# VizBlocks: A Data Literacy Education Tool Built on Scratch

## ABSTRACT

In the conversation of computational thinking as a vital ingredient of STEM, the role of data literacy education has been overlooked. Data literacy is fundamental to computational thinking, yet research on tools for data literacy is still in its infancy. This paper explores a way to promote data literacy education through a new platform called VizBlocks. It proposes that having an information repository of data literacy resources complemented by a visual programming tool, will enable K-12 children to creatively learn data visualization.

Through the discussion of related works, this paper highlights and provides evidence for the motivation of VizBlocks. In addition to identifying the shortcomings of existing tools that educate data literacy, we examine what visual programming paradigm is and how it fits into the narrative of educating data visualization literacy. Lastly, this paper also presents the development of VizBlocks.

## KEYWORDS

Data Literacy, Visualization in Education, Visualization with Children, Visualization Literacy, Visual programming paradigm

## 1. INTRODUCTION

In recent years, the argument for adding computational thinking (CT) to every child's analytical ability as a vital ingredient of STEM learning sparked by Jeannette Wing has rallied educators, education researchers, and policy makers. An examination of the current state of discourse on computational thinking in K–12 education shows that with broadly agreed on definitions of CT in K-12 education, focus has been shifted to investigating ways to promote and assess the development of CT (Grover, & Pea, 2013). In the U.S., the AI4K12 Initiative is a developing guideline on artificial intelligence (AI) education for K-12 students. In Touretzky and Gardner-McCune's recent work, they explore the key insights that K-12 students can gain into the big ideas of AI, and how the learning of AI may influence other aspects of their educational experience (Touretzky & Gardner-McCune, 2022).

Despite the conversation on promoting CT education broadening into the sub-branches of computer science, conversation on how data literacy education plays an important role in promoting CT has been sorely overlooked. One of the core CT skills is representing data through models. This however cannot be achieved without a firm grasps of data literacy. An examination gauging the ability to interpret data visualizations indicates that the public has a low level of data literacy (Börner, Maltese, Balliet, & Heimlich, 2015). This reflects that most people are unable to effectively comprehend valuable information using data visualizations which helps in learning, problem solving and making informed decisions. Education pertaining to data literacy is thus essential to be conducted in conjunction with CT education.

Building data analysis skills are now part of the modern elementary school curriculum, which includes creating and interpreting commonly seen data charts. While visual representations form a large part of elementary school teaching materials, research on educational tools for data literacy is still in its infancy (Bishop et al., 2019). As such, more research efforts are needed to assess how children acquire data literacy, along with pedagogical guidelines for improving it (Alper, Riche, Chevalier, Boy, & Sezgin, 2017).

Due to lack of data visualization resources and tools to educate data literacy for children, building data visualization skills prove to be a challenging task for educators. VizBlocks aims to bridge this gap by being an information repository of data visualization literacy resources complemented by a visual programming tool. Thereby, enabling K-12 children to creatively acquire the necessary data visualization literacy skills.

## 2. RELATED WORKS

This paper explores studies on the definition, importance, and current state of data literacy for children. Thereby highlighting and providing evidence for the motivation of VizBlocks.

### *2.1. Definition of Data Visualization Literacy*

The term data visualization is regarded as the ability to confidently create and interpret visual representations of data (Alper, Riche, Chevalier, Boy, & Sezgin, 2017). On the other hand, the term data visualization literacy is defined as the ability to make meaning from and interpret patterns, trends, and correlations in visual representations of data. (Börner, Maltese, Balliet, & Heimlich, 2015). Data visualization literacy has also been defined as the "the ability to confidently use a given data visualization to translate questions specified in the data domain into visual queries in the visual domain" (Börner, Bueckle, & Ginda, 2019).

Consolidating the definitions from different research papers, the definition of data visualization literacy for this work is summarized as the ability to interpret commonly seen data visualizations and the proficiency to create visualizations from raw data.

