles to interpreting and comprehending treemaps. To achieve this, a novel treemap literacy test is introduced, comprising various treemap designs and treemap-related questions. The test questions are classified based on treemap features, and the research aims to provide researchers with enhanced insights into the barriers hindering a thorough understanding of treemaps and propose a method for advancing treemap literacy.

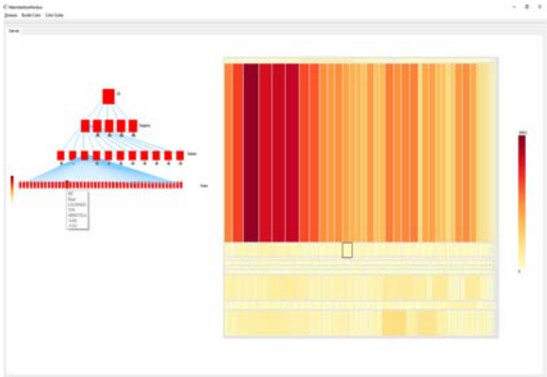

Figure 1. Instructional treemap tool interface with a traditional tree structure (left) and linked treemap visualization (right). The image courtesy of Firat et. al. [19].

In addition, interactive educational treemap software is developed to facilitate training and improve cognition of treemap design and supports the exploration of hierarchical data structures. The pedagogical treemap software is also an alternative to conventional treemap teaching, transforming passive learning into active learning practice.

Firat et. al. [19] conducted an experiment in a classroom environment. A total of twenty-five students participated in the study. The students were taught how to interpret and create treemaps using real-world data sets. Half of the students in the classroom were taught with the treemap software, while the other half were taught with traditional slides. The study utilized a pre-test and post-test design to measure the impact of treemap instruction on students' understanding and usage of treemaps. The participants were given a pre-test before joining the training session, followed by a post-test and a feedback session. The correct answers in both tests were counted to compare the understanding of treemap in both slides and the software groups.

The study found that students who used the pedagogical treemap software in the classroom performed better than those who used slides to learn about treemaps. The software facilitated a quicker and easier understanding of treemap properties, as reported by participants. The treemap software significantly improved students' treemap literacy skills, including comprehension of treemaps and the ability to extract meaningful insights from them. Moreover, the instruction positively impacted students' data analysis and interpretation abilities, enabling them to make informed decisions based on treemap visualizations.

The study highlights the importance of visual literacy in today's data-driven society and underscores treemaps as a valuable visualization technique for data exploration and analysis. The results suggest that including the treemap tool in educational curricula can enhance students' data visualization and analytical skills. By equipping students with the knowledge and tools to work with treemaps effectively, educators can empower them to understand better and interpret complex datasets.

4. PCP LITERACY-CROWDSOURCING EVALUATION

Parallel coordinates plots are a powerful visualization technique for displaying multidimensional data, allowing users to identify patterns and relationships among variables. This advanced visual representation may pose challenges for individuals without proper training, emphasizing the significance of improving parallel coordinates literacy skills.

Firat et. al. [20] focuses on visualization literacy, which refers to the ability to interpret and comprehend visual designs, particularly in the context of data visualizations. The authors emphasize the increasing importance of visualization literacy due to the growing volume of data and the need for non-expert users to explore and analyze complex datasets effectively. The study specifically investigates the barriers to understanding parallel coordinate plots (PCPs), which are advanced graphical representations used to display multivariate and high-dimensional data.

To address this issue, the authors develop a parallel coordinates literacy test that utilizes diverse images generated using popular available PCP software tools. The test aims to enhance users' PCP literacy skills and evaluate their comprehension abilities. Additionally, an interactive educational tool is designed to facilitate the teaching and learning of parallel coordinates. This tool offers a more active learning experience, aiming to improve the PCP literacy skills of novice users.

The research also briefly explains parallel PCPs as a graphical representation of multidimensional relationships using parallel axes. Each axis represents a different variable, and data records are represented by polylines that intersect the parallel axes at specific points, indicating the values of individual dimensions. PCPs offer advantages over Cartesian Coordinate Plots (CCPs) for displaying high-dimensional data, as the parallel layout provides a clearer separation of axes and allows for the representation of more dimensions.

The research hypothesizes that an interactive tool that links traditional Cartesian Coordinates with PCPs would enhance PCP literacy more effectively than static slides. To test this hypothesis and assess the efficiency of the educational software, the authors conducted an online, crowdsourced user study. Overall, both classroom experiments and crowdsourcing experiments have their own advantages and disadvantages in terms of data quality and validity. The choice between these settings depends on the specific research question, the target population, and the trade-offs researchers are willing to make in terms of control, generalizability, and other factors.

