Visualization Literacy at Elementary School

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ABSTRACT

This work advances our understanding of children's visualization literacy, and aims to improve it with a novel approach for teaching visualization at elementary schools. We first contribute an analysis of data graphics and activities employed in grade K to 4 educational materials, and the results of a survey conducted with 16 elementary school teachers. We find that visualization education could benefit from integrating pedagogical strategies for teaching abstract concepts with established interactive visualization techniques. Building on these insights, we develop and study design principles for novel interactive teaching material aimed at increasing children's visualization literacy. We specifically contribute C'e la Vis, an online platform for teachers and students to respectively teach and learn about pictographs and bar charts, and report on our initial observations of its use in grades K and 2.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI)

Author Keywords

visualization literacy; qualitative analysis.

INTRODUCTION

A recent examination of youth and adults' ability to interpret data visualizations [7] indicates that the general public has a relatively low level of *visualization literacy*: a concept generally understood as the ability to confidently create and interpret visual representations of data [8]. As visualizations are now commonly encountered in the news, books, and on the internet, having limited visualization literacy skills can be a serious handicap. Typically, it may prevent people from gaining access to valuable information, which could help them learn and solve problems, or make informed decisions. To better equip people with these essential skills, more research efforts are needed to assess how individuals acquire visualization literacy, and to issue structured pedagogical guidelines for improving it.

Figure 1: C'e is a tablet-based web application designed to support the authoring of interactive teaching material aimed at increasing children's visualization literacy at school.

Information visualization education currently remains poorly accessible to adult populations outside of higher education, albeit some recent attempts, e.g. [34]. Yet, certain aspects of visualization literacy are taught as early as at elementary school, where children learn to read basic charts and graphs in mathematics and science classes. Developing a better understanding of *what* and *how* these initial skills are taught can certainly inform broader visualization literacy efforts [7]. First, it can help improve current practices at school to ensure visualization literacy fundamentals are being taught effectively. Second, it can be used to develop more general pedagogical principles that can be deployed in other contexts, like teaching complex visualizations to adults.

In this work, we take a close look at the current practices and challenges met in teaching and learning data visualization in early education. We first analyze educational materials to develop insights on the methods and tools used in classrooms. We then identify challenges faced while teaching and learning visualizations, through a survey and interviews with elementary school teachers. These insights inform a set of design principles inspired by existing pedagogical methods, and interaction techniques used in InfoVis applications, but rarely in teaching materials. Building on these principles, we implement and observe the use of a proof-of-concept tool: C'e Vis, which enables teachers to create and edit exercises, and allows students to take those exercises (Figure 1).

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RELATED WORK

This work builds on research in visualization literacy, developmental psychology, and the design of educational material.

Visualization Literacy

Visual information literacy [1, 57, 61], or *visualization literacy* — the more concise term proposed in our community — is gaining increasing attention [8]. A series of workshops [30, 49] in major visualization conferences has initiated discussions among researchers, aiming at defining key research directions in the topic, and at building a platform to assess the visualization literacy of broad audiences. These efforts build upon a body of work often referred to as "visualization for the masses," which has engendered the idea of democratizing information visualization [21, 60]. Several studies [7, 27] illustrate the general public's severe limitations in interpreting data visualizations, increasing the urgency to address the issue.

Visualization literacy overlaps with different research fields, including cognitive psychology and education. The literature in both areas is extensive, and an exhaustive review goes beyond the scope of this article. To the best of our knowledge, there is no prior study on how to improve visualization literacy in early education. Relevant works in cognitive psychology put emphasis on defining the role that visualization plays in cognition and visual thinking [31], or provide guidelines for graphical displays to improve comprehension [53], but do not study teaching strategies. Related work in educational research [25, 37] focuses on the use of physical and representational models for teaching concepts such as quantities or scale, rather than how to read and create data visualizations.

A number of works address some aspects of visualization literacy, studying the value of embellishments in charts [3], and what makes visualizations recognizable and memorable [5, 6]; or studying literacy regarding a specific visualization such as parallel coordinates [34] or concrete scales [10]. All of these pieces shed some light on *what* makes visualizations accessible and popular to a large audience. Recent studies [8, 36] aimed at defining strategies to assess visualization literacy, while different research addressed *how* to improve it, borrowing knowledge from fundamental pedagogical philosophies. These efforts introduce novel teaching paradigms [23, 50] that aim to raise visualization literacy within the general public.

While research on visualization literacy is advancing in many aspects, our community has yet to reflect on the first and foremost place where most people gain this skill today: schools. In this article, we take a look at the role that visualizations play in the classroom, and survey the type of materials employed to teach data visualization in early grades. In contrast to previous efforts in surveying visuals used in education [12, 15], we look at teaching material through the lens of interactive visualizations. Our goal is to gain an understanding of what elementary school students know about data visualizations, and how they make use of them when learning new concepts.

Teaching and Educational Material

In the early twentieth century, the traditional vision of teaching mostly followed the principles of *instructionism* [44], which emphasize memorization of facts, often taken out of their context. Since the 1950s, the work of a French developmental psychologist Jean Piaget on *constructivism* [45] became the dominant influence in education. Perhaps one of the most accepted findings of Piaget's work is the natural progression of learning starting from concrete information, in the form of tangible objects or experiences, and gradually leading to more abstract forms. This influence led to the adoption of *manipulatives* in schools, such as colored blocks to teach addition or subtraction concepts, and helped shape a visual language of science [16]. In the 2000s, advocates of a new science of learning pushed for the use of computers to support teaching. Since then, a considerable amount of work has been conducted to better understand how children learn, and to inform the design of better learning environments that integrate technology. The handbook of learning sciences [52] is a solid introduction to these research endeavors.

