# Understanding Visual Literacy, Mathematical Literacy and The Teaching Potential of Infographics with Mathematical Representation: A Review of Literature

by

Anitha Francis

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Submitted by: **Anitha Francis**

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**Review Committee:**

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| Research Supervisor | Dr. Ami Mamolo |
| Second Reader | Dr. Joe Stokes |

The above review committee determined that the project is acceptable in form and content and that a satisfactory knowledge of the field was covered by the work submitted. A copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

## ABSTRACT

This literature review investigates research in education about describing visual and mathematical literacies and the competencies that makes an individual visually and mathematically literate. The educational benefits of infographics are examined with a focus on visual and mathematical literacy skills. The analysis conducted as part of this review indicates that visual and mathematical literacy skills are necessary to interpret infographics and the meaning behind the information being depicted. The literature reviewed emphasized infographics' capacity to reduce cognitive load, understandably convey abstract and complex information and aid in memorability. I provide an analysis of examples of infographics that highlights the value of visual and mathematical literacy skills and the potential educational applications of infographics.



**Keywords:** Infographic; Mathematical Literacy; Representation; Visual Literacy; Visualization

## AUTHOR'S DECLARATION

I hereby declare that this project consists of original work of which I have authored. This is a true copy of the work, including any required final revisions, as accepted by my committee.

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# Chapter 1. Introduction

The motivation for exploring the topic of this literature review, "Understanding Visual Literacy, Mathematical Literacy, and The Teaching Potential of Infographics with Mathematical Representations," is explained in this section. The importance of investigating this topic and the research questions are explained. The chapter concludes with the organization of the remaining chapters of this literature review.

## 1.1 Background of the Study

As an intermediate-senior mathematics and science instructor, I have seen many students struggle to make mathematical connections and interpret mathematical information through visuals such as charts, graphs, pictorial representations, and number lines. Diagrams are commonly used in teaching and learning mathematics, and due to how diagrams convey information, it is relevant to understand how visual literacy is required to interpret information from visuals with mathematical representation. Interpreting information from visuals requires students to analyze visuals and make associations with mathematical concepts, which seems challenging for many learners based on my observation. Furthermore, I have observed that numerous students struggle to comprehend mathematical concepts, which may lead to learning gaps detrimental to skill-building and learning. I have also observed that many students lack the critical thinking skills required to interpret information from the visuals. Such issues could negatively impact learners' ability to comprehend information from visuals with mathematical representations and their visual and mathematical literacy. Therefore, this is an issue in education that needs to be addressed. Moreover, in this digital age, the amount of information presented through visuals is increasing, and this emphasizes the need to develop visual literacy competencies. A general understanding of mathematics is required today to comprehend the data, and it helps to manage societal changes, which stresses the importance of gaining mathematical literacy competencies. Therefore, understanding visual and mathematical literacy and the ways to build visual and mathematical literacy skills is a topic that needs to be explored. Using scholarly articles, journals, books, and conference papers, I aim to gain an in-depth understanding of visual and mathematical literacy and the competencies required to be visually and mathematically literate. Based on research literature, I indent to explore the benefits of infographics in learning. Furthermore, infographics with mathematical representations are chosen and analyzed using research literature to understand their educational benefits.

### 1.2 Research Questions

To address the above-mentioned issues in education I developed the following research questions:

1. What is visual and mathematical literacy as described in educational research, and what competencies are needed to be visually and mathematically literate?
2. What does the research literature indicate about the benefits of infographics for learning?
3. How can research literature be used to analyze infographics with mathematical representations?

My aim in exploring these three research questions were to better understand how visualization and mathematical literacy come into play when learners try to make sense of infographics. Infographics are visual representations that blend text and images to deliver information clearly and concisely (Abilock & Williams, 2014; Afify, 2018; Naparin & Saad, 2017; Siricharoen, 2013; Yildrim, 2016). Researchers have linked mathematical literacy with general literacy skills, and suggest that such skills are essential for everyday lives, societal understanding, and social participation (Celik, 2019; Ojose, 2011)

### 1.3 Organization of this Literature Review

The remaining portion of this literature review is organized as follows:

Chapter 2. Visual Literacy: An Educational Perspective: This section draws on education research literature to discuss visual literacy, the competencies for visual literacy, and visualization and meaning generation. The section discusses the importance of visual literacy in education and everyday life. It may be noted that interpretations and terminology usage vary based on the researcher's perspective and the associations made. In this literature review, the terms ability, skill, competency, and proficiency have been used interchangeably to explain visual literacy.