The user-study implemented a crowdsourced approach using Amazon Mechanical Turk, dividing participants randomly into two groups: one using slides and the other utilizing the software for teaching the PCPs. Instead of relying on software or slides, tutorial videos were specifically created for the teaching session. The participants were given a pre-test, followed by watching the tutorials, and then took a post-test to evaluate their proficiency in PCP literacy after watching the tutorial videos. The study aimed to determine whether the software tutorial, compared to traditional slides, effectively improved participants' PCP literacy skills. The results showed that participants in the software condition significantly improved their PCP literacy skills compared to those in the condition of the slides. The software tutorial successfully enhanced participants' ability to read and interpret PCPs, as indicated by their higher scores in the post-tutorial test. Examining the feedback provided by the participants highlighted the benefits of the tutorial video and the positive impact of the educational PCP tool. Overall, the qualitative feedback supported the quantitative findings, indicating that the software tutorial was well-received and contributed to improving PCP literacy. The results and findings of the user-study confirm the effectiveness of the developed educational PCP tool in enhancing PCP literacy. The interactive tool with the tutorial video facilitated users' understanding of PCPs and their ability to interpret multidimensional data effectively.

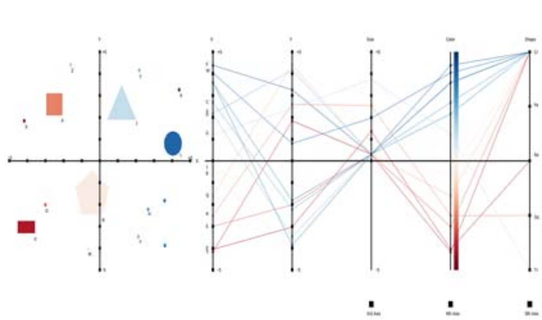

Figure 2. Pedagogical tool interface with Cartesian coordinate space (left) and the corresponding parallel coordinates plot (right). The image courtesy of Firat et. al. [20].

5. CLASSROOM VS CROWDSOURCING EVALUATION FOR VISUALIZATION LITERACY STUDIES

This paper presents the findings of two studies evaluating educational Treemap and PCP tools by comparing two different experimental settings: classroom and crowdsourcing to determine appropriate settings for data collection. Each approach carries its own set of advantages and disadvantages. This study compares the two methodologies and sheds light on the factors influencing data collection, study time and resources, data quality, and validity, and the challenging aspects of conducting experiments, including training for visualizations.

The research by Firat et al. [19, 20] conducted two separate studies to evaluate Treemap and PCP educational tools: one utilizing a crowdsourcing approach and the other employing a classroom experiment. The result reveals some interesting findings based on these two research. Table 1 briefly compares various factors that influence the selection of research methods between the classroom and crowd-sourcing settings.

5.1. Data Collection

The crowdsourcing experiment aimed to recruit participants from a diverse pool, ensuring a wide range of backgrounds. Data collection in this method was relatively efficient, allowing for a shorter time frame. On the other hand, the classroom experiment involved recruiting participants with similar backgrounds, enabling investigation under controlled and uniform conditions. However, the setup for the classroom experiment required a significant amount of time and effort.

In the research [20], it was reported that initially, 202 potential participants attempted to take the study through MTurk. However, applying filters such as the duration of participants' video tutorial viewing, their screening question responses, and their answers to simple tutorial-related questions, 60 participants remained. The result reveals that the crowdsourcing experiment yielded a large sample size due to the ability to tap into a vast pool of potential participants. This diverse pool provided a variety of perspectives, enhancing the generalizability of the findings. However, this method's lack of guarantee regarding participant attentiveness was a drawback. It was challenging to ensure the quality and reliability of the data collected, as participants may not have been fully engaged or committed to the experiment.

In contrast, the classroom experiment allowed greater control over the research environment. Participants with similar backgrounds were selected, ensuring a homogenous group for investigation, e.g. computer science students [19]. The advantage of this approach was the ability to set up standardized conditions, facilitating accurate comparisons and reducing potential confounding factors. Researchers could closely monitor participant engagement, resulting in more reliable data collection and credible results.

5.2. Study Duration and Resources

The process of recruiting participants and establishing the experiment in a classroom setting required a substantial investment of time and resources. For example, the research [19] indicates that the study's findings might have been influenced by self-selection bias and availability bias due to participant recruitment occurring during the summer period, and the presence of students with prior knowledge of data visualization could have affected their proficiency in navigating treemaps.

