VisLitE: Visualization Literacy and Evaluation

***Abstract*—With the widespread advent of visualization techniques to convey complex data, visualization literacy is growing in importance. Two noteworthy facets of literacy are user understanding and the discovery of visual patterns with the help of graphical representations. The research literature on visualization literacy provides useful guidance and opportunities for further studies in this field. This introduction summarizes and presents research on visualization literacy that examines how well users understand basic and advanced data representations. To our knowledge, this is the first tutorial paper on interactive visualization literacy. We describe evaluation categories of existing relevant research into unique subject groups that facilitate and inform comparisons of literacy literature and provide a starting point for interested readers. Additionally, the introduction also provides an overview of the various evaluation techniques used in this field of research and their challenging nature. Our introduction provides researchers with unexplored directions that may lead to future work. This starting point serves as a valuable resource for beginners interested in the topic of visualization literacy.**

Introduction and Motivation

Visualization literacy is an essential skill required for comprehension and interpretation of complex imagery conveyed by interactive visual designs. Developing visualization literacy is essential to support cognition and evolve towards a more informed society [CRA*18]. Gaining a deeper understanding of the visualization literacy of a cohort of participants or domain experts has become a prominent theme in the information visualization community. Visualization literacy was described as an essential skill in the IEEE VIS 2019 keynote talk *Data Visualization Literacy* by Katy Börner and a special issue on visualization literacy was introduced by IEEE CG&A [CGA]. Overall not many studies were published in the previous 20 years, however, in the last seven years, there have been many more papers published in this field as shown by Figure 1. If we look at different evaluation categories, there is no obvious trend yet due to immaturity in the field. In recent years, more studies feature classroom-based evaluation and literature reviews.

Literacy is described as the ability to comprehend and use something with an emphasis on the consumption aspect when the term is combined with other subjects like information literacy, health literacy, etc. Detailed terminology including definitions of literacy and related terms are presented in the next section.

In this paper, we present an introduction to visualization literacy, inform both mature and unsolved problems, and convey trends emerging from visualization literacy to readers who are interested in this topic as a research direction. The tutorial also provides an introduction to the

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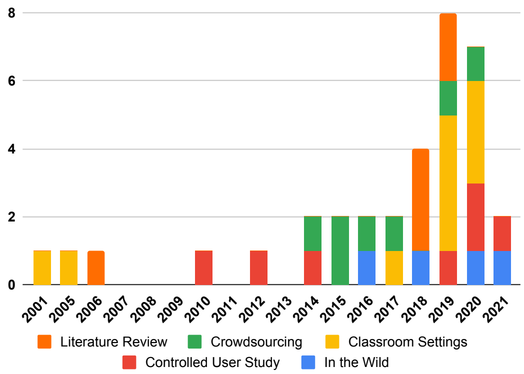

Figure 1. Number of visualization literacy papers by publication year and evaluation method used. There are 34 focus papers in total [FJL22].

evaluation methods used in visualization literacy studies. To investigate the state-of-the-art systems implemented for advancing literacy skills, we sample and classify a selection of literacy research. The contributions of this introduction are as follows:

- The first introduction of its kind on the topic of visualization literacy with a special focus on evaluation
- A literature classification of research papers in this area
- Beneficial meta-analysis to facilitate comparison of the literature
- Indicators in the field of both mature themes and unsolved problems

We collect literature referenced in this introduction in an online resource using an interactive literature browser called SurVis [BKW15]. This can be found at the following URL: http://www.cs.nott.ac.uk/~psxef1/index.html. We draw on this collection of visualization literacy research papers for many of the figures in this paper e.g., Figures 1, 2, 4, 6, 9. Interested readers may browse the collection of research papers for further investigation.

The rest of the introduction is organized as follows. We first look at the terminology and then present an overview of the related work that contains previous relevant papers that examine visualization literacy. The subsequent section provides a review of visualization subjects and technologies used to enhance users' ability to understand and interpreting visual representations in different research fields. We later present a discussion of future work and open directions for research.