Interactive tutoring systems, or more generally computer-supported learning environments, are studied across a number of disciplines [43, 54]. Substantial effort in HCI has focused on designing tools that take advantage of visuals by enabling students to sketch diagrams or add annotations while solving problems or learning a new skill [32, 33, 35, 62]. Recent work in educational psychology indicates that learning with multiple representations, while interactively showing how they relate to each other, can enhance the learning of mathematical concepts [46, 47]. Other research efforts, focusing on the collaborative use of interactive tutoring tools [42], suggest that young learners require less practice to achieve similar learning gains in collaborative setups than in individual ones.

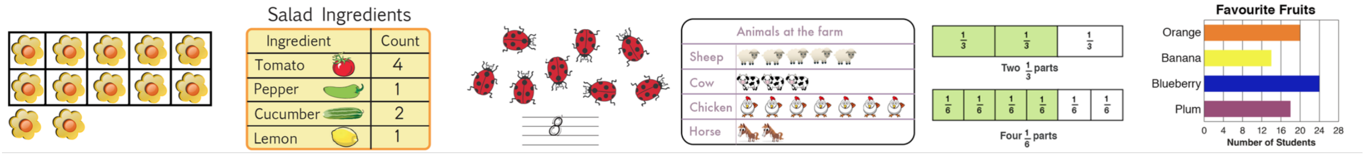
Not much research has yet studied educational tools to teach visualizations. The literature on InfoVis education has exclusively focused on education of visualization practice, at the graduate level [13, 51], covering reflections on curricula content [17, 28], and exploring novel pedagogical approaches to visualization design [19]. We aspire to shed light on what is taught about visualizations in early grades, and explore the use of interactive teaching materials in class.

METHODOLOGY

This research is the result of a close collaboration with elementary school teachers over the course of two years. We first provide insights from a formative study on a) *what* types of visualizations are being taught in grades K-4 via the **qualitative coding** of 2,600 visualizations found in a collection of textbooks; and b) *how* visualizations are taught in these grades through a **survey** with 16 teachers; as well as from a review of a dozen digital educational material resources.

Findings from the formative study led us to identify an opportunity for a visualization literacy tool taking advantage of the *concreteness fading* approach: an educational strategy employed in teaching of abstract concepts [14]. Focusing on pictographs and bar charts, we iteratively designed C'e Vis via feedback from **focus groups** with 8 teachers. Finally, a **field study** in grades K and 2 allowed us to gather observations on 21 students appropriating the app, and collect initial insights on how to teach interactive visualizations at school.

All of the material and C'e are available online at:
https://cestlavis.github.io/



Structured Pictograph 44% (65% in grade K)
Table 8% (35% in grade 4)
Free-form Pictograph 7% (15% in grade 4)
Pictograph 7% (>10% in grades 2 & 3)
Fraction Diagram 5% (>15% in grades 3 & 4)
Bar Chart 5% (>12% in grades 2 & 3)

Figure 2: Illustrations of the six most frequent visualization types encountered in our corpus.

FORMATIVE STUDY

We initiated our formative study with the analysis of visuals involving data representations, found in elementary textbooks.

Visual Materials in Elementary Textbooks

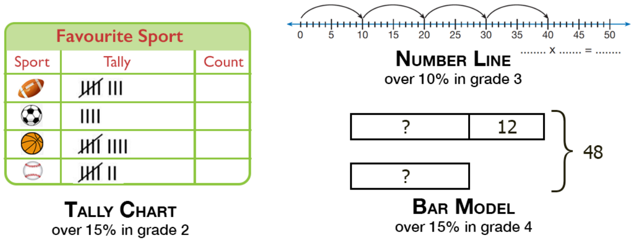
To select a corpus that is representative and canonical, we decided to use textbooks following the US common core standards — the most widely adopted standards in the US. For practical purposes, we surveyed five math eTextBooks (also available in print) from the Go Maths collection for grade K-4, published by one of the three biggest publishers of educational materials for K-12. We also note that the material curated appears to be consistent with some textbooks from other countries — we informally reviewed 6 French manuals from the “Cap Math” collection by Éditions Hatier and 8 Turkish elementary math textbooks provided by Turkish Ministry of Education — given the vast number of different textbooks and other resources used in education, the numbers presented in our analysis provide an outlook of what is common in our corpus, rather than a generalizable quantitative assessment.

We encoded about 5,000 visuals in 1,500 pages, including activities with tangibles. We discarded 44% that did not involve any representation of data, and categorized the remaining 2,600 using an open coding approach [56]. Three researchers coded 10% of the corpus, discussing conflicting codes and establishing definitions. Two coders iterated over 20% of the corpus, reaching an agreement score of 90%. The first author coded the rest. We report key percentages in Figures 2 and 6.

Types of Visual Representations

We found that visual material constitutes a large portion of the reviewed teaching materials: out of 1,500 pages, over half contained visuals. We encoded 16 different types of visualizations, noting that several of them have not been much studied by the research community. Figure 2 shows the 6 most frequent data visualizations used across grades K-4. Among these are visualizations featuring pictorial objects [40] recently studied in [18]; free-form pictographs, i.e., illustrative icons without apparent spatial organization (7%); structured pictographs, i.e., spatially organized icons (44%); and pictographs, i.e., stacked icons with reference axis (7%).

Figure 3 shows visualizations that are rarely seen in InfoVis, but are predominant in some grades: tally charts, number lines, and bar models. This finding calls for studies on the role these representations play in problem solving and acquiring fundamental mathematical concepts. Conversely, heavily studied visualizations are encountered less in our corpus. These include, in order of decreasing frequency, matrices and venn diagrams, line charts, histograms, scatter plots, trees and graphs.



Tally Chart over 15% in grade 2
Number Line over 10% in grade 3
Bar Model over 15% in grade 4

Figure 3: Visualization types pre-dominant in specific grades.

