Observations and Reflections on Visualization Literacy in Elementary School

Fanny Chevalier
University of Toronto

Nathalie Henry Riche
Microsoft Research

Basak Alper
Jet Propulsion Lab, NASA

Catherine Plaisant
University of Maryland

Jeremy Boy
UN Global Pulse

Niklas Elmqvist
University of Maryland

In this article, we share our reflections on visualization literacy and how it might be better developed in early education. We base this on lessons we learned while studying how teachers instruct, and how students acquire basic visualization principles and skills in elementary school. We use these findings to propose directions for future research on visualization literacy.

Visualization literacy is generally understood as "the ability and skill to read and interpret visually represented data and to extract information from data visualizations."[1] Recently, it has become a central topic of discussion and research in the information visualization (infovis) community, as several works have shown that people can initially struggle to confidently extract information from graphics,[2] or that they may not feel comfortable enough even with the most basic charts to prefer them over other media like text for simple data detection tasks.[3] Academic efforts attempt to address and document this latent problem, referred to as *visualization illiteracy*.[1,2,4,5]

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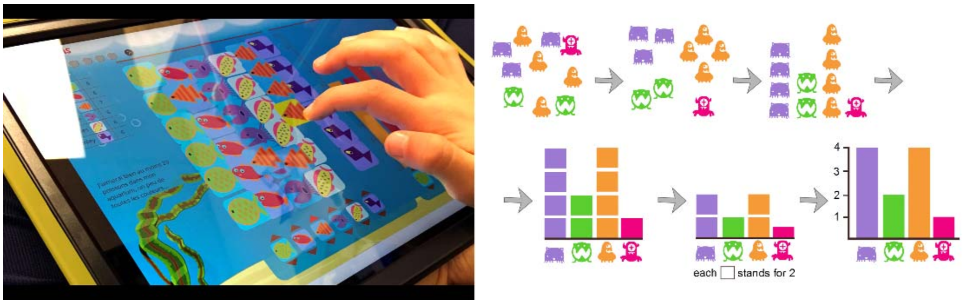

Figure 1. C'est la Vis is a tablet-based technology probe we co-designed with elementary teachers to support the teaching and learning of pictographs and bar charts in grades K-4, by revealing the relationships between concrete (i.e. set of elements) and more abstract (i.e. bar chart) representations of the same data.

Our approach has been to explore how basic visualization principles and skills are taught, and learned at elementary school in the United States[6] (see Figure 1). Here, we discuss three teaching paradoxes we identified, and the controversial role of technology in early education. We find these thought-provoking, and important to bring to the light of the infovis community, as they inspire a deeper reflection on the concept and definition of visualization literacy. This article serves as a first step towards reconciling efforts in infovis research with those of other disciplines, while pursuing the overarching goal of improving visualization literacy levels of generations to come.

THE IMPORTANCE OF VISUALIZATION LITERACY

It is both an exciting and daunting time for infovis research. Visual representations of data are omnipresent: people are routinely exposed to infographics online; news outlets enrich their articles with more and more data graphics; and both for-profit and non-profit organizations alike increasingly use visualizations to present success or progress data to stakeholders. Yet, despite this exposure, readers seem to not systematically consider visually presented information when it is accompanied by other media like text (to which they may be more accustomed), nor do they always spend the necessary time, or take the necessary precautions to interpret graphics correctly. They may enjoy a visualization for its aesthetic qualities, but completely oversee its meaning, or they may over-confidently rely on their visual judgment when estimating trends, even though these may have purposefully been visually inflated.[5,7,8] The use of visual metaphors may also be prone to misinterpretation, or to manipulation by design (Figure 2).

The bottom line is that decoding and understanding visualizations is a complex, multi-level activity requiring knowledge and skill that a significant portion of the population lacks. As infovis researchers, we believe it is our obligation to address this issue by providing the evidence to overcome the general belief that interpreting data graphics is an inherent and trivial skill. For example, while the idiom “a picture is worth a thousand words” conveys the idea that a visual depiction can communicate a complex message more effectively than text, it also alludes to a persistent myth that pictures are always easier to understand than words. This misconception can lead to grave miscomprehension of information, as well as to important miscommunication.

