Treemap Literacy: A Classroom-Based Investigation

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Abstract
Visualization literacy, the ability to interpret and understand visual designs, has gained momentum in the educational and information visualization communities. The goal of this research is to identify and address barriers to treemap literacy – a popular visual design, with a view to improve a non-expert user's treemap visualization literacy skills. In this paper we present the results of two years of an information visualization assignment, which are used to identify the barriers to and challenges of understanding and creating treemaps. From this, we develop a treemap visualization literacy test. Then, we propose a pedagogical tool that facilitates both teaching and learning of treemaps and advances treemap visualization literacy. To investigate the efficiency of this educational software, we then conduct a classroom-based study with 25 participants. We identify the properties of treemaps that can hinder literacy and cognition based on the results from the treemap visualization literacy test. Results also provide further support for the use of our tool that had a positive effect on treemap literacy skills of university students.

CCS Concepts
• ***Human-centered computing*** → ***Visualization systems and tools;*** *Empirical studies in visualization;*

1. Introduction and Motivation

Visualization is becoming a fundamental component of education. The use of visual design in pedagogy has a long history and is still evolving rapidly. Enhancing the educational process by enabling a better understanding of a given subject with graphical representations and promoting visualization literacy skills are important challenges. Visualization literacy is recognized as an important direction of research, indicative in workshops at EuroVis 2014 "Towards Visualization Literacy " [RVM*14] and at IEEE VIS 2014 "Towards an Open Visualization Literacy Testing Platform" [KBL*14]. It is also widely studied in the visualization community, e.g. [BMBH16, BRBF14, LKK17].

The simple definition of visualization literacy is the ability to read, interpret, and understand the information presented in graphical designs [Wil93]. Visualization literacy has also been defined as "The ability to make meaning from and interpret patterns, trends, and correlations in visual representations of data" [BMBH16] and "the ability to confidently use a given data visualization to translate questions specified in the data domain into visual queries in the visual domain, as well as interpreting visual patterns in the visual domain as properties in the data domain" [BRBF14]. Moreover, Borner *et al.* [BBG19] define the ability of reading and construction of information visualizations as essential as the ability to read and write text. For purpose of this study, we define treemap literacy as the ability to construct and interpret treemaps.

Treemaps are an efficient way to represent hierarchical data and they require a special layout algorithm. But displaying large hierarchical data sets increases the complexity of the treemap, causing difficulty in treemap comprehension. Poor design parameter choices for a treemap can cause ambiguity and pose challenges in exploring the information represented in the treemap [KHA10]. An investigation into the barriers of interpreting and designing useful treemaps is essential to enhance their effectiveness and intelligibility. Hence, the focus of this study is to identify these barriers to enable a complete literacy of treemaps.

This study is the first one of its kind focusing on treemaps. While the challenges posed by treemaps are not exclusive to this type of visualization, treemaps do have unique properties such as representing hierarchical data and requiring a special layout algorithm. We propose a novel treemap literacy test to assess the barriers to treemap literacy and advance a user's treemap literacy skills by designing an effective pedagogical tool that enables novices to improve their skills of reading, comprehending, interpreting, and creating treemaps. The tool attempts to transform the passive learning experience to an active learning process. Moreover, the educational software supports the analysis of hierarchical data and facilitates correct observations of that which it represents. The research prototype tool demonstrates the correspondence between the traditional tree structure and a treemap design simultaneously.

In order to investigate the potential impact, the result of an experiment conducted in a classroom environment with participants from a computer science department is reported. This study presents the results of the treemap evaluation using the educational tool in an attempt to improve understanding of users' visualization literacy abilities. The main contributions of this study are as follows:

1. Identifying and investigating the barriers to treemap literacy;
2. Introducing a treemap visualization literacy test and conducting a classroom-based user study to evaluate the impact of an interactive tool for the comprehension of treemaps;
3. Developing a novel pedagogical application that facilitates both teaching and the learning of treemaps, advancing treemap visualization literacy.

2. Related Work

Several studies focus on comprehension and interpretation of visual designs and assess users' understanding of visual representations. We start by examining the related literature on visualization literacy through the Survey of Surveys (SoS) on information visualization [ML17] and a survey of information visualization books [RL19]. A survey of interactive visualization for education [FL18] does not include any study on visualization literacy.

Using the Item Response Theory (IRT) [Rec09], Boy *et al.* [BRBF14] developed a method for visualization literacy evaluation by creating prospective test items that measure a user's visualization literacy level. The aim was to create an efficient and reliable test using line graphs, bar charts, and scatterplots for identifying users with lower visualization literacy. Similarly, an evaluation tool, created by Maltese *et al.* [MHS15], aimed at investigating the ability of groups with varying levels of experience in STEM fields to read and interpret graphical representations. Ruchikachorn and Mueller [RM15] present a learning-by-analogy method that illustrates an unfamiliar visual design by displaying a step-by-step transformation from another design. The transformation concept promotes comprehension of the uncommon visual representation by interacting with the transitions. They focus on understandings of parallel coordinates, the hyperbox, spiral chart, and treemap.