Types of Exercises and Tasks

We identified three major types of exercises, that correspond to the amount of input required from students. *Reading exercises* require the student to interpret a visualization, and possibly answer questions based on this interpretation. They are the simplest use cases for visualization exercises. *Completion exercises* provide visualization templates (e.g. an incomplete bar chart with labelled axes), where students perform fill-in-the-blanks types of exercises. Finally, *creation exercises* are the most challenging for students as they require them to solve a problem by creating a visualization that represents the data provided in a textual or tabular form. These exercises require a higher level of mastery of the fundamentals of visual data representation, and are more commonly found in later grades.

We also coded analytical tasks that students perform using the low-level visual analytic tasks defined in [2]. We found that all tasks were covered in the corpus, except three complex tasks: finding anomalies, identifying clusters, and identifying correlations. This highlights a potential gap in visualization literacy education. Although correlations may be too complex to teach before grade 5, finding anomalies and identifying clusters could possibly be introduced earlier.

Degree of Abstraction

Perhaps the most interesting code that emerged from our analysis is the great diversity in level of abstraction of visuals (Figure 4). This variety echoes with the *levels of iconic abstraction* described by McCloud [38], and is consistent with Piaget’s theories advocating for a gradual progression from concrete physical experiences to abstract information in children’s learning process [45]. A parallel in education literature also exists, referred to as *concreteness fading* [39] — a pedagogical method suggesting that new concepts should be presented first with concrete examples, before progressively abstracting them. A related dimension has also been proposed for classifying technical drawings [16] and visuals used in science textbooks [12] based on their *formality* — a notion that applies iconic abstraction to the domain of technical drawings.

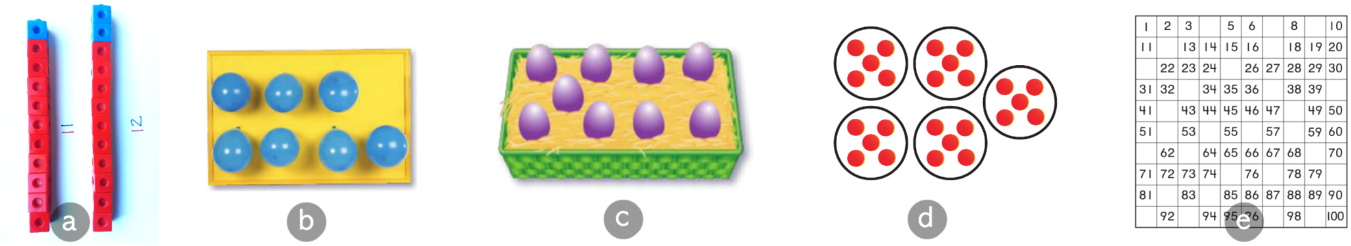


Figure 4: Degree of abstraction: (a) tangibles, (b) photographs, (c) illustrations, (d) abstract shapes, (e) spatial notations.

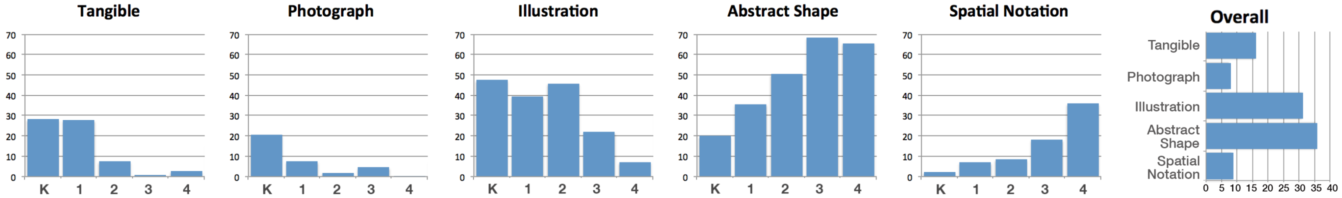


Figure 5: Distribution of different abstraction level visuals across grades.

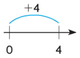
In our coding, we used an abstraction spectrum delimited by tangible objects on one end, and spatially organized notation on the other end. In practice, we found that the degree of abstraction was indeed a continuous spectrum, such that many visual materials spanned several levels of abstraction. We present the salient categories that emerged from our analysis below, which are also illustrated in Figure 4. In certain cases, we categorized an exercise in multiple categories, either because it contained multiple instructions (e.g. first use tangibles, then draw a diagram), or because the visualization contained different forms of representation.

TANGIBLE objects, frequently referred to as *manipulatives* [59] in education circles, are the most concrete teaching material. These include both tools specifically designed for teaching (Figure 4a), such as cube trains or plastic beads, and everyday objects, such as plants, coins, or fingers. Modeling numbers or arithmetic operations with tangible objects is the most common type of exercise. Recording the height of a plant over a week while teaching line plot, or cutting a cake into equal parts to model fractions are among other exercises involving tangibles.

PHOTOGRAPHS of physical objects, although not very frequent, are encountered especially in earlier grades (Figure 4b). Predominantly, photographs of isolated elements are used as icons within an abstract visualization, such as photos of fruits used in a pictograph. Even less frequent, but still interesting cases, involve the use of photographs of entire scenes, in which students have to count objects or compare quantities. These photographs help associate mathematical concepts with real-world experiences.

ILLUSTRATIONS of everyday objects or animals are the second most common representation found in our corpus (Figure 4c). Fractions illustrated as a sliced pizza, or numbers modeled as apples grouped in a basket are common examples. Within this category, illustrations where each item is represented with a unique drawing (i.e. drawings of fish varying in color or posture) are more realistic variations, whereas illustrations where each item is represented by reproducing the same drawing are more abstract.