Terminology

More specifically, visualization literacy is defined by Boy *et al.* as "a concept generally understood as the ability to confidently create and interpret visual representations of data [BRBF14]". Börner *et al.* explain, "the ability to make meaning from and interpret patterns, trends, and correlations in visual representations of data" [BMBH16], while Lee *et al.* refer to it as "the ability and skill to read and interpret visually represented data in and to extract information from data visualizations" [LKK17]. There are also related concepts such as visual literacy which is defined by Bristor and Drake as the, "ability to understand, interpret, and evaluate visual messages" [BD94]. Ametller and Pintó state that visual literacy "encompasses the ability to read (understand or make sense of) as well as write (draw) visual representations" [AP02] while Bradent and Hortinf identify it as "the ability to think, learn, and express oneself in terms of images" [BH82].

Scope

In this section, we provide a selection of visualization papers that *examine/test/study* users' visualization literacy skills and improve the literacy skills of understanding and creating advanced visual designs. Studies that concentrate on data visualization literacy using interactive visualization techniques are the focus of this introduction. The tutorial includes a selection of popular and recent papers to investigate the ability of reading, understanding, interpreting, and constructing visual designs. The main focus is to examine how the work advances user's basic comprehension and interpreting visual representations of data.

The research topics and papers presented here introduce methods or software that include advanced and interactive graphical representations developed and used for improving visualization literacy skills. A major challenge is to evaluate the effectiveness of the target methodologies and technologies for increasing a user's understanding with the support of interactive visualization systems. Evaluating the effectiveness of an interactive visualization technique to advance visualization literacy is a non-trivial endeavor. As such this tutorial pays particular attention to the type of evaluation used when examining the literature.

Methodology and Types of Evaluation

To categorize the papers and projects we examined, we developed a classification. We carefully examine the evaluation methods in each paper and further categorize the evaluation method used in the paper as well as providing the number of participants involved in the evaluation. For evaluation methods, we identify the following categories: **in the wild**, **controlled user study**, **classroom-based evaluation**, **crowdsourced evaluation**. The categories are presented in ascending order according to the approximate number of participants involved in the evaluation process.

- **In the Wild:** This evaluation method includes observing and recording a group of participants in a public setting and how this changes over the time in an uncontrolled environment [CCR*12]. The goal is defined by Roger and Marshall [RM17] as "*understanding how technology is and can be used in the everyday/real world, in order to gain new insights about: how to engage people/communities in various activities, how people's lives are impacted by a specific technology, and what people do when encountering a new technology in a given setting.*"
- **Controlled User Study:** A controlled user study is an experiment conducted in a controlled laboratory environment. Individual participants are asked to use new interactive and visual designs and perform specific tasks. Task performance time and correctness are measured and evaluated.
- **Classroom:** Researchers prepare pre- and post-experiment tests and examine a visual designs' effectiveness in a classroom environment based on a group of students. Task performance is evaluated on a cohort level. Pre- and post-experiment tests in a classroom evaluation environment are the most popular across all categories.
- **Crowdsourced evaluation:** This method includes studies that are conducted and evaluated online. Researchers collect feedback from a wide geographically-distributed pool of participants in order to collect the largest amount of participant data possible. Crowdsourcing using Amazon's Mechanical Turk offers a large number of experimental participants in a very short time at reasonable costs for obtaining participant data.

Evaluation Method & Characteristics	*Physical Distance*	*Proximity of the Observations*	*Control over the Environment*	*Number of Participants*
In the Wild	Medium	Medium	Medium	30–400
Controlled User Study	Close	Close	High	10–180
Classroom-based User Study	Close	Medium	Medium	10–50
Crowdsourcing Study	Far	Distant	Less	30+
Literature Review	N/A	N/A	N/A	N/A

Table 1. A summary of the evaluation methods and different characteristics of the classification categories.

We can see from Figure 2 in our related literature survey [FJL22] that classroom-based evaluation is the most popular followed by crowdsourced evaluation. The full set of research papers we drawn on can be found at the previously mentioned URL: https://bit.ly/3vljG4t.