Alper *et al.* [ARC*17] investigate visualization literacy teaching methods for elementary school children and present an online platform C'est La Vis, that enables students to create and interact with data visualizations and is used by instructors in the classroom for teaching the visualization by creating exercises for children. Moreover, Chevalier *et al.* [CRA*18] present an evidence-based discussion of visualization literacy, suggestions for improving it in early education, and future research directions for visualization literacy. Most recently, studying the impact of cognitive characteristics to advance users' visualization literacy has become essential. Thus, Lee *et al.* [LKY*19] concentrated on testing the correlation between visualization and cognitive features, such as cognitive ability, cognitive motivation, and cognitive style. Börner *et al.* [BBG19] propose a data visualization literacy framework (DVL-FW) to guide the visualization literacy teaching and assessment. The study provides a set of guidelines and an evaluation that can be utilized to measure and advance visualization literacy.

Further works for enhancing the teaching and learning experience are presented by Kwon and Lee [KL16] and Fuchs *et al.* [FIB*19]. Kwon and Lee [KL16] focus on parallel coordinates, an efficient method to display multidimensional data, to study the impacts of multimedia learning environments for teaching data visualization to non-expert users. The inspiration behind this research is to examine the active learning theory. EduClust [FIB*19] is an online application that assists both the learning and teaching of clustering algorithms. This application combines visual designs, interaction, and intermediate clustering results to facilitate the comprehension and teaching of clustering algorithms using scatterplots.

Our work is theoretically grounded in the above mentioned research. The focus of our research is, however, specifically on treemap literacy as we provide analysis and guidance to address the challenges of treemap understanding.

Tu and Shen [TS07] present a new treemap design algorithm to minimize abrupt changes in layout and establish clear visual patterns, and build a contrast treemap to compare attributes in one treemap from two snapshots of hierarchical data. An experiment to test the new layout and a user study to compare the data and examine the changes were conducted. Moreover, Tu and Shen [TS08] introduce Balloon Focus, a seamless technique for treemaps in multi-focus+context. A user study was conducted with 12 participants who were asked to perform a variety of tasks as well as a case study on the use of the system to convey NBA statistics.

Ziemkiewicz and Kosara [ZK08] investigated how the structure of a visualization affects how we interpret it. They evaluated the effects of a visual metaphor and a verbal metaphor on understanding of tree visualizations by measuring the participants' data comprehension questions on either a treemap or a node-link diagram. Another work by Woodburn *et al.* [WYM19] compared three common visualizations for hierarchical quantitative data, treemaps, icicle plots and sundown charts with a controlled user study with 12 participants. The study looked at performance task accuracy of the visualizations and the participant's visual designs preferences.

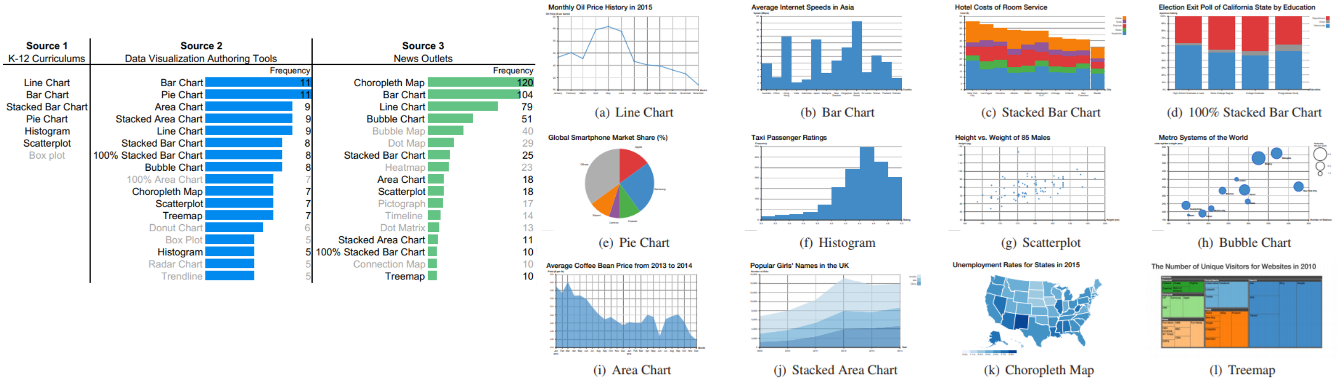
3. The Challenges of Interpreting Treemaps

Treemaps are a good solution for presenting large hierarchical data sets. The available screen space is divided into rectangles that are scaled, placed, and color-mapped to the variables in the data [RTL*16]. They do, however, present certain challenges to some.

We identified five barriers based on the review of related literature and feedback from students taking the data visualization class taught in our computer science department. One aim of our study is to test the hypotheses related to the existence of these barriers. What are the barriers to successful treemap interpretation?

- **H-Hierarchy** One of the barriers to treemap literacy is likely based on the fact that treemaps convey hierarchical data. A treemap displays the relationship between hierarchically structured data attributes. Identifying the multiple levels of the hierarchy can be a challenge to treemap comprehension.
- **H-Layout** The layout algorithms build useful treemaps by controlling the placement and aspect ratios of the rectangles that compose a treemap. Algorithms aim to increase the visibility of small items in a single image. However, the complexity of the layout algorithm, failing to maintain the order of the data, and layouts that are difficult to visually explore [BSW02] may lead to challenges in comprehension.
- **H-Size** The larger the data set size, the more difficult a treemap image would be to understand, because a larger number of rectangles results in higher visual complexity.
- **H-Labels** Node labels enable users to identify which variable a given treemap rectangle corresponds to. Absence of labels or limited display of the labels shown in a designated screen space can cause difficulty in understanding and interpretation.
- **H-Legend** A color legend situated near the treemap can be used to represent value ranges visually. The absence of a color scale can lead to barriers in treemap interpretation.