ABSTRACT SHAPES are the most common form of representation in our corpus, dominating even the illustrations after the first grade. These representations mostly appear in a spatial organization (Figure 4d), entering the realm of data graphics. We coded common visualizations such as bar charts, tally charts, and line plots in this category.



SPATIALLY ORGANIZED NOTATIONS are the most abstract representation form we classified. These representations are still a form of visual representation, as they rely on spatial organization to communicate data. Examples include number lines, matrices of numbers, and tables of numeric data (Figure 4e). If used to organize notations, we coded visualizations like Venn diagrams and flow charts within this category as well. Naturally, these representations are more common in higher grades.

Classifying visual material along a discrete abstraction spectrum across grades reveals that, while the body of visual material used at any grade spans the whole spectrum, there is a gradual increase in abstraction in higher grades. Figure 5 shows the distribution of the visuals we coded per grade. This finding confirms the adoption of the *concreteness fading* [39] approach in textbooks, which formalizes the progression towards abstraction under three stages: 1) an enactive form — concrete physical model; 2) an iconic form — a graphic or pictorial model; and 3) a notation form — a symbol, i.e., arabic numerals. However, our findings indicate a more gradual progression towards abstraction where *iconic form* is dissected into finer levels of abstraction.

Survey with Teachers

To capture school teachers' perception of the role that visual materials play in education, and to identify pedagogical strategies used in practice for teaching simple charts and diagrams, we surveyed 16 teachers (15 female) currently employed at public schools in the US (average age of 49). All had at least 4 years of experience in grades K-4 (average 14 years); 12 teachers taught in classrooms with an average of 23 students, and 4 taught in small groups. Half taught a specific grade while the others taught across grades within the same year. They answered 30 questions that were informed by prior informal interviews. Here, we report our most salient findings, noting the number of teachers agreeing in parenthesis.

Visual materials play an important role in grade K-4. Teachers indicated that visual materials constitute about 25% of all materials they use in the classroom, surpassing all other categories of materials including verbal, textual, tangible and interactive materials. They indicated that visuals are most important for engaging students (14), making abstract concepts more concrete (12), and reinforcing learning through the use of another medium (8). Considering the students' point of view, teachers strongly agreed that visuals facilitate learning new concepts (14), especially for students with learning difficulties (10). Teachers also emphasized the role of visuals for modeling problems in order to solve them (9). They also strongly agreed on the necessity to provide as many visual examples as possible for the same problem (13), mostly to support different learning styles, but also to build on knowledge from different life experiences (8).

Teachers seek diversity in visual materials and often create their own. All teachers reported that they use additional sources to gather visual materials with diverse themes illustrating different contexts. In addition to various print material from textbooks or children's magazines (9), they heavily use online resources such as `teacherspayteachers.com` to gather readily available visuals (11). A significant portion of teachers also edit or create their own visuals (12), either by drawing them (7), or more frequently by composing the images gathered online using the MS Office products (11). However, creating custom visuals is often limited by intense time restrictions (10), the difficulty of finding suitable and free images (2), not having access to dedicated software (2), and the impossibility to create animated visuals (2).

Interactive tools are attractive but hard to find and use in class. Teachers broadly agreed that using digital interactive material in class had many advantages: tracking students' progress (14), increasing student engagement (13), and enabling a variety of exercises (9). The main challenges noted were the difficulty to find customized material for specific contexts (12), the limited access to computers and tablets (12), and, even with access to computers, the difficulty of finding high quality materials (8).

Charts and diagrams are explicitly taught. Although some teachers indicated that children are already familiar with most data graphics (5), the majority mentioned explicitly teaching students how to interpret visualizations (11). Specifically for bar charts, besides setting up reading exercises like asking students to interpret labels and axes, to identify extrema, or to verbalize insights (4), teachers often propose activities in which the class collectively creates a bar chart (9). These activities typically begin with an in-class poll to collect data in the form of a tally chart or a numerical table, before using it to create a bar chart. Some teachers also conduct a similar co-creation exercise, in which students start by sorting and rearranging physical objects (6), before moving on to drawing.

The *concreteness fading* approach is used in practice. All teachers but one were familiar with the *concreteness fading* approach. A majority mentioned using it frequently (10). Five teachers provided extensive explanations as to why they implement this approach, emphasizing the importance of verbalizing concepts and personal experiences. One teacher also described using this approach *"not in one lesson or one grade level, but instead over time,"* corroborating our findings from the analysis of the textbooks.

Visualization literacy in grade K-4 can be improved. The majority of teachers we surveyed (11) believe that children completing their grade level are not entirely prepared to create and interpret data graphics accurately. The biggest difficulties are with the concept of *key* (elements representing multiple items) (8), and with the interpretation of labels and axes (2)—for example, when bar heights are halfway between axis tick marks, children have difficulty estimating the quantity. Moreover, teachers were generally not confident about children's ability to create their own graphs (8), commenting that their drawings often *"lacked accuracy and precision."*

Interactive Educational Tools

We extended our investigation into educational websites and applications including the ones provided with the eTextbooks, the top three online resources mentioned by the teachers we surveyed, and the top three most popular apps returned for the search "grade x math" for grades K to 4 in major app stores. Excluding duplicates, we reviewed a dozen unique resources in more detail, attempting to understand their characteristics, and identify opportunities for design.

The vast majority of these resources do not allow interactive authoring of visuals, but rather rely on visually appealing images and/or animated characters to keep students engaged while answering pre-defined questions (e.g. [55]). Some applications complement these simple reading exercises by highlighting labels or points on axes when students ask for a hint (e.g. [29]). Some applications automatically generate unique visual exercises for a randomly generated data table, and assess interpretation accuracy of students via multiple-choice questions (e.g. [24]). Few tools support interactive creation of a static bar chart or pictograph for a given textual problem (e.g. [22, 59]) by providing a template that can be filled in. Contrary to teachers' input, these applications do not allow teachers to customize the type of visuals, themes, or exercises to match their curriculum. Moreover, these interactive applications mostly target individuals rather than collaborative classroom activities. Regarding the pedagogical approach, we did not find any applications supporting the presentation of multiple coordinated or animated visualizations, or following a concreteness-fading approach.