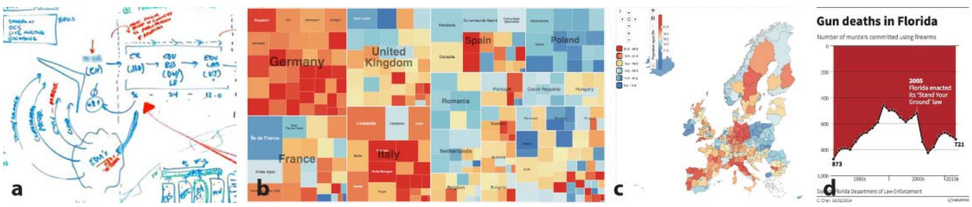

Figure 2. Several design issues can complicate or impede the correct interpretation of data graphics. (a) Use of nonstandard conventions; (b) use of uncommon conventions; (c) effects of perceptual bias (in this case larger geographical units overshadow other smaller regions); and (d) use of visual metaphors that may be deceiving.

VISUALIZATION LITERACY IN EARLY EDUCATION

Our work has focused on what happens in the early stages of education: *what do children learn about visual representations of data at elementary school? And how are they taught the principles and skills required to interpret and create visualizations?*[6] We have amassed a rich set of empirical data from diverse sources, which we have compiled in a 2017 article on visualization literacy at elementary school.[6]

In this work, we created and analyzed a corpus of **pedagogical artifacts** to assess the types of, and to which extent visualizations are taught at elementary school. We curated and classified 2,600 data-driven graphics (out of about 5,000 visuals spread throughout 1,500 pages of content), which we found in a collection of textbooks for grades K–4.

We also gathered data from **teachers** to assess their pedagogic strategies. We conducted a survey with 16 teachers (grades K–4) to understand how much they rely on visual materials in class, and whether they perceive visualization as an important pedagogical tool. We also conducted participatory design sessions and focus groups with eight teachers to collect input on the way they design teaching materials.

Finally, we developed *C'est la vis* (Figure 2), a tablet-based technology probe that aims to support the teaching and learning of pictographs and bar charts, which we deployed in two classrooms (grades K and 2) to assess what children know about basic visualization principles, and how they learn them. Using this tool, we conducted multiple observation sessions, during which a total of 21 students used the probe in small groups (pairs or triples), each on their own tablet device. We were able to observe the class dynamics, as well as a variety of other activities that went on.

Building on this, we focus on sharing the broader insights we gained from our immersion in the classroom environment while working closely with educators, and observing children learn and interact with each other around tangibles, printed material, and social activities. We also attempt to relate our reflections to literature on educational psychology.

THE STATE OF VISUALIZATION LITERACY

Through our work, we have developed a better understanding of how visualization fits into elementary school pedagogies, and how certain practices and beliefs can shape the way basic visualization principles and skills are taught and learned. We have identified three thought-provoking teaching paradoxes derived from empirical data we collected and observations in the field, which we reflect upon in this section, as we believe they can help expand the concept and definition of visualization literacy.

1. Visualizations are omnipresent in grades K–4… Visualizations are heavily used in elementary classrooms to teach or reinforce new concepts, and to convey information about various topics (Figure 3). More than half of the 1,500 pages of grades K–4 textbooks we analyzed contained at least one data-driven graphic (mainly pictographs and bar charts). In addition, teachers who completed our survey indicated that graphics constitute roughly 25% of their teaching materials, surpassing all other categories of materials (e.g., verbal, textual, tangible, or interactive).

… yet learning to interpret and create them represents only a small fraction of the curriculum. Visually representing and interpreting data constitutes only about 6% (2 out of 30 across grades K–4) of all math requirements in the Common Core Standards, an initiative that lists the knowledge and skills children should gain in K–12 education, adopted by public schools in 42 U.S. states. The textbooks we analyzed also contained very little information on basic charts conventions

2. Teachers believe visualizations are intuitive… The 40 teachers we interacted with over the three years of our research generally considered visualizations to be intuitive, while they saw other parts of the curriculum as harder to understand, requiring more pedagogical effort and attention. "This is such a small part of the program," some teachers would say during our focus groups, not only referring to the time and attention dedicated to teaching data graphics, but also alluding that the topic is of limited importance, or difficulty: "some kids can skip [being taught how to interpret pictographs and bar charts]."