The last two hypotheses relate to the simple absence or presence whereas the rest are more algorithmic in nature.



(a) (b)

Figure 1: *(a) Data visualization types surveyed from three sources: K-12 curricula, data visualization authoring tools, and popular news outlets. (b) The 12 visual designs that compose the VLAT. Images courtesy of Lee et al. [LKK17]*

In this work, we study these barriers preventing users from interpreting and comprehending treemaps correctly. Afterwards, we attempt to improve literacy skills in understanding of treemaps.

Our work is inspired by the Visualization Literacy Assessment Test (VLAT) developed by Lee *et al.* [LKK17]. VLAT identifies three major sources to search and determine the most popular visualizations to incorporate in their test [LKK17]. Figure 1a compiles the most frequently used visual designs from three different sources: the K-12 educational programs (core state standards for mathematics) [New13, oE13, Ind14, Was10], data visualization authoring tools (**Google Chart Tools**, **D3.js**, and news articles (The New York Times, The Guardian, and The Washington Post).

They identify data visualization designs included in the curriculum and the designs most often used in authoring tools and popular news outlets. Some of the visual designs covered by educational programs, however, are not as popular with authoring tools and news articles. Figure 1a indicates that the Choropleth Map is the most frequently used visual design in news articles although it was not included in the K-12 curriculum. Conversely, pie charts and histograms are used in the educational program and supported by tools, but they were not the most frequently used visualization types in news articles. Figure 1b illustrates the 12 data visualizations chosen for VLAT, selected from the most popular visualization types used in news articles e.g. Treemaps, Choropleth Maps, Scatterplots.

It is evident from Figure 1b that the treemap design features several characteristics that distinguish it from the other most popular visual designs shown:

- A treemap is not based on a simple Cartesian (nor geo-spatial) coordinate system. (**H-Layout**)
- It utilizes a layout algorithm, as opposed to a simple lookup table in order to guide the placement of geometric primitives such as rectangles, labels, and edges. (**H-Layout**)
- It is the only visual design out of the 12 most popular that incorporates hierarchical data. (**H-Hierarchical**)
- The treemap requires a more sophisticated label placement algorithm than the other visual designs. (**H-Labels**)
- In Figure 1b, particularly, the treemap is the only example that does not feature a color legend (where necessary). (**H-Legend**)
- The treemap does not feature labelled and numbered axes like the other visual layouts. (**H-Labels**)
- The treemap is the visual design that can be used to display the most individual data samples with the exception perhaps of scatterplots. (**H-Size**)

These observations relate to the requirements of creating successful treemaps and present differences that show ways in which treemaps can be viewed as more complex than other visual designs. We show the connection between these observations and our hypotheses in parentheses. The design complexity results in barriers to comprehension and interpretation of treemap visualization.

4. Treemap Literacy Assessment

The data visualization module at our university has been taught to final-year undergraduate and master's level students since 2006. The course consists of two-hour lecture and one-hour labs run weekly during one semester. As the construction of a visual design is a way of assessing visualization literacy suggested by Borner [BMBH16], we explored how effective students were at creating a treemap by looking at the historical results of the information visualization assignment in 2018 and 2019. Thus, we sought to assess the students' strengths and weaknesses in generating the treemap images, as well as their level of comprehension and interpretation.

Based on our hypotheses and the work of Lee *et al.* [LKK17], we derived criteria that enabled the assessment of treemap literacy. The criterion consisted of questions examining treemap features that were correctly interpreted by the user, including the hierarchy, internal nodes, leaf nodes, labels and legends, and color mapping (See Figure 2 and Supplementary Material for Treemap Literacy Assessment). The results of the treemap literacy assessment indicate how many treemap features the students correctly incorporate and interpret while creating an appropriate image.

The treemap literacy criterion was applied retroactively to evaluate treemaps submitted by students as part of an information visualization assignment. In 2018, 83 computer science students enrolled in the data visualization module. For the information visualization coursework in 2018, students were required to submit five visual designs to study the Public Health Data of England using existing visualization software. Public Health Data of England [Eng13]