Chapter 3. Mathematical Literacy: An Educational Perspective: This section includes information on mathematical literacy, the competencies for mathematical literacy and a discussion about the overlap between visual literacy and mathematical literacy competencies. The section discusses the importance of mathematical literacy in education and everyday life.

Chapter 4. Mathematical Visualization: Benefits in Education: This section covers visualization in mathematics and the benefits of visualization in learning. The fundamental characteristics of a good data visualization and reasons for using data visualization are explored.

Chapter 5. Mathematical Visualization: A Look at Infographics: This section of the literature review introduces a definition of infographics and examines the different types of infographics by exploring specific examples. Furthermore, the storytelling features of infographics are explored, followed by an analysis of three general infographics.

Chapter 6. Educational Benefits and Developing Infographics for Education: This section reviews literature which describes the benefits of using infographics in teaching and learning and examines how one can develop infographics for educational purposes. The section reviews literature about how infographics can be beneficial in cognition, comprehension of information and memorability. Components that determine the instructional power of infographics are discussed along, with design features.

Chapter 7. An Analysis of Three Infographics: This section analyzes three infographics that use mathematical representations. Each infographic is analyzed based on specific visual and mathematical literacy competencies required to understand the story conveyed. Furthermore, how each infographic can be used to teach visual and mathematical literacy competencies and critical thinking skills are proposed. The specific mathematical concepts that can be taught using each infographic are included.

Chapter 8. Limitations, Further Research and Conclusion: My paper concludes by discussing the limitations, recommendations for further research and the findings of this literature review.

# Chapter 2. Visual Literacy: An Educational Perspective

## 2.1 What is Visual Literacy and How is it Important?

This section explains visual literacy and why it is essential in education and everyday lives. According to Curtiss (2004), the oldest form of literacy is visual literacy. Visual literacy is the ability to explore the world gracefully by speaking, recognizing pictures like reading, and creating images like writing (Curtiss, 2004). Being visually literate allows an individual to understand their perspectives and principles of visual expression to analyze visuals they see and create exceptional graphics in their work (Curtiss, 2004). According to researchers, visual literacy has been linked to several abilities, skills, and cognitive functions. Visual literacy is a skill which enables the observer to develop visual ideas and make meaningful interpretations by constructing visual messages (Avgerinou, 2003; Benoît, 2016; Botha et al., 2019; Celik, 2019; Cimen and Ayguner, 2018; Curtiss, 2004; Dunlap & Lowenthal, 2016; Ilhan et al., 2019; Kibar & Akkoyunlu 2017; Vermeersch and Vandenbroucke, 2015). Another interpretation refers to visual literacy as a cognitive capacity that includes thinking, reasoning, envisioning, inferring, meaning formation, and communication through visuals (Avgerinou, 2001 b). According to Avgerinou (2003), visual literacy refers to a set of capabilities, such as thinking and studying using visuals, reading and comprehending information from visuals, and producing visuals. This description is similar to the explanation by Cimen and Ayguner (2018), Curtiss (2004) and Vermeersch and Vandenbroucke (2015). Visual literacy is a skill that allows people to generate images and communicate through visuals (Cimen and Ayguner, 2018; Curtiss, 2004; Vermeersch & Vandenbroucke, 2015). Thus, it is possible to define visual literacy as the ability to interpret visual information, produce visual representations and communicate using images.