### *2.2. Importance of Data Visualization Literacy for Children*

Today, visual culture is a constant in daily lives and is more so for students. As a group they spend less time attending school than watching television and interacting with a computer, smart phones, or laptops (Avgerinou, 2009). Visualization literacy is thus essential in helping children navigate "the visually rich Web, photo dependent social networks, video saturated media, and graphically sophisticated entertainment and gaming" (Metros, 2008). In addition, visualization literacy helps improve "verbal skills, more highly developed self-expression and ordering of ideas, motivation and engagement in a variety of subjects, self-image and relationship to the world and selfreliance, independence and confidence" (Flynt & Brozo, 2010).

In addition, national associations in the U.S. such as National Association for the Education of Young Children (NAEYC) and National Art Education Association (NAEA) have recognized the importance of visual literacy in young children (Lopatovska, 2016).

### *2.3. The State of Data Visualization Literacy for Children*

To understand the current state of data visualization literacy for children, this paper explores the work “Observations and Reflections on Visualization Literacy in Elementary School” (Chevalier et al., 2018). Though the study was conducted in the United States, it is reflective of the current landscape of data visualization.

Participants of this study consist of children and teachers of grades K-4 (aged 4 to 10). In this work, Chevalier et al. identified three thought-provoking teaching paradoxes (Chevalier et al., 2018):

1. **Visualization is omnipresent in the educational content of grades K-4**. An analysis of 1,500 pages of grades K-4 textbooks revealed that more than half of the pages contained at least one data-driven graphic. Additionally, a survey completed by teachers indicated that approximately 25% of their teaching materials constitute graphics, surpassing all other categories of materials. **However,** learning to interpret and create a data visualization 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.
2. The consensus of the 40 teachers in the study is that data **visualizations are intuitive as well as of limited importance and difficulty**. **However,** 11 of the 16 teachers surveyed in the study felt that children after completing their grade level were not entirely prepared to create and interpret data graphics accurately.
3. **Elementary students learn and develop skills in both reading and writing (or creating) data graphics from preschool onwards**. Pedagogical methods employed generally included comprehension questions, as well as creation activities that require translating data into a graphic. **However,** students are unable to approach data visualizations in a critical manner. In an exercise of the study designed to assess students’ data visualization literacy, none focused on fixing, or critiquing erroneous visualizations.

These paradoxes are a manifestation of the fact that despite the abundant usage of data visualizations in teaching many early education concepts, data visualization education itself is not consistently addressed. Additionally, the third paradox 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.” (Chevalier et al., 2018).

## 3. EXISTING TOOLS

A discussion of existing tools that aim to educate visualization literacy provides insights that can be learnt and built upon. In this section, a few educational tools have been analyzed. These are either deployed for use or are undergoing research and development.

### *3.1. C’est La Vis*

#### *3.1.1. Key Features*

C’est La Vis is a platform for students to learn about pictographs and bar charts. A live version of the platform can be accessed at https://cestlavis.github.io/. The core motivation of C’est La Vis is to integrate pedagogical strategies for teaching abstract concepts with established visualization techniques (Alper, Riche, Chevalier, Boy, & Sezgin, 2017).

Alper et al. found that there is great diversity in the level of abstraction in the visuals taught across grades K-4. Firstly, the visuals were consistent with Piaget’s theories advocating for a gradual progression from concrete physical experiences to abstract information in children’s learning process (Piaget, 1948). Concreteness fading, a pedagogical method suggesting that new concepts should be presented first with concrete examples, before progressively abstracting them was also utilized (McNeil & Fyfe, 2012). Classifying visual material across grades also reveals that there is a gradual increase in abstraction in higher grades. The findings from the formative study led Alper et al. to identify an opportunity for a visualization literacy tool taking advantage of the concreteness fading approach.

#### *3.1.2. Limitation and Insights*

C'est La Vis presents great potential in teaching visualization literacy with design goals inspired from 2 years of research while also aligning with pedagogical strategies such as the concreteness fading approach. However, C'est La Vis focuses heavily on pictographs and bar charts, a small subset of commonly seen visualizations. More variety of commonly seen charts needs to be explored for children, such as pie charts, dot plots etc.