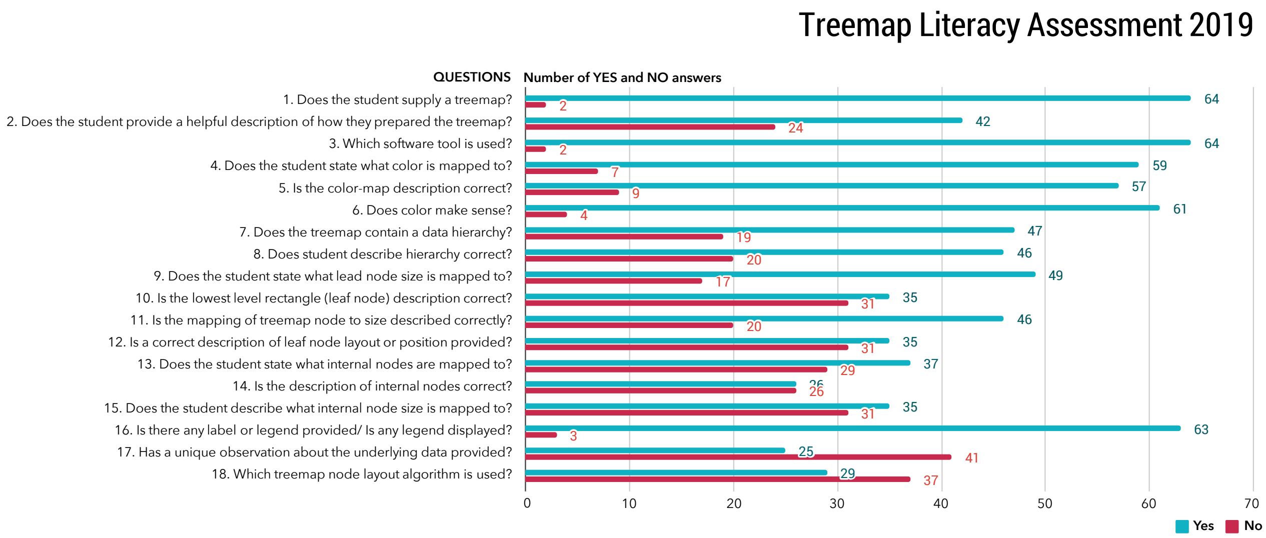


Figure 2: *A treemap literacy assessment test results from the information visualization assignment in 2019.*

is a geographically hierarchical data with England divided into a hierarchy of areas and diagnosis [TML*17]. Students were asked to create and explain at least five unique visual designs using existing data visualization tools. Although there was no explicit requirement to generate a treemap, 68 students in the class attempted to create a treemap as a part of the assignment. Only 38 out of the 68 students specified how they prepared the data before producing the treemap. Usually, this involves formatting to create a hierarchy. This result indicates that the data pre-processing required for a treemap can lead to barriers in treemap generation (**H-Hierarchy**). Some 16 (out of 68) treemaps did not feature a critical feature of a treemap, namely a data hierarchy (**H-Hierarchy**), even when they were explicitly informed about this challenge. 65 of the 68 students defined what color was mapped to, and the color-map was described correctly by 58 (out of 68) of them (**H-Color**).

We examined the students' ability to explain the internal and leaf nodes displayed on the treemap, concluding that students struggled more to describe the internal nodes. 57 out of the 68 students who provided treemaps defined the lowest level (leaf node) rectangles and the leaf node size correctly. Only 42 students were able to describe what the internal node rectangles represent accurately, and only 35 students explain what the size of internal rectangles represents (**H-Hierarchy**). Again, this provides evidence that the hierarchical aspect of treemaps can be a challenging concept for some. Only 42 students provided labels or a legend, in spite of the software being used in class allowing for the creating of a legend (**H-Labels**, **H-Legend**). A correct interpretation of the treemap and unique observations were provided by only 44 students.

We examined the information visualization coursework of the 2019 class using the treemap literacy assessment described previously. As a modification to the previous year's assignment, we asked students to go into greater depth and create a treemap image from the Project Tycho data [vPCB18] in addition to generating five images in the first part of the coursework. We provided students with 18 explicit questions that assess treemap literacy related to the color mapping, data hierarchy, internal nodes, leaf nodes, labels and legends, software choice, and the treemap layout algorithm (see Supplementary Materials-Treemap Literacy Assessment).

Some 66 students attempted the coursework, and only two of them did not provide a treemap example. While 64 students in the class mentioned the software tool used to create a treemap, only 42 students (of 64) supplied a detailed description of the treemap example. Figure 2 demonstrates that colors used in the treemap were identified appropriately by 59 out of 64 students (**H-Color**). However, 19 out of the 68 treemaps did not contain a data hierarchy, and 20 of them were not defined correctly (**H-Hierarchy**), pointing towards the challenging nature of the hierarchical aspect of treemaps. Some 49 out of the 64 students were able to correctly identify what the lowest level rectangle size was mapped to, but only 35 of leaf node descriptions were accurate. Leaf node layout or position was described incorrectly by 31 students. Similar to the 2018 test results, identification of an internal node was a challenge for students in comparison with identification of the leaf nodes.

All students attempted to define what the internal node size represents, but only 35 out of the 64 students did so accurately (**H-Hierarchy**). In contrast to 2018, all treemaps had a label and a legend. Only 25 students provided unique treemap observations and 29 correctly identified the layout algorithm used (**H-Layout**), indicating that the layout algorithm is a barrier to treemap literacy. Overall, considering that the students taking the course are all in their later stages of the computer science degrees, the error rates and the interpretation of treemaps and topics related specifically to H-Hierarchy and H-Layout can be considered somewhat high.

Additionally, we investigated the software used, the treemap layout algorithm (see Supplementary Materials), the students' observations about the data from looking at the treemap image, and how students prepare the data to generate the treemap in both years. Students created treemaps using Tableau [CHS03], IBM Watson [Wat13] etc. Students used a squarified or ordered treemap algorithm. Students' unique treemap observations were solicited to assess students' abilities at the interpreting the treemaps they produced. We also assessed them on the accuracy of these answers. Our treemap literacy evaluation result provides insights into students' treemap literacy skills and enhances our understanding of the barriers to treemap construction. This evidence guides the development process of our educational treemap application.