Learners will gain an active role in interpreting the visual material that piques their attention; however, this is possible only if the learners are visually literate (Murphy, 2011). Since visuals can be complex and challenging to comprehend and generate meaning from, students must learn how to interpret and develop meaning from visuals; therefore, visual literacy education is essential in today's world (Williams, 2019). Avgerinou (2001 b) emphasizes that visual literacy skills can be learnt, taught, developed, and improved. Visual literacy is an educational requirement that requires teachers and instructors to be able to arrange, manipulate, and use graphics for teaching and learning (Aisami, 2015). When applied to teaching, such competency promotes learning and encourages learners to attain academic success (Aisami, 2015). According to Beauchamp et al. (1994), visual literacy follows reading, writing and numeracy as the fourth component of general education. The following factors explain the significance of visual literacy. Firstly, visual literacy involves using the brain's right hemisphere, which is crucial for human development. Secondly, visual literacy entails understanding abstract ideas, which requires using the brain's left hemisphere. Therefore, visual literacy entails employing both hemispheres of the brain to decipher the visual and produce a comprehensive idea of the information from the visual. Thirdly, visual literacy enables individuals to digest the same information in various ways. Finally, visual literacy enables people to understand and analyze their environment and reach independent conclusions (Beauchamp et al., 1994).

According to Avgerinou (2003), visual literacy is one of the essential literacies required to withstand the daily challenges of the twenty-first century. The importance of visual literacy is increasing as the amount of digital information expands (Dunlap & Lowenthal, 2016; Ilhan et al., 2019). Because people spend more time with mass media, people in the new generation interpret the world primarily through visuals (Yildiz et al., 2019). As visuals have become more important for communication and meaning generation, the relevance of visual literacy increased (Kibar & Akkoyunlu, 2017). Therefore, visual literacy may be focused on in education and visual literacy competencies may be taught. Such skills will enable learners to interpret visual information in their environment, which could come from education, media, or any other source.

### 2.2 Visual Literacy Competencies

Based on research from some of the articles, this section identifies and describes the competencies required to become visually literate, which are the skills that enable a learner to interpret information from a visual accurately. Avgerinou (2009, p. 9) identified the following visual literacy competencies based on the following articles (Avgerinou 2003, 2007). Furthermore, supporting information about these competencies from other researchers is also included.

- *Visual Terminology and Conventions:* This competency refer to knowledge about the essential components of visual languages, such as "point, line, shape, form, space, texture, light, colour, and motion." Also, awareness of the visual signs and symbols and their socially accepted meanings supports the viewer in developing meaningful interpretations; for example, the meaning of certain symbols in the western culture enables the viewer to interpret information based on its meaning. Vermeersch and Vandenbroucke (2015) assert that visual literacy is about being aware of images. This statement is consistent with the explanation of having an awareness of visual terminology and conventions as a visual literacy competency (Avgerinou, 2009).
- *Visual Thinking and Visualization:* These competencies aid in critical thinking, reasoning, meaning generation, and visual expression. Visual thinking entails thinking about visuals and generating ideas, which helps viewers decode complex concepts from a

visual presentation (Aisami, 2015; Bamford, 2003; Botha et al., 2019; Felton, 2010; Murphy, 2011). Understanding and producing visuals both need the use of visual thinking. Using ideas generated from visual thinking to construct mental images is referred to as visualization (Avgerinou, 2009; Williams, 2019). Visual elements such as colours, figures, location, and various forms such as film, comic books, comic strips, photos, and pictures may be used to develop images and visually express ideas (Williams, 2019).

- *Critical Viewing, Visual Reasoning, and Visual Discrimination:* These skills allow viewers to observe and analyze visuals critically. According to Avgerinou (2009), critical observation aids in extracting information about the visuals and in assessing the visuals. Furthermore, individuals need critical observation and reasoning skills to develop sensible interpretations from visuals. Inspecting the scales of graphs, dimensions of the visual representation, identifying potential distractions, identifying the presence of irrelevant information, and any other aspects affect the fair portrayal of data is part of critical observation (Cui and Liu, 2021). This inspection would help spot misleading information, uncover any concealed information, and identify misleading representations (Cui & Liu, 2021). Readers may examine the image to spot any potential distractions that could taint the judgment of the data, and this idea can be correlated to Avgerionou's (2009) explanation about critical viewing.