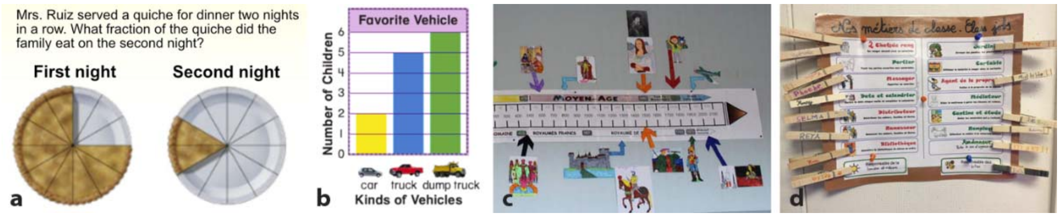

Figure 3. Data graphics are heavily used in the classroom to teach new concepts, or to reinforce learning in arithmetic operations (e.g. (a) pie chart to teach fractions). They convey information on various topics such as personally-relevant data (e.g. (b) bar chart of classmates' favorite vehicle), history (e.g. (c) timeline of important events), or the classroom's routine (e.g. (d) chart of duties).

Nearly half the teachers we surveyed claimed their students were already familiar with basic charts, including grade K. One teacher in grade 4 even explained that pictographs, tally charts, and bar charts were "too simple" to warrant spending time teaching students to interpret them correctly.

… yet many think children are not prepared. Eleven of the 16 teachers we surveyed felt children were not entirely prepared to create and interpret data graphics accurately after completing their grade level. Some teachers in early grades believed their students would have a hard time moving onto more advanced data graphics by the end of the year, while other teachers in higher grades felt a lack of time to teach the basic principles and skills in their classrooms. A grade 1 teacher explained that "[her students were] developmentally only ready for some instructions on charts and diagrams." A grade 2 teacher claimed her students needed "more exposure and manipulation of displaying the data in a variety of ways." Another grade 2 teacher commented that "most will be able to use graphs on a primary level well. [However,] Some second graders are less exposed to using graphs outside the classroom setting, and the concepts don't stay as consistently." Finally, a grade 4 teacher noted that "not enough time [is spent] on graphing and charting skills."

3. Elementary students learn to read and create visualizations in early grades… Elementary students develop skills in both reading and writing (or creating) data graphics from preschool onwards. The exercises involving visualization we collected in our corpus of pedagogical artifacts generally included both comprehension questions, which only require interpreting visually presented information, as well as creation activities, which re-quire translating data provided in a textual, or tabular, form, into a graphic. The kindergarten (grade K) teacher we surveyed also described a collective chart creation exercise: "Use one apple and two bananas to create the simple bar graph […]. The teacher [demonstrates] then gives a [candy] package to each student [that they can] open, sort into colors, count each color, complete bar chart with same color crayons…" One teacher even mentioned conducting this exercise with special education preschool students: "We would discuss favorite modes of transportation (by land, air, or water) and have students indicate their favorite, and place into [a] graph. We would then count and visually compare amounts. Because my classroom consists of special education preschool students, we would complete this activity as a whole group activity."

… yet they are not taught how to approach them in a critical manner. The teachers in our focus groups were quite partial to specific elements they believed made for "good" charts: "There are a number of characteristics that a graph has to have […] the axes labelled […], a title […], a key […]. All of these things need to be there, or your graph is not considered complete." Teachers did not comment much on poorly designed, or deceptive visualizations. Similarly, the exercises in our corpus of pedagogical artifacts would require students to "fill in" missing elements of a chart (e.g., the height of a bar, a label, a tick mark, or a key), or to identify which of two charts encodes a given dataset. None focused on fixing, or critiquing erroneous charts. We believe this indicates a disconnect between the way students (at least elementary) are taught to approach visualization at school, and the misleading uses of it in mass media.

EXPANDING THE CONCEPT AND DEFINITION OF VISUALIZATION LITERACY

Literacy, initially referring to the basic ability to read and write, has come to mean something much broader than the finite set of technical skills required to compose and decode text. Over the past 50 years, its definition has considerably broadened to encompass underlying cognitive processes and strategies, such as information foraging, reasoning, and critical thinking. Literacy is now considered a gateway skill (or set of skills) necessary for achieving one's goals, and for developing lifelong learning, knowledge and potential.[9] In contrast, the most recent definition of visualization literacy—"the ability and skill to read and interpret visually represented data and to extract information from data visualizations"[1]—seems quite limited. The three teaching paradoxes described above have lead us to reflect on what the development of visualization literacy at elementary school should entail, and, more broadly, on the concept and definition of visualization literacy.

Beyond Reading Graphics

Our first stance is that the definition of visualization literacy should be broadened to encompass the principles and skills necessary for both interpreting and creating visualizations. Visualization literacy has so far mainly been addressed as the ability to read data graphics, leaving out the ability create them, i.e., to write visualizations. Just as elementary students develop textual literacy by learning to read and write, we have observed that they learn to interpret and create visualizations as early as preschool. We propose that visualization literacy should be considered more generally as the ability to reason with graphics: it is knowing when and how to create a visual representation of data to facilitate the extraction of information, and, in turn, knowing how to interpret visual representations in order to read directly from the data.