5. Treemap Visualization Literacy Test

We developed a treemap visualization literacy test to measure a user's treemap literacy skills and identify the barriers to comprehension of a treemap. In-class investigation is based on treemap construction whereas the treemap visualization literacy test focuses more on treemap interpretation. We searched for appropriate treemap examples with diverse treemap visual designs to test the comprehension of users with varying levels of treemap literacy and enable them to attempt a range of questions related to treemaps. We first selected examples with correct hierarchical data structure and eliminated examples without labels or a legend – these provide clues as to what internal and leaf nodes are mapped to and how color is used on the treemap design. Finally, we ensured that the treemaps are of high quality, excluding low resolution images.

We surveyed four sources to find a number of treemaps chosen from each source as follows: The Visualization Literacy Assessment Test by Lee *et al.* [LKK17] (1 image), The Book of Trees: Visualizing Branches of Knowledge by Manuel Lima [Lim14] (3 images), Google keyword search for "Treemap" (3 images), and students' treemap examples submitted for the information visualization coursework for the Data Visualization course (6 images). We used Google search engine that provides high resolution, and interpretable treemap images with a correct hierarchy. All treemaps were static for consistency.

Once the treemap examples were selected, we prepared five questions for each treemap image that test the comprehension of different aspects of a treemap. The test was prepared to explore the user's ability to make sense of the treemap by asking them a variety of questions. Answering treemap literacy test questions requires the evaluation of multiple factors. Therefore, the questions were coded to identify how users perform in interpreting the data hierarchy, internal and leaf nodes, labels color mapping, a range of data sizes, a legend and layout algorithm (see Hypotheses) using treemap literacy skills. Each question in the literacy test required understanding of at least two treemap features (see Supplementary Material for the classification of questions). The full list of questions is available at **pre-intervention test** [PT19b] and **post-intervention test** [PT19a].)

6. A Pedagogical Treemap Tool

In order to improve treemap literacy, we developed an instructional software tool for classroom use. The treemap application facilitates understanding of a hierarchical data structure and supports accurate observations by displaying the data correspondence between a traditional tree structure and a treemap layout simultaneously (Figure 3 and Supplementary Video). Our treemap tool can be used on different kinds of data, which can be set up by the user.

Tree Features: The tree view (Figure 3, left) enables users to analyze the hierarchical data structure and control the treemap.

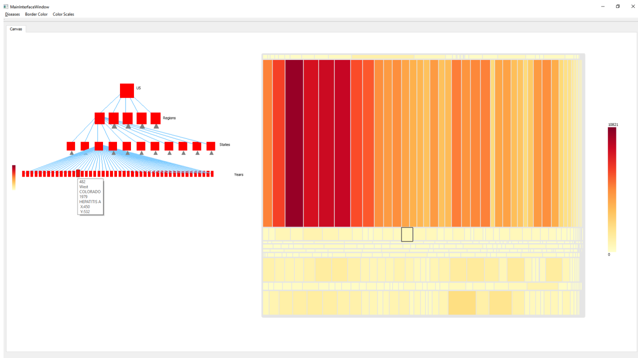


Figure 3: *Instructional treemap tool interface with traditional tree structure (left) and linked treemap visualization (right).*

- The user can hover the mouse over any rectangle in the tree view. The rectangle is highlighted, increases in size and displays a tooltip with the underlying data values.
- The user can click on any internal node, and the user selected node dynamically displays its child nodes.
- If an internal node displays its children and the user clicks on it again, the child nodes collapses into a representative rectangle.
- In addition, the tree view displays labels identifying the levels of the hierarchy.

Treemap Features: The treemap (Figure 3, right) demonstrates the hierarchical data structure with a layout algorithm.

- The treemap displays the equivalent of the tree view using a treemap layout algorithm, in this case, slice and dice [SW01].
- The treemap view has a user-modifiable color-map where color is mapped (redundantly) to the size of each leaf node rectangle.
- The user can hover the mouse over any rectangle, and a tooltip shows the underlying data values. The rectangle is also highlighted/enlarged.

Coordinated and Linked Treemap and Tree Features: The traditional tree and treemap views are linked and synchronized. Interacting with either one causes updates to other. Interactive control of drawing treemap and tree view allows users to determine the properties of the data hierarchy and provides real-time feedback.

- The treemap view is updated whenever the user clicks on a node on the tree view.
- The treemap view reflects the number of internal and leaf nodes shown in the tree view.
- If the user hovers the mouse cursor on any node or rectangle in the tree view the corresponding node or rectangle is highlighted/enlarged in the treemap view, and vice-versa.

Menu and User Options: The menu options offer more features to the user. The 'disease' menu option lets the user choose between a selection of diseases to visualize from Project Tycho [vPCB18]. The list of diseases includes: Hepatitis A, Measles, Rubella, Mumps, Polio, Pertussis, and Smallpox.

Color Selection and Color Legend: Six color scales are provided in order to explore different mappings. We utilize a color library [RMAL18] with the assistance of Colowbrewer [HB03], an online source for selecting color scales.

- The user can choose any color scale among the given color-map options.
- The color legend is updated based on user choice of color scale options.
- The color legend shows maximum and minimum values of the smallest level of the current treemap view and represents color distribution on the treemap according to the current range of data values.
- Maximum and minimum values are updated when the user chooses a disease, region, state and year for the treemap using tree view.