Sensory responses while viewing pictures enable the viewer to notice specific elements about the visual and to make distinctions about visuals; this is known as visual discrimination. Visual discrimination lets the observer learn insightful things about the representation (Avgerinou, 2003; 2009). Visual discrimination can help learners focus on specific visual elements, such as a graph's periodical shift or increasing/decreasing pattern, or on sections of the visual that may be misleading. Connecting such distinct elements and the corresponding sensory impulses facilitates differentiation between them and other visual components. These connections enable the observer to dig deeper into the visual, making it easier to decode the additional information. Thus, it may be stated that critical observation is not just observing the presentation's visual elements but also probing deeper to uncover insightful information that might not be clear from merely observing the visual.

- *Visual Association and Meaning Generation:* These competencies help an observer develop meaningful and accurate interpretations by making associations between visuals or parts of a visual that share a common element. An example of visual association could be associating between all parts of a graph that shows a decreasing trend. Making verbal-visual associations by linking verbal messages with visual representations (and vice versa) also aids in developing a deeper understanding of the visuals. It may be said that such associations include connecting text or descriptions to a visual representation or framing a description about the visual representation. Since the viewer is thinking and making such associations, visual reasoning is also involved.
- *Visual Reconstruction:* Visual reconstruction enables observers to generate meaning from partial images or images not fully displayed. In this context, constructing meaning entails developing a visual message in its original structure from partially obscured images based on any evidence from the visual.

The above-mentioned visual literacy competencies also relate to the visual literacy competencies stated by other researchers. According to Vermeersch and Vandenbroucke (2015), visual literacy involves the following processes: visual perception (collecting data), visual imagination and creation, and visual conceptualization (developing a form based on a visual and meaning generation) and visual analysis. These processes can be related to the following visual literacy competencies outlined by Avgerinou (2009), such as critical viewing, visual reasoning, visual reconstruction, visual association, visual reconstruction, and visualization.

According to Avgerinou and Pettersson (2010), visual literacy competencies are

- reading/decoding/interpreting visual statements
- writing/encoding/creating visual statements
- thinking visually

Furthermore, Avgerinou and Pettersson (2010) pointed out that visual literacy strongly correlates with visual learning. Visual learning requires the skill of reading visuals/pictures, interpreting the visual impulse and developing meaning, and image construction. These visual learning skills can be associated with some of the visual literacy competencies outlined by Avgerinou (2009) as follows:

- Reading visuals/pictures can be related to critical viewing and visual reasoning.
- Interpreting the visual impulse and developing meanings can be related to visual association and visual reconstruction.
- Constructing meaning and image construction can be related to visualization.

According to the explanations by Avgerinou (2009), Avgerinou and Petterson (2010), and Vermeersch and Vandenbroucke (2015), the processes involved in visual literacy and visual learning are similar. These three skills for visual learning are part of the set of competencies for visual literacy, but visual literacy is more extensive.

## 2.3 Visualization and Meaning Generation

This section defines visualization and how it aids in a meaning generation. Trifunov et al. (2019) state that visualization is the process of creating, interpreting, and reflecting on visuals in our minds, on paper, or digitally with the support of technology. According to Yin (2010), the ability to visualize and understand a problem scenario is known as visualization. In line with Ozdamli et al. (2016), the main aim of visualization is to develop a map of the problem by building meaning in the learner's mind about the scenario in the problem. Researchers state that visualization is the ability to interpret information from visuals and deduce meaning appropriately (Avgerinou, 2009; Cimen & Ayguner, 2018; Curtiss, 2004; Guzman, 2002; Ozdamli et al., 2016; Vermeersch & Vandenbroucke, 2015). This meaning generation involves "human culture," which is the human nature of giving meaning and structure to present events using memories and making connections to existing knowledge (Vermeersch & Vandenbroucke, 2015, p. 4). This description is in line with Trifunov et al. (2019). They emphasize that the goal of visualization is to make connections to previous knowledge, develop a deeper understanding of the visual, and communicate information (Trifunov et al., 2019). Guzman (2002) and Yildiz et al. (2019) support the above notion and emphasize that visualization is a complicated process (Guzman, 2002; Vermeersch & Vandenbroucke, 2015; Yildiz et al., 2019). Therefore, how a visual is interpreted and the meaning generated depends on each individual's human nature, their existing knowledge and how they make connections, which could vary between individuals. Furthermore, different tasks are involved in generating meaning from visuals, and this may be why researchers have emphasized that visualization is a complicated process.