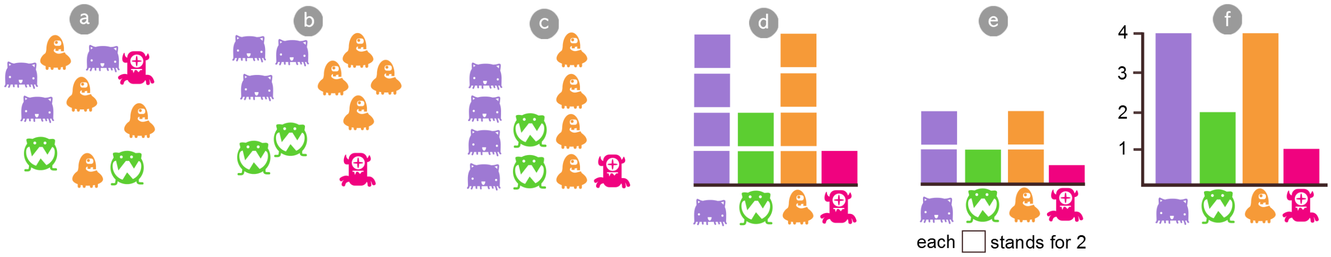


Figure 6: Degree of abstraction from free-form pictograph (concrete) to bar chart (abstract).

C'e

The formative study outlined opportunities for designing interactive teaching material that can improve visualization literacy in early grades. We first synthesize our conclusions under five generalizable design goals. Within the specific context of teaching bar charts, we then present our design decisions for C'e , and describe its iterative design incorporating the feedback from two focus groups with teachers.

Design Goals

G1: Same data, different abstraction levels. We propose to take advantage of the pedagogical practice of providing students with visuals of varying abstraction levels for the same data. Figure 6 illustrate the progression towards more abstract representation for a bar chart.

G2: Reveal relationships between visualizations. While the *concreteness fading* approach is adopted both in textbooks and by teachers, we could not see explicit connections explained between different abstraction levels. We hypothesized that we could help students understand how different levels of abstraction relate by employing two approaches commonly found in InfoVis for connecting two visualizations : animated transitions [20, 58, 50], and coordinating multiple views via brushing and linking [4, 9, 48]. Note that prior work [50] suggests that animations can be used for teaching unfamiliar visualizations to adults by morphing them into familiar ones.

G3: Direct manipulation. Noticing the omnipresence of tangibles in education, we conjecture that interactive applications should attempt to mimic physical experiences when possible. Manipulating visual icons as tangibles or digital manipulatives [59] by supporting free-form re-arrangement of objects via direct manipulation and using images of physical objects can be utilized to mimic physical experiences.

G4: Variability in the levels of input. Our studies revealed the use of visualization activities requiring different input levels: read, complete, and create from scratch, all of which should be supported by interactive applications.

G5: Customization of visuals and data. As per the teachers' comments, the diversity in visuals and themes keeps children engaged, and helps them transfer their knowledge to different contexts. As noted in our survey, teachers often craft and customize visual materials on their own to match their curriculum in different disciplines. However, few interactive educational tools allow for such customization, which may contribute to their lack of adoption. This should be addressed.

Design Decisions

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We developed C'e as an online application accessible by teachers and students without any installation.

Selecting visualizations along the abstraction spectrum

As a first attempt, we focused our attention on bar charts and built C'e . Our first decision was to identify the different steps along the abstraction spectrum leading to bar charts. For deployment simplicity, we discarded tangible representations. We identified free-form pictograph as the most concrete representation, and considered two aspects that could abstract them into bar charts: spatial layout and visual encoding.

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We identified three stages pertaining to the spatial layout of the visualization. 1) The free-form pictograph represents data in the form of illustrative icons scattered around in space without any apparent organization (Figure 6a). 2) The structured pictograph introduces the notion of collections of items by clustering them spatially (Figure 6b). 3) The pictograph organizes these collections into stacks placed along a reference line (axis, Figure 6c). This latter representation ties the notion of quantity to the height of stacks and can convey the purpose of axes in data visualizations. The next three stages break down the progression in abstraction of the visual encoding. 4) The discrete bar chart is a variation of a tally chart, where the illustrative icons are abstracted to geometric shapes that play the role of unity tokens (Figure 6d). 5) A key defining the value of tokens introduces an additional abstraction level (Figure 6e). 6) The most abstract representation, the bar chart transitions from discrete units to a continuous bar, its height corresponding to the value noted on the y-axis (Figure 6f).

Designing interactions

C'e supports direct manipulation of objects in the free-form pictograph and structured pictograph views. Children can typically drag and re-arrange icons, mimicking tangible interactions. We designed this for touch interactions, as we hypothesized them more direct and engaging. Note that all materials use consistent color palettes across visualizations to reinforce the connection between levels (Figure 6c–d). We implemented three types of materials, described below, to convey relationships between visualizations as children interact.

Animated transitions use staged animations to move different categories of elements separately in a sequential order, and at a slow pace. The animation morphs visualizations from one level of abstraction to another, including intermediary levels. Interactions enable children to pause, play and rewind the animation, possibly editing the number of items in each category to observe changes in the representation.

Coordinated views display side-by-side coordinated visualizations at different levels of abstraction. We designed a variation of traditional brushing and linking between a free-form pictograph view (Figure 6a–b) and a chart view (Figure 6c–e). Tapping on a bar at a specific height highlights the part of the bar up to that point, as well as the corresponding amount of visual elements in the other view. Conversely, tapping any single item in a pictograph always highlights the bottom of the corresponding bar up to 1 unit. Figure 9 illustrates the result of these interactions. In addition, editing the number of items in one view also alters it in the coordinated view.