### *3.2. Construct-A-Vis*

#### *3.2.1. Key Features*

Construct-A-Vis was motivated by the realization that there is a limit to how children can incorporate creativity and their own ideas into their visualizations when using approaches that guide visualization creation with templates such as the approach taken by C’est La Vis (Bishop et al., 2019).

Templates encourage children's understanding of links between different visual representations via completion exercises. However, allowing children to explore their own ideas when visually representing a data set may lead to a more grounded understanding of how to represent and communicate data (Bishop et al., 2019). The research explores the design of free-form visualization tools for children that allow the creative creation of visualizations without step-by-step guidance and templates. Construct-A-Vis is a tablet-based tool designed to enable this exploration.

A demonstration of the workings of Construct-A-Vis can be found on the official website at https://construct-a-vis.cs.st-andrews.ac.uk/video/. The concept of free-form visualization comes in the form of "tokens". In Construct-A-Vis, children interact only with "tokens" and can alter their individual visual properties to encode data. Options for visual properties include shape, color, and images. When the tool is started, children are presented with a blank canvas and a small set of data presented in tabular form. The children can freely create, manipulate, and position tokens on this canvas to visually represent the given data set in any way they want. In addition, Construct-A-Vis features a collaboration mode that supports the shared creation of visualizations between two children.

#### *3.2.2. Limitation and Insights*

It is noteworthy that Construct-A-Vis allows children to learn visualization literacy creatively rather than follow a straightforward template, thereby encouraging critical thinking of the visualization process. Although formal studies have yet to be conducted, having a collaborative feature has shown potential to encourage productive discussions and behaviours among peers which facilitates the learning process (Chevalier et al., 2018).

However, there are some limitations worth noting. The visualization types supported by Construct-A-Vis is limited by the visual properties of tokens. For instance, common visualizations such as line graphs cannot be explored by children, thereby limiting their design explorations. A potential draw-back of free-form visualizations is that children are not explicitly taught the key components that construct a visualization. When encountering a new type of visualization, they may be unable to critically analyse and interpret meaning from the visualization.

In addition, the collaborative mode of Construct-A-Vis requires 3 devices to facilitate learning between 2 children. Furthermore, the 2 children need to be in close physical proximity. These requirements may be a hurdle to learning and is especially true in these times of a global pandemic. A more effective and efficient online approach should be considered.

### *3.3. Diagram Safari*

#### *3.3.1. Key Features*

Diagram Safari was motivated by the belief that games can be a valuable facilitator of teaching visualization since they are highly visual in nature and may thus lend themselves very well for fostering the understanding of visualizations (Gäbler et al., 2019). However, research on using educational games for educating visualization literacy is not explored extensively.

Diagram Safari is designed as a mobile game to educate children between 9 to 11 years old about diagrams and charts. It aims to foster an understanding of how bar charts are created, how to read and interpret them, as well as how they relate to pie charts. The game is available on the Google Play Store to download as an 'early access' version restricted to certain regions.

An adventurous explorer theme was used to make the game appealing to children. Each level in the game is designed in a way such that it can be solved with a straightforward solution or with a more advanced solution. This was done to increase replayability and to accommodate different skill levels.

#### *3.3.2. Limitation and Insights*

Research has shown that educational gamification is beneficial for motivating students to learn (Chapman & Rich, 2018). It is an interesting approach as an educational tool for visualization literacy. An in-classroom evaluation was carried out by the Diagram Safari team; however, it focuses on the usability and playability of the game rather than the relationship between Diagram Safari and visualization literacy of bar charts and pie charts. In addition to the lack of formal studies in the gamification of visualization space, the validity of this approach has yet to be proven.