## Chapter 3. Mathematical Literacy: An Educational Perspective

### 3.1 What is Mathematical Literacy and How is it Important?

This section contains research and everyday descriptions of mathematical literacy, as well as a discussion of the mathematical concepts and skills that makes individuals mathematically literate. Höfer and Beckmann (2009) stated that "the core of mathematical literacy is formed by the ability to apply mathematical knowledge to various and context-related problems in a functional, flexible and practical way" (p. 224). Ozgen and Bindak (2011) share a similar theme and describe that the perception of mathematics literacy, in general, is an individual's belief in their abilities, skills, and circumstances they experience. Researchers (Celik, 2019; Ilhan et al., 2019; Ojose, 2011) and organizations (The Organization for Economic Co-operation and Development, 2003; Ontario Ministry of Education, 2014) describe mathematical literacy as the ability of a person to comprehend mathematics and apply mathematical reasoning to problem solve. The Organization for Economic Cooperation and Development (1999) explains mathematical literacy as a person's ability to recognize and appreciate the role of mathematics in the world. Moreover, mathematical literacy enables an individual to make well-informed decisions and apply mathematics in ways that meet the demands of that person's current and future life as a productive, thoughtful, and reflective individual.

Mathematical literacy entails using critical thinking, reasoning, and mathematical thinking skills to solve problems in the real world and the development of individuals in the field of mathematics (Ojose, 2011). Mathematical literacy involves a general understanding and appreciation of what mathematics can accomplish. Mathematical literacy "does not imply detailed knowledge of calculus, differential equations, topology, analysis, linear algebra, abstract algebra, and complex sophisticated mathematical formulas" (Ojose, 2011, p.90). However, students need to gain the necessary conceptual knowledge and understand the relevance of mathematics in daily life in order to apply mathematics in everyday life as adults (Ojose, 2011). Furthermore, developing mathematical literacy is as significant as gaining proficiency in reading and writing, and it will be beneficial for learners to know the following mathematical concepts explained by Ojose (2011). I created Table 3.1 by gathering the mathematical concepts and skills outlined by Ojose (2011, p. 97), then I classified them according to the areas of mathematics that are emphasized in school curricula across Canada.

***Table 3.1***

*Mathematical Concepts and Skills Required to Gain Mathematical Literacy*

| **Area of Mathematics** | **Mathematical Concepts and Skills** |
|---|---|
| Number Sense<br>and Numeration | • Express and evaluate using basic arithmetic operations (addition, subtraction, multiplication, and division in whole numbers, fractions and decimals).<br>• Understanding roots, square roots, ratios, percent, absolute values, reciprocals, and exponents. |
| Measurement | • Knowledge about imperial and metric measures of length, area, volume, weight (or mass), time, and temperature.<br>• Perform conversions between imperial and metric systems. |

| | |
|---|---|
| Algebra | • Knowledge about simple linear equations and the concept of proportional reasoning.<br>• Plotting graphs of linear equations, slopes, and operations in positive and negative integers. |
| Geometry | • Know the various area and circumference formulas for circles, squares, rectangles, and triangles.<br>• Familiarity with the Cartesian coordinate system in two and three dimensions.<br>• Convert scale drawings on a model or map to actual dimensions; develop basic constructions using a compass and straightedge.<br>• Familiarity with three-dimensional shapes in terms of finding the volumes and surface areas of shapes like the cone, pyramid, prism, cylinder, and sphere. |
| Statistics | • Find the measures of central tendencies (mean, median, mode and range) from a data set.<br>• Express data as a visual such as histogram, pie chart, bar graph, and line graph. |
| Probability | • Knowledge about probability based on theory (theoretical probability) and experiment (experimental probability).<br>• Compare risk factors of a given situation. |

| | |
|---|---|
| | • Calculate the basic probability of outcomes using the multiplication principle, permutations, or combinations. |