Un-matching coordinated views are a variation of the coordinated views described above, where one visualization serves as reference, and the other one requires children to edit items to match it (See Figure 9, middle). In this view, we extended the coordinated highlights to explicitly show what matches, as well as what is missing in the other view. Missing elements are represented as empty icons with a dashed border. Children can self-check their progress. They also receive feedback when they successfully match the visualizations.

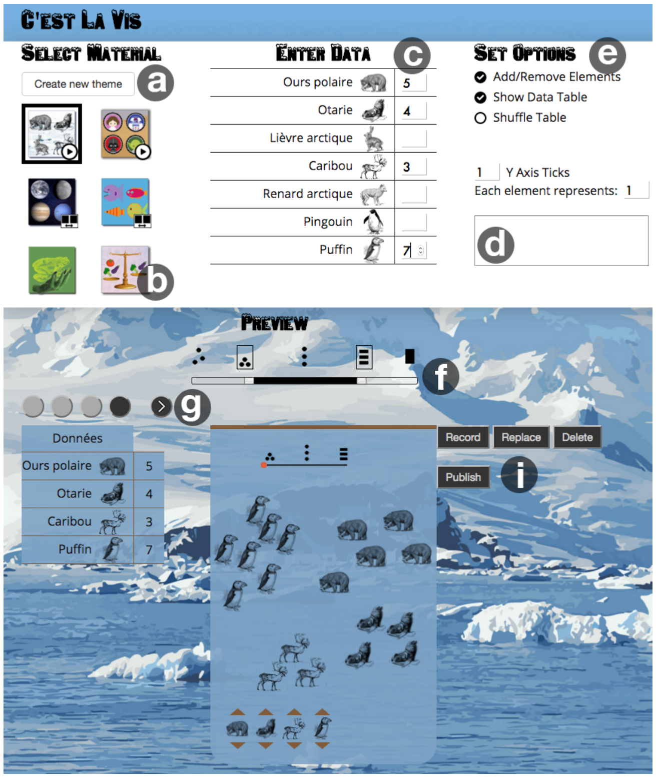
Authoring Interface

We developed an authoring interface for C'e , enabling teachers to create visualizations for any data they wish to use, and to produce a variety of visuals with a minimal set of options. Teachers follow four steps: 1) select one type of material, each of which is provided in a variety of visual themes (Figure 7b); 2) enter tabular data (Figure 7c) and textual description (Figure 7d) for an activity; 3) refine options such as the number of axes ticks, adding a key, and enabling (or disabling) data editing (Figure 7e); and 4) select two visualizations along the abstraction spectrum (Figure 7f).

Teachers can create their own visual themes by selecting a type of material, and uploading a set of icons and a background image (Figure 7a) to match any content of the curriculum. Color palettes are automatically extracted from the set of icons and background provided. They can use photographs of tangible objects to extend the abstraction spectrum. Finally, they can record a series of exercises (Figure 7g) requiring different skills and level of input from students, and publish their results in the activity mode to be viewed by the students. URLs encode the recorded exercises in authoring or activity mode, providing a simple mechanism for saving and sharing.

Iterative Design

To gather feedback on our design decisions, and to iteratively improve the design of C'e , we conducted two focus group sessions with experienced teachers. We recruited 8 teachers (4 per session) with a minimum teaching experience of 5 years in grades K-4. Teachers in the first group taught full classes, while teachers in the second group instructed across multiple grades. Two of them worked with gifted students, while the other two focused on students with learning difficulties. Both sessions lasted about an hour and a half. We dedicated the first 45 minutes to collect participants' experiences, present the general research objectives, and collect feedback on our design goals. In the remaining 45 minutes, the moderator demonstrated C'e and led a discussion on its design. We recorded both sessions for further analysis.



Ours polaire	5
Otarie	4
Lièvre arctique	
Caribou	3
Renard arctique	
Pingouin	
Puffin	7

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Ours polaire	5
Otarie	4
Caribou	3
Puffin	7

Figure 7: Main steps of the authoring user interface consist of material selection (b), data entry (c,d), setting options (e), visualizations selection (f), and recording activities (g, i).

All 8 teachers provided positive feedback on our design goals. We gathered many comments describing the central role that the abstraction spectrum plays in the teachers' pedagogical approach (G1). *"I am a believer that you start at the concrete level and you work your way up to the abstract"* says a participant. In the same session, while noting that they do not use the discretized bar chart much (Figure 6d), all participants agreed that *"This is a real natural progression. This [pointing at Figure 6] does make sense. Well, some kids can skip it, really they should all be instructed in this way"*.

Discussions confirmed that explicitly teaching how visualizations of varying degrees of abstraction relate to each other is crucial, yet not supported by existing material (G2). Both groups found the coordinated views most compelling. Regarding the animations, one participant commented on the usefulness of *"show[ing] the steps [. . .] how we build to get there."* The discussions led to modifications in animation, such as reduced speed, and subsequent animations per category.

Teachers emphasized the engaging quality of touch interaction to construct charts (G3). They also confirmed the importance of providing a lightweight authoring interface (G5) that supports the creation of varied exercises. Participants positively commented on the small set of steps, and while the group was brainstorming about possible additional features, one participant cautioned the group about selecting just a few important ones, stating *"as long as it does not become too cumbersome, like we find in a lot of the software out there! oh my gosh!."*

Figure 8: Deployment in grade 2 showing the setup in the classroom, discussions between students and a written activity.

These findings led to a number of iterations on the authoring interface. We added an option to manipulate ticks, as teachers commented on the difficulty for students to read axes, especially with infrequent tick marks. We also introduced charts with a key (Figure 6e), since many teachers cited it as a major teaching unit in the curriculum, and a hard concept to grasp.