Critical Thinking

Our second stance is that visualization literacy should be considered in close relation to critical thinking. Critical thinking can be simply defined as "seeing both sides of an issue, being open to new evidence that disconfirms [our] ideas, reasoning dispassionately, demanding that claims be backed by evidence, deducing and inferring conclusions from available facts, solving problems, and so forth;"[10] it is considered an integral part of (textual) literacy.[11] As visualizations can be deceptive by design (see Figure 2), it is not only important to be able to decode data in graphics, it is also important to be able to interpret and critique the data representation to make sure it is not misleading. This implies knowing that perceptual and cognitive biases may occur during the decoding phase.

Connecting with Other Literacies and Abilities

Our third stance is to argue that visualization literacy should also be considered alongside other literacies and abilities, necessary for higher-level cognitive activities. Literacies like information literacy and data literacy (see box) are important for being able to inquire about, and critique data collection methods—this can help assess the credibility of sources. They also drive the cross-checking of conclusions drawn from visual data analysis, by consulting other information sources. Other abilities like sensemaking[12] and visual thinking[13] enable connecting multiple pieces of information together, and challenging established visual conventions to best fit analytic and communication needs. Teaching the principles and skills of visualization should therefore encompass developing the ability to relate several pieces of information from several sources together (be they visual, textual, or other); and should go beyond the simple creation of standard charts, following established conventions, but rather encourage to challenge conventions.

THE CONTROVERSIAL ROLE OF TECHNOLOGY IN EARLY EDUCATION

Through our deployment of *C'est la vis*, we have observed first-hand the controversial role of technology in early education. While there is already considerable literature on this topic in education research—which we cannot fully cover, nor claim to be entirely aware of—we focus on three specific insights we gained in this section, as we believe they can help inform the design of future visualization teaching materials for elementary schools.

1. Technology could curtail learning… Teachers believe that children generally engage with technology, especially when it features appealing visuals and animations. However, they are concerned that students may focus more on figuring out fast and mechanical strategies to solve exercises rather than concentrating on the underlying concepts to learn. Discussions during our focus groups and pre-deployment phase revealed a fear that students would interact with *C'est la vis* as they would with a game.

… but could help promote active learning. We started our observation sessions with an open, exploratory exercise rather than with an explicit problem-solving exercise to avoid developing the notion of "successful completion." We believed that providing students with no immediate tasks to complete would make it harder for them to set up mechanical strategies for solving the exercise, and that this would help them focus on the principles and skills they had to learn. We noted that students were deeply engaged with *C'est la vis*, and that our exercise fostered curiosity in most of them. They would attempt to figure out what the animation and interaction meant, while verbalizing key visualization principles along the way. As such, we believe developing technology-driven visualization teaching materials for open-ended exercises could prove valuable for promoting active learning strategies.

2. Technology could curtail social interactions… Teachers consider social interactions and verbalization—the verbal formulation, or reformulation, of knowledge acquired—essential to the learning process. They feared that students engaged in individual activities on a tablet would have fewer verbal interactions with educators, and peers.

… but it could foster collaboration and peer-learning. We grouped students into pairs or triples and provided each with a tablet device to ensure they could all interact with the application without interference. We noted that most interacted verbally with their peers, despite the individual devices. We believe our choice of open-ended exercises was partially the reason behind students to engage in conversation, as they would share their ideas about what to do, and why. Students in each group would either ask for advice, or spontaneously offer it. We also noted that these verbal interactions sometimes referred to underlying visualization principles, like how to read an axis. We believe this indicates that the same application may lead to different learning experiences and outcomes depending on the context of use. Considering these multiple contexts, and conducting situated observation sessions in each of them, will surely prove valuable for the design of future technology-driven visualization teaching materials.

3. Technology takes away the practice of basic skills… The three teachers we collaborated most closely with during the deployment of *C'est la vis* all expressed concerns about the time technology would take away from developing more fundamental skills. They pointed out that technology can be too assistive, preventing elementary students from practicing other skills they must acquire, and were sometimes skeptical about the benefits. For example, the kindergarten teacher mentioned students need to develop fine motor skills to correctly grasp a pen to write, while the grade 2 teacher mentioned students' need to learn to draw straight lines using a ruler, and to space tick marks regularly on an axis.