In our classroom-based experiment, we used Project Tycho – a large-scale data of the US records disease incidence frequency data between the years 1888-2014, recorded weekly. The dataset, provided by the Public Health Dynamics Laboratory at the University of Pittsburgh Graduate School of Public Health, provides a record of the number of cases or deaths due to a given disease in a specific location over a time duration e.g. 5 people diagnosed with Hepatitis A in Alabama in week 33, 1966. For our study, we selected a group of diseases recorded based on the states (some of them contain specific cities). In order to create a hierarchy, we grouped states for each disease according to five regions in the US (West, Southwest, Midwest, Southeast, and Northeast) as a level in the hierarchy.

7. Classroom Evaluation

We designed a classroom-based user study to evaluate the participants' treemap literacy and the effectiveness of the pedagogical treemap software. We provided two tests, a **pre-test** [PT19b] and **post-test** [PT19a], which featured 30 and 27 questions, respectively. Both tests contain a collection of treemaps, multiple choice questions, and a description of each treemap. Both the treemap designs and the data sets used in this study varied in their complexity. For each correct answer, students were given 1 point in both tests. After the pre- and post-intervention tests, 12 open-ended interview questions (see Supplementary Material) were given to participants to collect feedback. These tests were administered using Qualtrics [SSSO02], an online survey tool for collecting data.

7.1. Experimental Classroom Procedure

The experiment was run in a classroom environment. Some 25 computer science students (2 female) were recruited to participate in the study. Participants were students at different degree levels (14 Bachelor's, 4 Master's, and 7 PhD). The age of participants ranged from 18 to 38. Only 4 students had a data visualization background from various taught classes. Participants were randomly assigned to one of the two groups: a presentation SLIDES group and a SOFTWARE group. The participants in the SOFTWARE group were provided with a treemap software demonstration and given time to interact with the educational treemap tool. The SLIDES group was shown only traditional treemap slides, used for teaching treemap concepts. Each participant was provided with an Amazon voucher upon the study's completion.

We described the procedure of our study and asked for the students' consent to participate. Upon their agreement, we provided all participants with the pre-intervention test treemap questionnaire, which took approximately 20 minutes to complete. After the completion of the pre-intervention test, we randomly sampled half of the participants to be allocated to the SOFTWARE demonstration group (every other participant).

Both sessions, SLIDES and SOFTWARE, were delivered by the same member of academic staff to eliminate the possibility of a delivery confound. To facilitate this, half of the students had the traditional slides delivered to them, while the other half (the SOFTWARE group) waited in a different room. Once the slides session finished, the SOFTWARE group switched rooms with the SLIDES group. Both the SOFTWARE and the SLIDES sessions were 20 minutes long.

The SOFTWARE group were introduced to the pedagogical treemap application. They were then asked five questions related to the Project Tycho data set provided. The students answered the questions verbally by exploring the dataset for answers using the features of treemap software.

The SLIDES group returned to the classroom once the software session was over. Both groups were then given the post-intervention test questionnaire. Upon its completion, all participants answered 12 interview questions, referring to their background, the test questions, and the treemap software (see Supplementary Materials).

7.2. Quantitative Results of Test Data

The data we collected was normally distributed, as indicated by the Shapiro-Wilk test for both pre- and post-intervention test groups. Hence, we used one-way ANOVA for our data analysis (significance level at $\alpha = 0.05$).

The pre-intervention test results did not differ significantly between the two groups: $F(1,24) = 1.841$, $p = 0.188$, $\eta_p^2 = 0.074$. Those students who then attended the SLIDES session answered on average 62% of the pre-intervention test questions (SD = 19%), and the students who then took part in the SOFTWARE demo answered 72% of these questions (SD = 16%). However, the results of the post-intervention test differed significantly between the two groups: $F(1,24) = 5.074$, $p = 0.034$, $\eta_p^2 = 0.181$. Those who attended the SLIDES session answered on average 79% of the post-intervention test questions (SD = 15%), which was significantly lower than the results of the students who interacted with the SOFTWARE – they answered 89% of the questions correctly (SD = 4%).

The SLIDES group have seen a 17% improvement in their results from pre-intervention test to post-intervention test (SD = 18%) and the SOFTWARE group have improved their results on average by 17% (SD = 17%) (Figure 4 top). There was no significant difference between the two groups with regards to their treemap literacy improvement. Participants in both groups answered the post-intervention test questions faster than the pre-intervention test ones: $F(1,24) = 23.222$, $p < 0.001$, $\eta_p^2 = 0.492$ (Figure 4 bottom). There was no interaction effect based on the manipulation.

Nonetheless, as we hypothesized that the software would provide additional support to the students in overcoming different barriers to understanding treemaps, we have also looked at the students' performance in the different parts of the test aimed at measuring one's comprehension of different attributes of a treemap. We did so by looking at the question classification based on the treemap features that could influence the participants' answers in the test.