FIELD STUDY

C'e is a departure from existing teaching material, enabling students to create and interact with data visualizations, while explicitly showing the relationships across multiple representations of the data. By deploying it in a classroom, our goal was twofold: 1) to assess how students would interact with the tool to gauge their interest, their understanding of the activity, and highlight opportunities for further improvement; and 2) to gather feedback from the teachers on how C'e Vis changed existing teaching practices and the classroom dynamics. A controlled, longitudinal study on the learning value of C'e is beyond the scope of this work.

Participants

We conducted the study at a private French immersion school in an upper-class district in Seattle. The school follows both the Washington state and the French teaching standards. Students in grades 1 to 4 are familiar with technology: classrooms contain an interactive whiteboard, regularly used throughout the day, and two desktop computers, sporadically used for individual student activities. The teachers also have access to a cart of touch-enabled tablets, and reported using them very sporadically, usually for web-browsing activities. Students in grade K used the interactive whiteboard sporadically, rather as a projection medium than an interactive one, and had no access to tablets or computers in the classroom. Three teachers worked with us for the field study: one grade 2 and one grade K teacher in their own class, as well as one grade 3 teacher who observed the study sessions with the grade 2 class. None of the students had been exposed to bar charts at school before.

Procedure

We first conducted pre-deployment interviews with the three teachers. We had them experiment with the app and generate the activities, and we gathered their hypotheses on how C'e la Vis would change their existing practices. Before agreeing to use the app in class, the grade 2 teacher selected 6 students with strong math skills, and assigned them a set of C'e Vis activities as extra-curricular. After these students successfully completed a written activity (Figure 8 right) showcasing their understanding of bar charts a week after the session, the teachers agreed to deploy C'e in their classroom.

We deployed C'e in two classrooms (grade K and grade 2) over multiple days. Teachers orchestrated the class activities, and one observer was present to take notes during the sessions with C'e , occasionally asking or answering questions from students. Sessions lasted 30 minutes in grade 2, and 20 minutes in grade K. We observed a total of 21 students using the app in small groups (pairs or triples), each with their own tablet (Surface Pro 3 or Surface 3).

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As we were not allowed video or audio recordings, the observer wrote down a report after each session in class, synthesizing the observations of the use of the app, and noting questions on students behaviors or skills for the teacher to comment on. At the end of each day, we conducted hour-long debriefing interviews with the teachers, gathering their feedback on how students received the app, how it changed the class dynamics, and how it altered existing teaching practices.

Pre-deployment

In the pre-deployment session, all three teachers used the authoring interface to craft a series of exercises without any instructions. They did not encounter any particular issues while authoring custom interactive material. They commented that the slider with different degrees of abstraction was the least “intuitive” component. All commented positively on the balance between the number of options and the expressivity of the tool. They reported that such a lightweight interface, and the possibility to upload images, would significantly increase the chances of adoption, expressing multiple times the limited amount of time they had to create custom materials.

While all three teachers used technology in their class on a regular basis, they were generally sceptic about providing students with interactive activities on their own tablets. They expressed that completing activities on tablet devices might isolate students, and curtail the verbalization of new concepts — an important part of learning that occurs when students are explaining or asking questions to each other. The teachers were also concerned that the playfulness of the interface might distract students from the underlying concepts, and more generally disrupt classroom activities. The grade 2 and 3 teachers also wondered whether the app could help students grasp the concept of key without significant human intervention, as they considered it a challenging notion to teach.

Données	
Tulip	1
Clover	5
Daisy	2
Poppy	1
Sunflower	1

Données	
Limace	4
Escargot	1
Crapaud	10
Ortie	6

Potion magique numero 1. Pour s'entraîner, on commence avec le dîner de ce soir: une soupe aux crapauds assaisonnée à l'ortie et à la limace! miam!

Données
Ortie
Rat
Serpent
Chauve-souris
Escargot

Chaque forme représente 3 éléments.

Potion magique numero 3. Hmmm, celle-ci, c'est la potion la plus difficile mais la plus utile! pour en finir avec les devoirs...

Figure 9: Sample activities used in the field study. In grade K (left), students freely explored while being occasionally prompted by questions. In grade 2, students solved problems (middle, right). For instance, a "witch" activity (middle) consisted of completing a bar chart given a pictograph of required ingredients, its harder version (right) employs a free-form pictograph as a reference.

Given these comments from teachers and our own goals to understand how C'e would be appropriated by students in the class, the observer focused on the following aspects:

1. **Touch interactivity**: Are students interacting with the app? Do they appear to interact with a purpose? Do they complete activities? Do they skip certain activities? Do their interactions and interests change/slow down over time?
2. **Verbal activity**: Are students initiating discussions about the activities, about the interface and the themes? Are they asking questions to teachers/observers or other students? Are they verbalizing their knowledge?
3. **Class dynamics**: Are students generally willing, or even excited to use the app? Is the organization of the group activities altered by the presence of tablets in the classroom?

Observations

Touch interactivity. We observed that all 15 students of grade 2 interacted with the app for the duration of the 30 minute session without any observed decrease in interactions, or loss of focus. Occasionally, one student in the group would skip to the next activity before completion, but s/he would usually go back to complete it later on. Only 2 out of 15 students "toyed the interface." During the "Witch" activity (Figure 9), they would use the highlighting mechanism to achieve correct results, rather than attempting to interpret the reference visualization and match it. The remaining 13 students however, only used the highlighting mechanism to check their answers. Out of the two students who appeared to play rather than learn, we observed one describing the underlying concept to his peer, indicating that he had probably understood the activity.