Table 1. The table compares various factors that influence the selection of research methods between the classroom and crowdsourcing settings. The checkmark represents a higher impact or significance compared to the other setting.

	Classroom	**Crowdsourcing**
Attentiveness	√	
Compensation	√	
Data Validity	√	
Data Quality	√	
Ease of Finding Participants		√
Duration of Data Collection	√	
Participants Diversity		√
Effort in Design	√	

Classroom studies require offering higher compensation payments, e.g. vouchers, than crowdsourcing studies to encourage participants to participate in research. The treemap study offered a

£5 worth Amazon voucher, while the PCP study provided only £1 to the participants for their time and effort. Some crowdsourcing platforms like Prolific [21] aims to ensure fair compensation for participants' time and effort. To maintain a certain standard, they often set minimum hourly payments to ensure that workers are adequately compensated. These minimum payments can vary depending on the platform and the tasks involved. This policy helps maintain fairness and attract quality participants willing to engage in tasks that meet the minimum payment criteria.

5.3. Data Quality

In a classroom setting, researchers have direct control over the experimental environment and can ensure consistent procedures and standardized data collection. This control can lead to higher data quality, as researchers can closely monitor participants' actions and behaviour. Additionally, researchers can provide clear instructions and explanations, reducing the likelihood of errors or misunderstandings. In contrast, crowdsourcing experiments involve recruiting participants from online platforms, which introduces variability in participant characteristics, motivation, and attention levels. While the data collected in crowdsourcing experiments can still be of high quality, the lack of direct control over the experimental environment and participants' actions may lead to a slightly higher risk of lower data quality. However, some crowdsourcing platforms have built-in quality control mechanisms, such as attention checks and quality ratings, to mitigate this risk. The test [18] includes sanity check questions that aim to identify inattentive participants and remove their data to ensure the reliability of the collected data.

5.4. Data Validity

Classroom experiments often benefit from a more controlled and naturalistic environment, allowing researchers to observe participants' behaviour in a context closer to real-world situations. This can enhance the external validity of the findings, making them more generalizable to real-world scenarios. However, the presence of a known researcher or authority figure in the classroom setting can sometimes influence participants' behaviour, potentially affecting internal validity. For example, the study recruited participants with similar backgrounds and ages, which might influence the validity of the results. Crowdsourcing experiments can provide access to a larger and more diverse pool of participants, allowing for increased generalizability of findings across different populations. However, the external validity of crowdsourcing experiments may be influenced by the fact that participants often complete tasks in isolation, without the social context that may exist in a classroom setting. This lack of social influence can impact the generalizability of findings to real-world social interactions and anticipated focus on the experimental stages. For instance, participants were asked the watch tutorial video that demonstrates how PCP technique works with an animation and they expected to watch the entire video before proceeding to the post-test questionnaire. However, the lack of guidance and social influence led to many participants not watching the entire video and consequently struggling to answer the questions correctly about the examples presented in the tutorial [18].

6. CONCLUSION

Data visualization is a powerful tool for understanding and communicating complex information. To fully understand the trends and patterns in the data, individuals need to develop visual literacy skills. Educational tools are vital in improving visualization literacy by providing guidance, resources, and hands-on experiences. Evaluating the effectiveness of these tools through experiments such as classroom integration and crowdsourcing enables us to continuously refine and enhance visualization literacy education.

Both classroom and crowdsourcing experiments have advantages and disadvantages in terms of data collection, study time and resources, data quality, and validity. The choice between these settings depends on the specific research question, the target population, and the trade-offs researchers are willing to make regarding control, generalizability, and other factors.

One potential future research project is to conduct a crowdsourcing experiment for the treemap study and compare the results with the classroom study. By comparing the findings from the crowdsourcing experiment with those from the classroom study, researchers can assess the effectiveness and generalizability of treemap education across different settings and participant populations.

Similarly, it would be valuable to conduct the same PCP study in a classroom setting. This would involve integrating PCP education tools into the curriculum and evaluating their impact on students' visualization literacy and comprehension of PCPs. Comparing the results of the classroom study with the existing crowdsourcing study can provide insights into the similarities and differences in the effectiveness of PCP education in these two settings.

By conducting these additional experiments, researchers can gain a more comprehensive understanding of the strengths and limitations of both classroom and crowdsourcing settings for visualization literacy education. This comparative analysis will contribute to refining and enhancing educational tools and practices, enabling more effective and widespread adoption of visualization literacy education in various contexts.

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