To investigate where participants struggle the most and evaluate their visualization literacy skills, we developed a variety of treemap

	PRE-INTERVENTION TEST					POST-INTERVENTION TEST				
	Slides	**Software**	$F(1,24)$	p	η_p^2	**Slides**	**Software**	$F(1,24)$	p	η_p^2
C: Color	58.7 ± 22.8	74.2 ± 16.4	3.763	0.065	0.141	72.6 ± 20.1	88.0 ± 10.0	5.662	0.026*	0.198
H: Hierarchy	65.6 ± 20.8	71.6 ± 18.2	0.577	0.455	0.024	77.7 ± 17.5	87.3 ± 5.2	3.298	0.082	0.125
LN: Leaf node	59.2 ± 21.1	68.3 ± 15.3	1.504	0.233	0.061	81.4 ± 12.5	89.5 ± 5.0	4.398	0.047*	0.161
LB: Label	65.7 ± 19.0	77.3 ± 15.5	2.742	0.111	0.107	79.8 ± 15.3	89.2 ± 4.9	4.161	0.053	0.153
LA: Layout algorithm	58.0 ± 20.3	68.6 ± 17.2	1.973	0.173	0.079	75.5 ± 17.6	87.0 ± 5.0	4.770	0.039*	0.172

Table 1: *The results of pre- and post-intervention tests for the* SLIDES *and* SOFTWARE *groups ($M \pm SD$ in percentages), based on the categories of questions. Significant results are shown as follows:* $*p < 0.05$.

test questions, considering treemap features such as: Color legend, Hierarchy and Internal node comprehension, Leaf node, Labels, and Layout Algorithm. There was no significant difference between the two groups of participants taking the pre-intervention test in any of the five categories (Table 1).

In the post-intervention test, there was no difference in the results obtained by participants in both groups for the questions about neither Hierarchy and Internal nodes nor Labels. However, participants who interacted with the software performed much better in the questions related to the Color legend, Leaf nodes, and Layout Algorithms (Table 1).

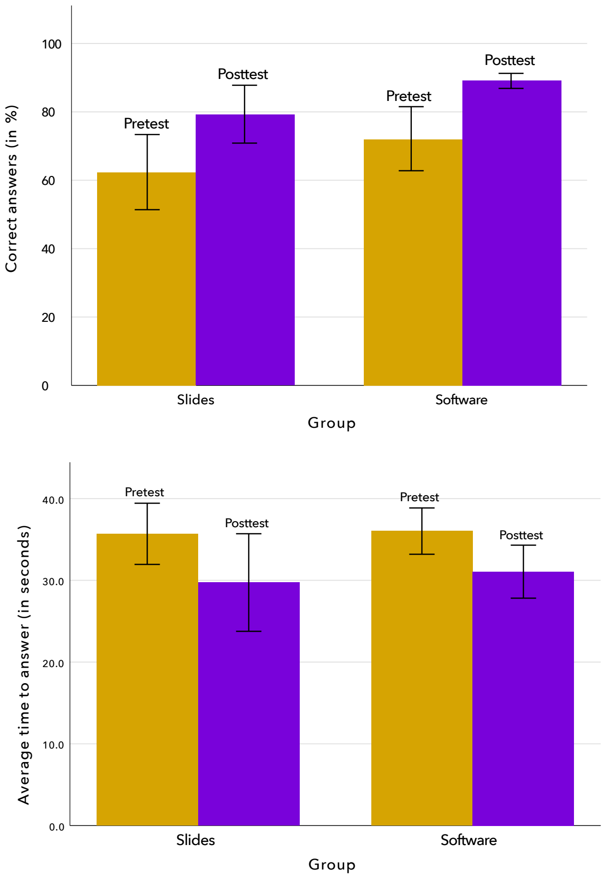


Figure 4: *(Top) The percentage of correctly answered questions in the pre- and post-intervention tests for* SOFTWARE *demonstration and* SLIDES *groups. Error Bars (95% CI). (Bottom) The average time participants in* SOFTWARE *demonstration and* SLIDES *groups spent answering questions in the pre- and post-intervention tests. Error Bars (95% CI).*

The number of correct answers in the pre-intervention test for all participants correlated negatively with the number of rectangles on a treemap (r = -0.520, p = 0.003). The higher the number of leaf nodes the more difficult the label placement, and hence, they can be more difficult to interpret. However, there was no correlation between the number of rectangles and the correct answers of participants in the post-intervention test (r = -0.084, p = 0.677). Similarly, there was no correlation between the number of rectangles on a treemap and the amount of time participants spent answering each question: r = 0.207, p = 0.123.

7.3. Qualitative Analysis of Interview Data

Thematic analysis was jointly conducted by the authors using the feedback gathered from the interview session. For this, we followed the procedure by Braun and Clark [BC06]. We first familiarized ourselves with the answers to understand the participants' experiences of the treemap literacy test and the treemap instructional sessions. We used a deductive approach to establish the themes based on the barriers of the treemap literacy identified in the hypotheses. However, we did not limit the analysis to the barriers alone and looked for further insights into the challenges of treemap literacy through the feedback.

We identified five themes in our analysis of the qualitative data: *Hierarchy, Labels, Colors, Layout, and Size.* These themes indicate that our analysis had strong links to the initially identified barriers.

Hierarchy In contrast to the quantitative data, qualitative feedback gathered from the students in both groups did not highlight many problems regarding the exploration of the hierarchical relationship between data features on treemap designs. Only one student mentioned this category in their feedback: *"I had a hard time recognizing the levels of hierarchy in the images."* (P10, SLIDES).