… but enables scaffolding, i.e. focusing exclusively on a concept to learn. While *C'est la vis* did not support the development of these basic motor skills, we argue it provided *scaffolding*: a temporary support that enabled students to focus on acquiring basic visualization principles and skills, such as creating a bar of the correct height to map a given value without having to accurately control a pen to draw a straight line, or to place items correctly on an axis beforehand. Considering technology as a scaffold for learning visualization principles and skills could prove valuable for the design of future teaching materials, but requires thinking about the "height" of the scaffold, i.e., how assistive the technology should be, as well as strategies for helping students move up and down the scaffold (e.g., progressively adding, or removing elements of support to favor the development of more advanced, or more basic skills).

TOWARD A RESEARCH AGENDA

So far, we have shared our reflections on expanding the concept and definition of visualization literacy, and on the role technology could play in teaching visualization at school. These reflections are based on the lessons we learned while studying how teachers teach, and how students learn basic visualization principles and skills at elementary school. We conclude this article by proposing directions for future research that we believe are key to the development of visualization literacy.

Demonstrate the Importance of Visualization

As infovis researchers, we are uniquely positioned to gather and provide evidence that visualizations play an increasingly critical role in (Western) everyday life, and that visualization education can be improved significantly. Compiling and exposing examples of perceptual and cognitive biases that affect our interpretation is also important in order to raise awareness amongst educators and education policy makers.

Draw a Map of the Skills Involved

The range of skills, such as sensemaking and visual thinking, and the knowledge required to develop visualization literacy remains largely unclear. Similarly, the interactions between visualization and other tightly related literacies, such as information literacy, data literacy, and statistical literacy have to be investigated.[14-15] Creating a map of competencies and related literacies required to achieve visualization literacy appears as a prerequisite to improving visualization literacy.

Partner with the Education Research Community

Infovis researchers interested in developing and improving visualization literacy should partner with the education community to create novel interactive, tangible, and printed materials for teaching visualization principles and skills. Most infovis researchers have the skills to leverage technology to support active learning, peer-learning, social interactions, and scaffolding, while education researchers and specialists should have a deeper understanding of student's underlying learning mechanisms, and of the classroom context, and environment.

SUMMARY AND TAKEAWAY

Developing visualization literacy through education is vital for combating misinformation, and for progressing towards a more informed society—especially if infused at an early age. We have identified a number of thought-provoking manifestations of the fact that, despite visualizations are abundantly used to teach many concepts in early education, visualization education itself is not consistently addressed in early years of education. Current practices and beliefs at school suggest that there are several barriers to overcome in incorporating an overdue visualization program to the curriculum. However, should this be the only challenge, it would not be so difficult to surmount. The truth is that visualization literacy is still a blurry concept, which remains to be further contemplated in light of the vast relevant knowledge from disciplines other than infovis, including cognitive psychology, education, and HCI. It should also be further explored through field studies in the same vein as our work. Effective and efficient interventions (technology-enabled or not) remain to be conceived and studied in order to determine what works, when, and why. This viewpoints article has presented our efforts towards this goal, and has provided general directions that we believe will pave the way for future research on this vital, societal issue. The difficulty of addressing the challenge posed by visualization illiteracy should not be underestimated, and we hope that this article will spark and inspire such discussions.

SIDEBAR: RELATED LITERACIES

Information literacy: “the set of integrated abilities encompassing the reflective discovery of information, the understanding of how information is produced and valued, and the use of information in creating new knowledge and participating ethically in communities of learning” [16]

Data literacy: "the knowledge of what data are, how they are collected, analyzed, visualized and shared, and the understanding of how data are applied for benefit or detriment, within the cultural context of security and privacy" [17]

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AUTHOR BIOS

Fanny Chevalier is an assistant professor of computer science and statistical sciences at the University of Toronto. Contact her at fanny@dgp.toronto.edu.

Nathalie Henry Riche is a researcher at Microsoft Research. Contact her at nathalie.henry@microsoft.com.

Basak Alper is a researcher at NASA-Jet Propulsion Laboratory. Contact her at basakalper@gmail.com.

Catherine Plaisant is a senior research scientist at University of Maryland, College Park. Contact her at plaisant@cs.umd.edu.

Jeremy Boy is a data visualization specialist at UN Global Pulse. Contact him at myjyby@gmail.com.

Niklas Elmqvist is an associate professor of information studies and director of the Human-Computer Interaction Laboratory at University of Maryland, College Park. Contact him at elm@umd.edu.

Contact department editor Theresa-Marie Rhyne at theresamarierhyne@gmail.com.