Evaluation Methodology

For each category we describe, there is a physical distance involved between the participants and the researcher. For example, classroom-based and controlled user studies involve very close distances meaning that experiments are generally conducted in the same room. At the same time, crowdsourcing evaluation involves participation across the globe. Another evaluation characteristic is the level-of-detail of the observations that can be recorded based on the distance between experimental participants and observers. The level of observational detail for each participant differs for each type of evaluation. For instance, observations are made with the studies in the wild by paying attention to an uncontrolled cohort of individuals. User-studies support the highest level of detail for making observations, usually measuring every individual task sometimes with supplementary video. The focus of the observation is a cohort in a classroom style evaluation while it is a distant larger group of people in a crowdsourcing study. We also have different levels of control over the environment. We have strict control over the environment for user-studies. There is a higher level of control over the environment with a lab-based user-study than a classroom-based study. The number of participants also changes depending on your evaluation method. It is usually around 10–50 people in a classroom-based study, while it's more in a crowdsourcing study e.g., 30–200 (see Table 1).

Related Work

In this section we describe related surveys that systematically review papers with visualization user studies. A survey provided by Fuchs *et al.* [FIBK16] reviews 64 research papers with quantitative controlled studies focused on data glyphs to help researchers and practitioners gain understanding, to find the most relevant papers, and obtain an overview of the use, design, and future research directions involving glyphs.

Johansson and Forsell [JF15] provide a comprehensive literature review that examines user-centric assessments and explores usability challenges with parallel coordinates. They present 23 papers in four categories: analysis of axis configurations, comparison of clutter reduction approaches, practical application of different parallel coordinates, and comparison of parallel coordinates with other analytical techniques. The survey identifies challenges within the field and provides guidelines for possible future studies.

Firat and Laramee [FL19] present a historical overview of studies on gender diversity and spatial cognition and share gender bias research findings in data visualization classrooms for university students studying computer science. The paper offers concise recommendations on how to make the visualization classroom more inclusive in order to encourage diversity. Our survey on interactive visualization literacy by Firat *et al.* [FJL22] provides a comparative overview of the papers published in this field, including more detailed meta-data and summaries of each related paper as well as introducing an additional category of literature reviews. In all, it contains about 19 pages and over 80 related references.

An introduction to Visualization Literacy Literature

This section presents a collection of important re-occurring themes related to visualization literacy and a selection of associated research papers. Each research paper is summarized in a systematic way [Lar11]. Each paper is placed in its respective category (in the wild, controlled study, classroom study, or crowdsourced evaluation).

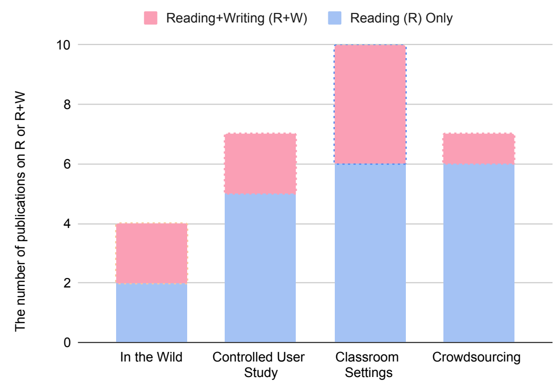

Figure 2. An overview of the visualization literacy literature with classification categories. The evaluation technique that each research paper uses is categorized into: in the wild, controlled user study, classroom setting, crowdsourcing. ***R*** indicates that reading and understanding are tested whereas ***W*** indicates where the ability to construct (write) a visual design is evaluated. See our online collection of papers for more details: [https://bit.ly/3vljG4t] [Sur]

Visualization Literacy In the Wild

This subsection introduces literature in which a study is conducted in a public setting in order to demonstrate the idea presented in the research. Study participants in this category are members of the public. They are not confined to a specific classroom or university. The exact number of participants is not controlled, neither is the selection process for participants. Each study provides a use-case scenario for the given software and a test in an uncontrolled open environment. This evaluation method is one of the methods used to evaluate visualization systems.

Börner *et al.* [BMBH16] study the familiarity of young and adult museum visitors with a selection of visual designs. A study is conducted in three US science museums, considered informal learning environments. Börner *et al.* [BMBH16] chose 20 visualizations from textbooks and widely used online visualization libraries such as the D3.js library [D3]. These visual designs consist of two charts, five maps,