Labels Finding the right answer to the questions was possible through information provided by labels. The visibility of labels on treemaps played a major role in participants' performance during the test. Feedback from five students indicated that too much or too little information about data was a challenge. This challenge might have been a byproduct of the cluttered visual design showing a large dataset: *"Visual information is easier to process, so a lot of questions were simple."* (P24, SOFTWARE) and *"[In] the question with commodities, labels where not visible and too many of them."* (P11, SLIDES).

Colors Questions requiring interpretation of the treemap color-mapping were indicated as difficult by four students. This was despite the inclusion of a color legend or color description: *"Treemap visualizations and attached explanation of mapping color/size were clear."* (P19, SOFTWARE), but *"It [was] not clear how to compare [the nodes] and sometimes too many colors."* (P11, SLIDES).

Layout Finding a specific data point among the treemap rectangles could be enhanced through the understanding of the layout algorithm. Feedback showed that only three participants explicitly struggled with this aspect, e.g.: *"Some of the categories or specific data was hard to find."* (P06, SOFTWARE). However, *"knowledge of the domain represented seems to be very useful to answer quickly, as you know where to look."* (P01, SOFTWARE)

Size Qualitative evidence showed that both groups found data size to be an issue regardless of which group they were in. Feedback from 10 students mentioned the size of the data as a major barrier to being able to correctly interpret the treemap, e.g. *"The treemap contains many boxes that are hard to see."*(P15, SOFTWARE) and *"The more data being represented translated in more convoluted/dense treemaps which made certain things hard to spot."* (P17, SLIDES).

We also analyzed the feedback that referred specifically to our pedagogical application, which was obtained from the students who had interactive practice with the software. We coded the feedback based on the features of the software that were perceived as having a positive effect on the student experience and the feedback referring to the features that could be improved in the future software development iterations. Two most prominent themes emerged: *Hierarchy* and *Interaction and Active Learning*.

Hierarchy Responses collected showed that most participants in the SOFTWARE group found the ability to freely interact with and explore the hierarchical data structure particularly helpful. Five students commented on the difficulty of interacting with the hierarchy, e.g. *"It breaks the tree down so you can only view what you want to see."* (P07) and *"I can see the relationship and the categories of the different data."* (P15).

Interaction and Active Learning Students who participated in the interactive software session predominantly responded positively to their active learning experience, e.g. *"The visual feedback when hovering and the pop up were helpful"* (P01), *"Hands-on approach was effective"* (P19) and *"The tree next to the treemap allow[ed] me to view the path. The boxes in the treemap where also highlighted when you hovered over them in the tree"* (P07).

8. Discussion and Limitations

We coded every question with respect to the treemap aspects that are necessary to understand in order the answer questions correctly. The classification for the pre- and post-intervention questions (see Supplementary Material) that are ranked from the easiest to the most difficult based on the number of correctly answered questions. The corresponding aspects of each question are annotated below it. Contrary to our initial belief that questions might focus on only one aspect, for example, hierarchy, questions require a user to understand three or four features of the treemap simultaneously. This finding indicates that perception of multiple aspects of a treemap is required for its complete understanding and is a barrier to treemap literacy. We also noticed that the most difficult questions were characterized by dense rectangles with only partial labels. Of course, the more dense the rectangle, the more difficult it is (or impossible) to place labels.

Despite the relatively small sample size, the open-ended questions allowed us to gather sufficient data to interrogate and posit reasons for the students' positive or negative experiences with the software, as per our intentions for this study. The majority of the participants who had the opportunity to interact with the software provided positive feedback regarding their experiences. Nonetheless, a self-selection bias, as well as availability bias, might have played a role in shaping our findings, as the participant recruitment happened over the summer period. Finally, some of the students taking part in the study had some background in data visualization, which could have impacted their ability to navigate treemaps. Despite the split of students with this background between the two groups being equal, we hope to investigate our hypotheses further using audiences from broader backgrounds in our future studies.

9. Conclusion and Future Work

In this paper, we presented a study that investigates possible barriers to interpretation and comprehension of treemaps. A novel treemap literacy test is introduced that includes a variety of treemap designs and treemap questions with a question classification based on treemap features. This paper offers researchers a better understanding of barriers to a complete comprehension of a treemap and a method to advance treemap literacy.

Moreover, we developed an interactive pedagogical treemap application for training and cognition of a treemap design that supports the exploration of a hierarchical data structure. The educational treemap software transforms a passive study to active practice in classrooms and can be use a replacement of traditional treemap teaching approaches. Results of the user study indicate that the students who interacted with the software outperformed students who only learned through slides before taking a treemap literacy test. Furthermore, participants' feedback signifies that the pedagogical treemap software offered an effective learning experience through easier and quicker access to treemap properties.

For an even more reliable test for further research, improving the literacy test with wider variety of data and treemap visualization designs is recommended. More studies are recommended with a diverse group including more participants to reinforce the efficacy of the educational treemap tool. Further research with participants from non-computer science fields for investigating the influence of users' familiarity with treemaps on the study result would be interesting. Also, analyzing the experiment regarding the varied background of the participants can be a helpful next step to understand treemap visualization literacy skills.

Additionally, improvements to the pedagogical software have been identified for the treemap view, nesting the top level of the data hierarchy and providing labels for each rectangle directly instead of requiring mouse-over interaction are potential further attributes that might be possible. In addition enabling users to display large datasets with a different layout algorithms and a greater number of data hierarchies, interacting with the treemap for additional nesting exploration, and keyboard control are future endeavors.

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