Furthermore, a gamification approach lacks opportunities for children to verbalize insights and identify features of charts. This is due to the lack of self-assessment tasks, which results in little learning value after playing the game. In addition, there are issues faced when transferring knowledge from educational games to real-life settings in the design of games (Sigmund, Fletcher, Dai, & Wind, 2011). This results in children not being able to see the relationship between the charts they have seen in the games and charts used to represent data presented in real-life scenarios.

## 4. SCRATCH'S ADOPTION OF THE VISUAL PROGRAMMING PARADIGM

### *4.1. Visual Programming Paradigm*

When programmers explain to a novice about the semantics and workings of a program, they often end-up using a graphical representation of the control flow with boxes and arrows. In line with this concept, the visual programming paradigm let users create programs through the manipulation of graphical elements, as opposed to the text edition of source code (Rémi, 2015).

### *4.2. Scratch*

Scratch is an object-oriented, visual programming tool which does not require prior programming knowledge and experience. As a tool that offers "programming without proper programming", Scratch is a simple and clear programming language (Marji, 2014). While Scratch is primarily designed for 8-to-16-year old's, it has also been used in the context of higher education (Almeida, & Pessoa, 2017).

### 4.3. *Key Features of Scratch*

A key design goal of Scratch is to support self-directed learning through tinkering and collaboration with peers. Scratch supports tinkering by allowing users to experiment with commands and code snippets the way one might tinker with mechanical or electronic components. Tinkerability encourages hands-on learning and supports a bottom-up approach to writing scripts where small chunks of code are assembled and tested, then combined into larger units. (Maloney et al., 2010).

In addition, a key goal of Scratch is to introduce programming to those with no previous programming experience. This goal drove many aspects of the Scratch design (Maloney et al., 2010):

1. A visual blocks language:
   One of the main advantages of Scratch is that operation of simpler program modules is much better understood graphically rather than textually (Jancheski, 2017).
2. The single-window user interface layout:
   The Scratch user interface centers around making navigation easy. It uses a single window, multi-pane design to ensure that key components are always visible. Commands are divided into distinct color-coded categories, with the most self-explanatory and useful commands appearing near the top of the command palette. The constant visibility of the command palette invites users to tinker and explore.
3. Immediate feedback:
   There is no compilation step or edit/run mode distinction. Users can click on a command or program fragment at any time to see what it does.

When you learn to code in Scratch, you learn important strategies for solving problems, designing projects, and communicating ideas (Vlieg, 2016).

Moreover, Scratch projects can be saved to the file system or shared on the Scratch Website. The website enables children from around the world to learn from each other, to get and give feedback, to share interactive tutorials, guided tours, science experiments, book reports, online newsletters, and much more (Vlieg, 2016; Pollock, 2014).

### 4.4. *Insights Drawn*

The visual programming paradigm which encodes source code as graphical elements lends very well for encoding key components (e.g., axis and labels) and data points that construct a data visualization as graphical elements. These graphical elements function like Lego blocks, allowing users to write a multitude of programs or construct various types of visualizations, simply by arranging them in a way that "fits". This bottom-up approach deconstructs the thought process behind the concept being taught. It not only greatly reduces the learning curve, but it also reinforces knowledge on the individual parts that make up a program or visualization in this case.

Scratch's barriers to entry are very low, while the ceiling is limited only by your creativity and imagination (Marji, 2014). Its success and advantages in adopting the visual programming paradigm reveals an approach to educating data visualization literacy that addresses all the areas of improvement in existing tools mentioned previously. Namely this approach allows for a more powerful form of free-flow visualization, supporting a more efficient and accessible collaborative learning feature as well as equipping children with the skill to critically analyse any variety of visualizations.