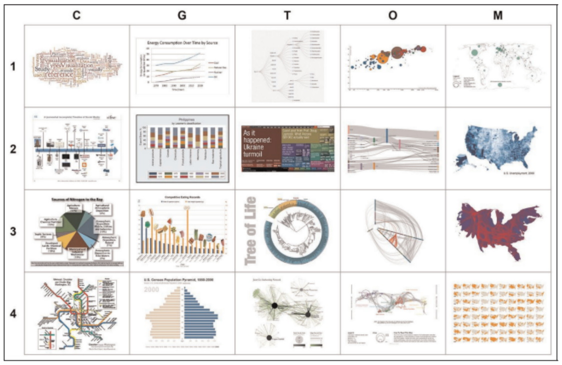

Figure 3. Four sets of five visualizations each row represents one set. All four rows make up the complete set of all 20 visualizations used in the study. Image courtesy of Börner *et al.* [BMBH16]

eight graphs, and five network layouts (see Figure 3). Charts are defined as representing data graphically without relying on a predefined reference system while a graph, translates data variables to a well-defined reference system, such as coordinates on a horizontal or vertical axis [BMBH16]. Five of the 20 visual designs were displayed to visitors of the science museums. Museum visitors are asked to state their familiarity with the visual designs and to identify the name of the design.

Some 127 youths aged between 8-12 years old and 143 adults participate in a pre-test experiment. Visitors with a known perceived gender comprise 110 youth and 117 adults. Before exploring the set of five visualizations, participants were asked to report their interest in science, math, and art on a scale of 1-10. During the test, visitors are asked the following five questions. "Does this type of data presentation look at all familiar?", "Where might you have seen images like this?", "How do you think you read this type of data presentation?", "What would you call this type of data presentation?" and "What types of data or information do you think make the most sense to be included in this type of visual?"

During a post-test, a total of 53 subjects sorted the five visual designs in order from easiest to most difficult to read. The results indicate strong experimental evidence that a very high proportion of the studied population, both adult and youth cannot name or interpret visual representations beyond very basic charts. They show low performance on the main aspects of data visualization literacy. The results indicate charts are easiest to read, followed by maps, and then graphs. Network layouts were identified as the most difficult to read.

Data Sources
Global properties, Brand Price and Quality
Baseball, Food Cost, Duration of Sleep, etc.
Biochemistry Education
Sales Data
Social Service Website
Monthly Unemployment Rates
Fictional Financial Data
Energy, Time
Average Temperature, Greenhouse gases, Tornado Events, etc.
Features of Cars
Sources of Nitrogen, Energy Consumption, US Unemployment, etc.
Flowers, Animals, Ingredients, etc.
Oil Price, Internet Speed, Cost of Food, etc.
Health and Wealth of Nations, International Airport, etc.
Oil Price, Internet Speed, Cost of Food, etc.
Shape , Points, Clustering Algorithms
Fictional Data, Fictional Characters
Car Sales, Syrian Refugees, World Economy
Music, Eating, Screens, Water, etc.
Market, Earthquakes, Investment Funds
Olympics, Iris, Cliques, Clusters, or Bridges
Mock Data
Constellations, Fictional Data, Fictional Characters
Data-driven Story
Oil Price, Internet speed, Cost of Food, etc.
Personal data

Table 2. A table indicating the data themes used in the literature [Sur]

Visualization Literacy and Controlled User Study-Based Evaluation

A controlled user study is an investigation carried out in a controlled laboratory environment. Participants are required to undertake given tasks interacting with visual interfaces. The success rate and completion times for each individual task are recorded. Generally, the experiment is performed one participant at a time. A wide age range of participants are involved in the user studies spanning ages 11 to 69, and the duration of the studies typically averages 60-70 minutes.

Huron *et al.* [HJC14] explore how users build their visualizations and what kinds of visualizations they create. They introduce a visual mapping model to explain how users utilize tokens to form a visual arrangement that conveys their data as well as providing implications for designing tools.

The study's goals are to understand more about the visual mapping process, determine what makes the process easy or difficult for users, and investigate the suitability of constructive authoring of abstract visual designs as a method to construct images. Some 12 participants are assigned three tasks (create, update and annotate a visualization) based on a given financial scenario to represent using tokens. The video of the whole user study process and the photos of visual designs are captured. Also, participants are interviewed on how they created designs to collect more information about the construction process. By examining the collected data, the visual mapping process was analyzed as three activities: construction, computation, and storytelling. They provide details of the logical tasks and actions of visual mapping (e.g. build data, build and combine, construct etc.).