In grade K, all 6 students interacted with the interface for the duration of the 20 minute session. Most spent significant time with the animation activities. Since these students could not read, the observer prompted them with questions sporadically. These students did not converse much with their peers, even when prompted, thus it was difficult to determine if their interactions were meaningful. However, it is interesting to note that all 6 students completed the last activity (creating a bar chart by matching it to a structured pictograph) without guidance.

Verbalization. In grade 2, students initially asked the teacher for directions. As she encouraged them to figure things out themselves, all groups but one initiated a discussion. This initial phase likely helped stimulate the communication between peers. For all groups, verbal exchanges dealt with the activity. Typically, we observed that students struggling with one activity would ask their peers for help, and students finishing early would tend to voluntarily offer their support to others. The observer noted that students in every pair verbalized visualization literacy concepts, such as how to read an axis with infrequent ticks, or how to use the key.

Class dynamics. We observed that C'e did disrupt the organization of the class, although not significantly, as confirmed by the teachers. The observer frequently noted that students assigned to different activities came to observe what was on the screen (several times per group), sometimes interrupting the activity by asking questions on what it was or if it was fun. The teacher usually asked the students to focus on the present activity. We also observed two students arguing with the teacher for completing the tablet activity rather than their assignment. Note that these events occurred most during the first days of the deployment, suggesting that they might decrease over time. We did not observe such disruption of class dynamics in grade K.

Post-deployment interviews

During debriefing interviews, the observer first gathered feedback from the teachers, collecting their impressions of the session. She then shared her observations to trigger discussions about specific aspects of the deployment.

All three teachers were not surprised that students were engaged with the app and immersed in the activities for the duration of the session. If anything, they reiterated why this immersion could be detrimental to the classroom, as students limit their interaction with peers and do not verbalize the knowledge acquired. However, the grade 2 and 3 teachers were also positively surprised by the social dynamics that the app created, and commented that verbalization did indeed occur, as with other class activities. The grade K teacher explained that the students were too young to verbalize their knowledge, and that C'e would probably be inappropriate as a peer learning experience for this age group. However, she commented on the ability of C'e to capture their attention, and thus to provide an engaging support for 1:1 tutoring scenarios.

Although further evaluation is necessary to evaluate the learning value of C'e, the grade 2 teacher commented on several specific students who appeared to have understood concepts from the session with C'e —although she noted that they would require more 1:1 time with her. She commented that the activity with the infrequent axes was a hard concept to teach with traditional material, but that it appeared most successful with C'e. The grade 3 teacher observed two sessions in grade 2, and commented that she usually spent one hour every day for two weeks to teach the concept of key: *"By Friday they have it [. . .] but on the following Monday that's another story."* She was surprised that grade 2 students successfully completed these activities in a single 30 minute session. She hypothesized that the strength of C'e was to let students focus on fundamental concepts, suppressing the additional complexity of drawing precise bars, axes, or icons using a pen and ruler on paper. She plans to integrate the app in her curriculum.

These initial positive experiences led 4 other teachers (from grades K to 3) to request access to C'e, which we consider an encouraging result given their limited bandwidth to experiment with novel software.

DISCUSSION

C'e is an application of the concreteness fading approach to the specific problem of teaching visualizations — bar charts in particular — at early grades. A different school of thought argues for relying exclusively on abstract representations when teaching new concepts [26], claiming an increased portability of knowledge and more effective generalizability to multiple contexts. According to [26], concrete examples, with their extraneous features, compete for attention, and hinder what is generalizable and transferrable to a novel context.

However, a more recent study replicating the experimental design in [26] provided counter-evidence for more successful knowledge transfer to another concrete domain when concrete examples were given as opposed to abstract ones [11]. The educational psychology literature is also rich with studies showing the utility of physical and representational models [37], as well as employing multiple representations [46, 47] in children's learning of abstract concepts, a notion that echoes with concreteness fading.

These different points of view reveal that the concepts being taught, and the age of the children, are important factors in selecting the right pedagogical strategies. Observations from our formative study and discussions with the teachers clearly show the widespread adoption of concreteness fading in practice. Hence, we argue that the same approach can also be used to teach visualizations. C'e provides a proof-of-concept implementation of this approach for teaching bar charts.

We should note that, at this early stage, we do not provide any evidence regarding the pedagogical utility of our approach. The observations we collected indicate that students were focused on the activities, interacting meaningfully with them, and verbalizing critical concepts of visualization literacy as they completed them. However, these insights are solely qualitative and limited to the small number of students we observed, and the feedback from our interviews with teachers. Collecting concrete evidence on the learning value of a new pedagogical tool is beyond the scope of the present work. The field study was conducted in an upper middle-class district, with classrooms equipped with internet connectivity and tablet devices. Although not many schools have access to these technologies today, there are significant efforts to enable wider access [41]. Thus, results from our field study may not be generalizable, but our findings are demonstrative of the potential of our approach, and call for more efforts and longitudinal studies to assess its viability.

CONCLUSION AND FUTURE WORK

In conclusion, we offer a different look at visualization literacy, focusing on the role of data visualizations in grades K to 4. Our formative study included the qualitative analysis of educational materials, a survey with teachers, and a review of educational software. Insights from this study advance the knowledge of our research community regarding what is currently being taught to children about data visualization. We have also identified an opportunity to enhance visualization literacy in early grades, and formulated a set of design goals inspired by pedagogical approaches advocating that students should be guided from concrete examples to abstract knowledge, while leveraging interactive techniques commonly used in information visualization. With these goals in mind, we developed C'e, a tool for teaching and using pictographs and bar charts in early grades. In the near future, we plan to iterate over C'e and attack more advanced literacy skills, such as introducing the notion that charts of different aspect ratios may look different but encode the same data. We also intend to investigate how the approach presented in this paper can be adopted to teach adult populations a larger range of visualizations, such as parallel coordinates or tree-maps.

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