## 5. VIZBLOCKS

### 5.1. *Objectives*

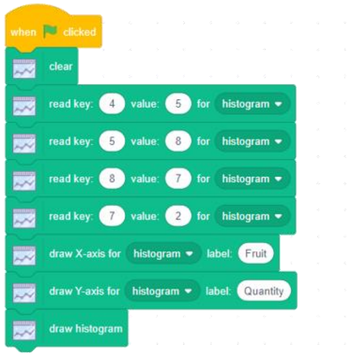
The core objectives of the VizBlocks are:

1. Build a tool based on a visual block-based paradigm to enable K-12 children to learn data visualization literacy creatively
2. Build an information repository of data visualization literacy resources

To allow children to learn data visualization literacy skills creatively, they can use a visual programming extension of Scratch called Vizblocks. By extending the successful model of Scratch, the goal is to allow children to creatively learn data visualization literacy skills whilst strongly enforcing knowledge on the individual parts that make up a data visualization.

The information repository would serve as a one-stop platform for elementary school teachers and students to access materials used for teaching and learning of data visualization literacy, access the Vizblocks tool as well as contribute to the resources. This in turn, builds a community of shared learning.

### 5.2. *Vizblocks Tool*



```
when ⚑ clicked
clear
read key: 4 value: 5 for histogram ▾
read key: 5 value: 8 for histogram ▾
read key: 8 value: 7 for histogram ▾
read key: 7 value: 2 for histogram ▾
draw X-axis for histogram ▾ label: Fruit
draw Y-axis for histogram ▾ label: Quantity
draw histogram
```

*Figure 1.* Script using Vizblocks extension blocks to draw histogram.

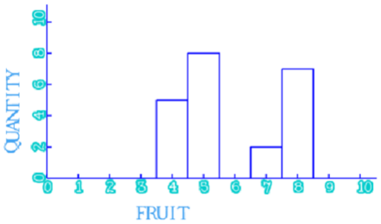


*Figure 2.* Histogram drawn with script in Figure 1.

Vizblocks currently supports the creation of 8 types of visualizations:

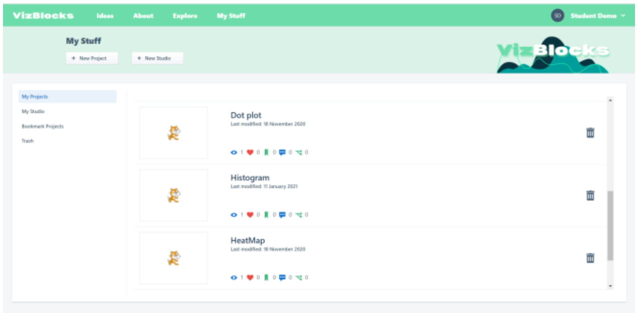
1. Dot Plot
2. Pictograph
3. Bar Chart
4. Pie Chart
5. Histogram
6. Line Chart
7. Scatter Plot
8. Heatmap

The choice for these 8 types of data visualizations was made by studying Pre-K-12 Guidelines for Assessment and Instruction in Statistics Education II (Bargagliotti et al., 2020).

Vizblocks is built with little assumption of children's prior knowledge of Scratch. Most data visualizations can be built in a drag and drop manner without programming knowledge. However, since Vizblocks is built on Scratch, children can make use of existing Scratch blocks to read in data programmatically instead of using multiple similar blocks for the same purpose. An added benefit of learning with Vizblocks is that children might be keen to explore computational thinking to ease visualization creation.

### *5.3. Vizblocks Information Repository*

A minimum-viable-product of the information repository has been built and is currently deployed at https://vizblocks.comp.nus.edu.sg.



Dot plot
Last modified: 18 November 2020
1 0 0 0 0

Histogram
Last modified: 11 January 2021
1 0 0 0 0

HeatMap
Last modified: 18 November 2020
1 0 0 0 0

*Figure 3.* A user's main page: list of projects and studios.

Users can access the Vizblocks tool through the website. by simply clicking the "new project" button or on existing projects. They can create, read, update, and delete projects on the cloud.

The Vizblocks website also supports a "Studio" feature. From an educator's point of view, a studio functions as a classroom where folders can be organized as submission boxes. It is also a place where teachers and students can communicate; From a student's point of view, a studio can be a collection of similar projects, serving to organize projects for ease of access. It can also be a place for like-minded students to gather and learn from each other.