Data Sources: Table 2 provides an overview of the data sets that are displayed and used in the literacy evaluation in the literature [FJL22]. The data sources span a very wide breadth of different subjects and categories and do not show convergence on any particular subjects. While some fictional data is chosen for a few studies, most of the selected data sets are non-fictional based on convenience that can be easily accessible online. The table does not indicate any special data source theme that the researchers used in the visualization literacy field.

Classroom-Based Evaluation

In a classroom setting, researchers design tests for pre- and post-experiments and investigate the visualization literacy skills of users based on participants' answers to questions. In this category, a cohort of participants carry out an experiment as a group simultaneously, usually in a classroom. Preparing questionnaires to ask in pre- and post-experiments in a classroom environment is the most popular evaluation method among all categories as indicated in Figure 2.

Figure 4 displays a summary of studies that use a classroom evaluation approach. Evaluation categories are further sub-divided according to the classroom evaluation method. In some cases, the entire class experiences the same education: pre-test, a new educational technology, and a post-test. We call this a united evaluation. In other evaluations, the classes are split in half. The whole class takes the same pre- and post-tests. However, one half of the class is taught the traditional way, while the other half uses new visualization technology. We call this a divided classroom evaluation. A united classroom corresponds to a within-subject design whereas a divided classroom corresponds to a between subject design. Figure 4 indicates that researches mainly prefer the united classroom approach for the experimental setting. We also provide the education level of the participants (primary school, high school, or higher education) involved in the study.

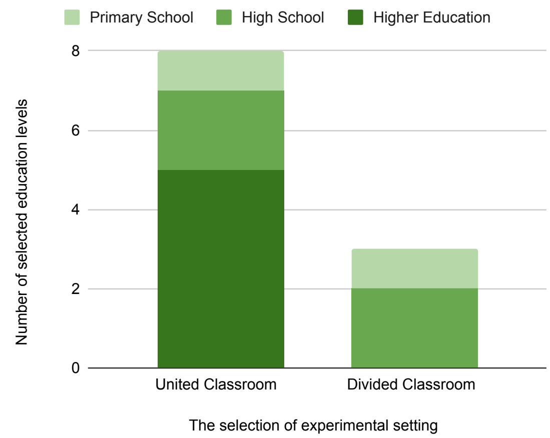

Figure 4. The figure shows the studies that use a classroom evaluation approach. Literature is classified as using a united (the entire classroom of students) or divided (the classroom is divided in half: a control group and an experimental group). The participants' education level (primary school, high school, or higher education) is indicated [Sur].

For example, 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 visual data representations. It is used by instructors in the classroom by creating exercises for children (see Figure 5). Alper *et al.* [ARC*17] provide the results of an investigation of visualization types taught in

Figure 5. Deployment in grade 2 showing the setup in the classroom, discussions between students and a written activity. Image courtesy of Alper *et al.* [ARC*17]

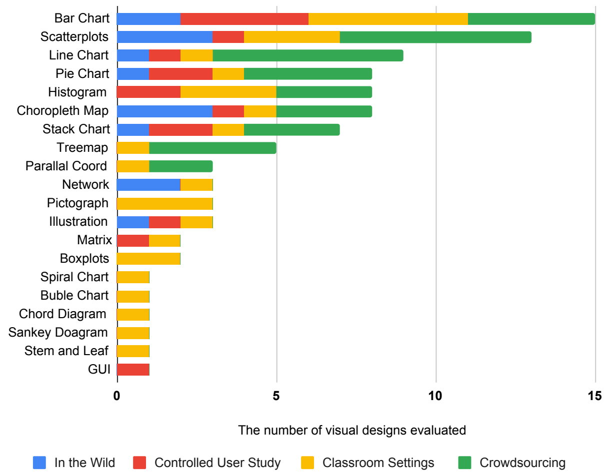

Figure 6. An overview of the type of visual designs evaluated and how many times it is used by each literature. Each individual paper is colored according to evaluation techniques used [Sur]

grades K-4, in a formative study. They analyze visuals designs included in elementary textbooks and study textbooks that follow the US common core standards. These include five math eText-Books from the Go Maths collection, six French by Éditions Hatier and eight Turkish elementary math textbooks provided by the Turkish Ministry of Education [ARC*17].