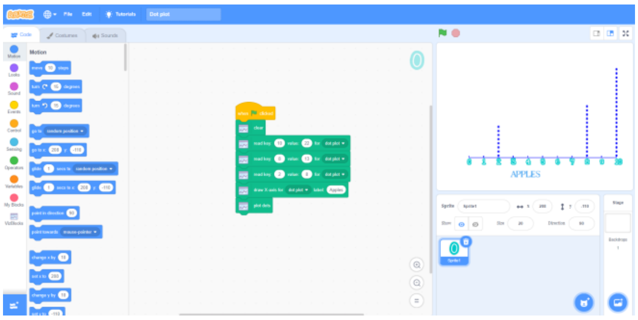
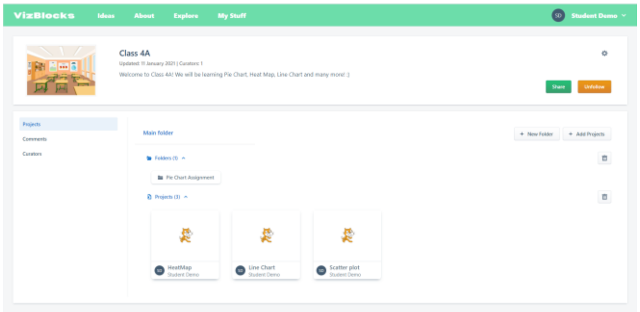
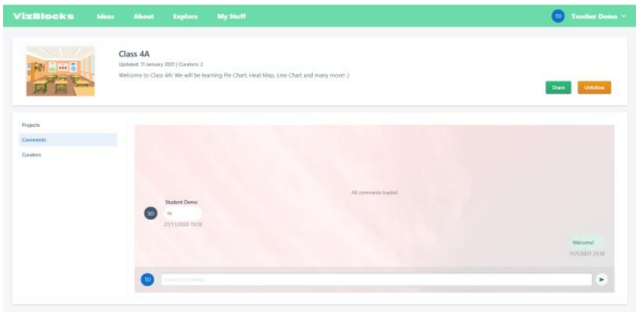


*Figure 4.* User using the Vizblocks extension blocks.



Class 4A
Updated: 11 January 2021 | Curators: 1
Welcome to Class 4A! We will be learning Pie Chart, Heat Map, Line Chart and many more! :)

*Figure 5.* Sample studio on the VizBlocks website.



Class 4A
Updated: 11 January 2021 | Curators: 2
Welcome to Class 4A! We will be learning Pie Chart, Heat Map, Line Chart and many more! :)

Student Demo
Hi
27/11/2020 15:18

Welcome!
11/1/2021 23:36

*Figure 6.* Users communicating through the "comments" tab in Studio.

Notable features in development include interactive tutorials as well as the ability to search and view other users' projects or studios.

## 6. CONCLUSION AND FUTURE WORK

For K-12 children and educators who need to receive or give education on data visualization literacy, VizBlocks is both an information repository and visual programming tool that allows creative learning of data visualization literacy through a visual block-based paradigm, easy access to relevant materials and a community of shared learning. Unlike existing tools such as C'est La Vis, Construct-A-Vis and Diagram Safari, VizBlocks is a more powerful free-form visualization tool. Its bottom-up approach not only has a low barrier of entry but also reinforces knowledge on the core concepts of visualizations thereby equipping children with the skill to critically analyze any variety of visualizations. Additionally, it has an extensive support for collaborative learning that is not constrained by physical proximity and additional hardware.

As VizBlocks is still in development, user testing and evaluation of the visual programming tool will be conducted in the near future to study the relationship between learning with Vizblocks and data visualization literacy. As formal studies have yet to be conducted, no insights can be drawn on the effectiveness of our approach. However, the main intention of this paper is to draw attention and increase efforts to bring improvement to the landscape of data literacy education as well as spark conversations on the role of data literacy education in promoting CT.

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