Students interacting with the tool are evaluated in a field study that aims to understand their interest and understanding of the exercise and to collect feedback from the teachers on how the tool enhances current teaching in the classroom. Some 15 students, split into small groups, from two classrooms (grades K and 2) have their activities observed. An observer takes notes during the sessions with C'est La Vis, occasionally asking or answering questions from students. The main goals are to understand touch interactivity, verbal activity and class dynamics. Observers reported 13 students interacting with the app as playing a game rather than learning. A selection of 6 students also verbalize visualization literacy concepts (how to read an axis), and they are generally willing to use the app. Also, 16 teachers are surveyed to identify educational strategies for teaching simple visual designs. As a result, a set of design goals are provided to enhance visualization literacy in early grades.

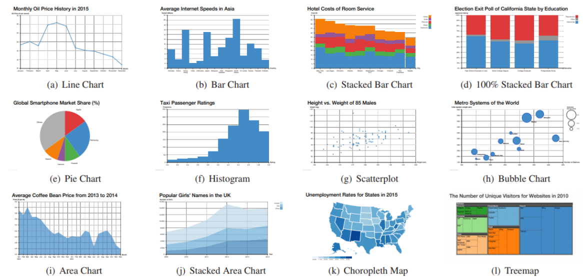

Figure 7. The 12 data visualizations that compose the VLAT. Image courtesy of Lee *et al.* [LKK17]

Figure 6 provides an overview of visual designs that are included in the evaluation in previous visualization literacy studies. The evaluation methods used in the studies are mapped to color. The table indicates that the most evaluated designs in literacy are bar charts and scatterplots. In contrast, images containing bubble charts, spiral charts, sankey diagrams, and chord diagrams have only been evaluated in a single study.

Visualization Literacy and Crowdsourced-Based Evaluation

Some studies prefer to conduct experiments using an online platform to recruit a large number of participants from a geographically diverse pool. Crowdsourcing using Amazon's Mechanical Turk (MTurk) offers access to a great number of participants at affordable prices for collecting data in a relatively short period of time. Visualization literacy literature develops experiments carried out utilizing crowdsourcing platforms or online tests for sharing with crowd. The studies are grouped according to the type of platform used for collecting participants' responses. Amazon Mechanical Turk is a popular platform chosen by 5 studies out of 7 for crowdsourced studies [Sur].

For example, Lee *et al.* [LKK17] develop a test to assess ordinary users' visualization literacy skills, especially users who are not experts in data visualization. Three different sources are examined: K-12 curriculum, data visualization authoring tools, and news articles in order to determine the content of the test. They organize a pilot study before generating the test items to analyze the usage of vocabulary and phrases when test takers read and interpreted the data visualizations, which may influence test participants' performance. After developing a group of test items, domain experts review them to ensure the

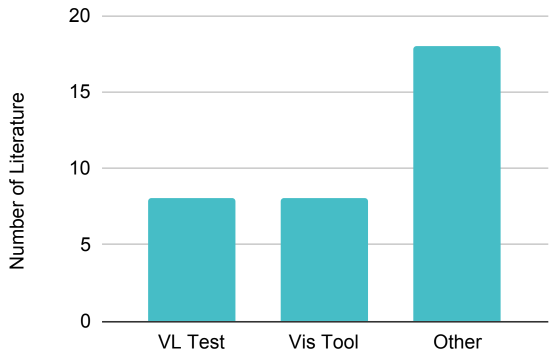

Figure 8. A summary of the contributions made by the literature for research purposes to visualization literacy (VL) [Sur]

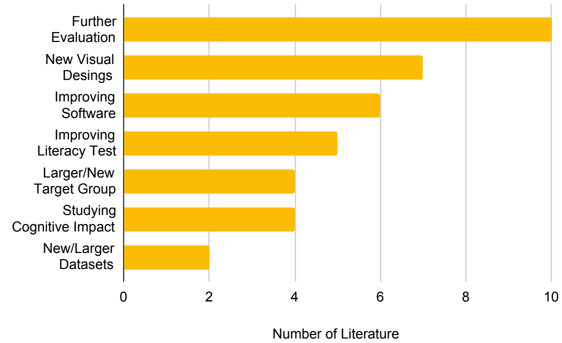

Figure 9. An overview of future research directions discussed in each paper [FJL22]. The directions displayed represent common research areas that reoccur in the literature and are sorted according to occurrence frequency [Sur]

test contains appropriate contents and tasks (see Figure 7).

A total of 191 participants (MTurk) consisting of 105 females and 86 males with an age range of 19-72 take the visualization literacy test. The test includes 54 test questions composed of 34 four-option multiple choices, 3 three-option multiple-choice, and 17 true-false questions. Based on the results, all the items are reviewed in order to eliminate inappropriate items and finalize test items for the Visualization Literacy Assessment Test (VLAT). A final experiment is preformed with finalized VLAT test item choices. A total of 37 people (MTurk) 14 females and 23 males in the age range of 22-58 participate in the study. The experiment is designed to measure visualization literacy and the ability to learn an unfamiliar visualization. Participants complete 53 questions and were redirected to a Parallel Coordinates Plot (PCP) test with an online learning tutorial developed by Kwon and Lee [KL16]. After the tutorial material, participants are asked to answer 13 test items related to PCPs. The result shows that visualization literacy is positively linked with the users' ability to learn an unfamiliar visualization.

Figure 8 summarizes the contributions provided in the literature. The main themes in visualization literacy literature are grouped: 1) tests that are created to assess users' visualization literacy level, 2) developed tools or games aimed at advancing user's visualization literacy level or support learning visual designs 3) other. The studies generally focus on examining the users' visualization literacy skills using a test and assessing the test results. The impact of the specialized tools on the users is evaluated. The rest of the contributions are provided in the *other*. The novelty in the literature includes the effects of tool designs, the results of the evaluation of users' visualization skills, and the identification of barriers to visualization literacy, etc.

Future Work

We examined each paper to identify common research areas that are discussed in each individual paper presented in Figure 2 and summarize the common future research directions in Figure 9. The summary facilities identifying a number of potential research areas in the scope of visualization literacy.

Further Evaluation: The most common future research goal identified in eight papers is to continue the investigation with new experimental settings including different parameters or materials with the aim of understanding barriers to visualization literacy.

New Visual Designs: Much of the research uses specific visual methods (see Figure 6) and targets incorporating various visual representations for further investigation on advancing visualization literacy.

Improving Software: Another common future work direction is developing the visualization tools introduced further by including new features to support visualization literacy.

Larger/New Target Group: In order to gain a better understanding of the visual literacy skills of individuals from various ages and backgrounds as well as achieving more reliable results, some papers suggest conducting experiments with larger or different target groups.

Studying Cognitive Impact: Individual differences amongst each user's unique background and education will affect visualization literacy skills. Understanding these differences and their impact is considered unsolved.

New/Larger Datasets: The type and size of a dataset plays an important role in an individuals comprehension of visual designs. Normally the larger the data set, the more difficult it is to comprehend. Understanding relationship between data set size and cognition is still an unsolved problem.

Visibility: In addition to the most frequent future work presented in the literature in Figure 9, we note that visualization literacy is not a high visibility sub-field yet. Even though data visualization is growing in prominence, the significance of visualization literacy does not yet stand out in research communities. The amount of literature we presented in the survey [FJL22] also supports this idea. Gaining visibility and momentum is necessary in order to improve literacy skills which enable effective use of visualization in various research areas.

Standards: Some basic subjects have a standard assessment test e.g. mathematics, languages, and analytic reasoning. Although some studies have taken the first steps in this direction by providing visualization literacy tests, we suggest developing a series of a standardized assessment tests for visualization literacy that can vary according to the complexity of visual designs and data sets for students with different backgrounds.

Conclusion

This paper contributes an introduction of visualization literacy research. We provide a classification of literacy themes that enables readers to explore published literature. This classification emphasizes the evaluation method chosen to test individuals' visualization literacy skills, presents introduction to the topic of visualization literacy and evaluations methods. The figures present meta-data of literature summaries and trends including visual designs, the number of participants involved in the study, target groups (e.g., age), chosen study platforms and more. The tutorial offers valuable information identifying experimental settings required to assess individuals in uncovering problems in the area as well as having a more complete understanding of advancing visualization literacy skills. Moreover, we share an overview of future work from the literature that enables readers to identify areas of open research subjects in this scope. We believe our introduction is beneficial for both new or experienced researchers interested in visualization literacy.

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