Knowledge of the above mathematical concepts and how to apply them will enable learners with the necessary skills to be mathematically literate (Ojose, 2011). Cui and Liu (2021) point out the importance of knowing statistical concepts such as mean, median, mode, and outliers and how to apply those concepts to extract information from visualizations. Summary statistics such as mean or average from a set of graphical marks (for example dots, circles and bars) may be extracted from a visualization (for example scatter plots and bar graphs), which is referred to as ensemble perception. Ensemble perception helps make inferences, interpret messages, identify trends or patterns, and detect deceptive graphs and representations. Nonetheless, this is possible only if the learners know basic statistical concepts and how to apply those concepts to deduce meaning from a mathematical representation. Therefore, mathematical concepts outlined in Table 1 may be taught to students to equip them with the necessary skills to interpret mathematical information in their environment, which could come from education, media, or any other source.

According to Ozgen and Bindak (2011), a literate person, in general, is anticipated to have higher cognitive talents, including communication, reasoning, problem-solving, and judgment, and can employ these talents successfully in their daily lives. These skills also overlap with the mathematical literacy proficiencies explained by Ojose (2011), which are explained later in this section. Furthermore, a mathematically literate person can express using mathematics, estimate, evaluate, derive and elucidate their reasoning for math-based problems. Additionally, being mathematically literate means being able to analyze and comprehend data presented in a variety of formats, including textual, visual, numerical, and geometric forms, as well as from a variety of mathematical representations, including charts, scale drawings, two and three-dimensional shapes, mathematical statements, calculations, and bar, circle, and line graphs. Thus, a mathematically literate person can use mathematics to express ideas and utilize mathematical knowledge to deduce meaning from text and images with mathematical information.

The need and relevance for gaining mathematical skills as part of education, work and daily lives can be considered the starting point of mathematical literacy (Ozgen and Bindak, 2011). Ojose (2011) explains mathematical literacy as the ability to identify mathematics in different contexts and the confidence to apply mathematical knowledge in everyday life. For instance, numeracy applications can be found in different areas such as personal life, work and school life, entertainment, and community (Steen, 2001). Furthermore, in personal life, mathematics is used in monetary calculations, making purchases and comprehending information from images, graphs, and maps. Examples of mathematics in work-life include interpreting statistical and financial data and calculating taxes and budgeting. Organizing, sorting and planning for school-related activities, calculating game scores and comprehending the importance of mathematics in the community are all related to school life. In the local community, individuals making proper judgments, and decisions, analyzing findings, gathering data and drawing inferences, and adopting a critical attitude are some benefits of being mathematically literate. Mathematical literacy helps develop the skills needed to make logical decisions, assessments, and interpretations (Ojose, 2011). Mathematical literacy allows us to remember mathematical concepts, apply mathematical skills in real-life situations, and analyze and synthesize numerical data (Ilhan et al., 2019). On the other hand, mathematical illiteracy is defined as the inability to manage numerical data, solve problems, formulate mathematical statements, perform mental calculations, and make estimations (Ojose, 2011).

**3.2 Mathematical Literacy Competencies**

The following discussion includes descriptions of mathematical literacy competencies, ways to enhance such competencies along with teaching and learning strategies from some research studies. Some of these mathematical literacy competencies are interconnected and not distinct. Ojose (2011) explains the following mathematical literacy competencies, and this is in line with the mathematical literacy competencies put forth by the Organization for Economic Co-operation and Development (2003) and Steen (2001). Below, I summarize Ojose's (2011) descriptions of competencies found on pages 98-99, and draw connections to related research literature.

- *Thinking and Reasoning:* This skill requires asking questions related to mathematics, having an awareness of various mathematical statements, and understanding mathematical concepts. Pugalee (1999) explained that students should engage in informal mathematical thinking during their primary years of schooling to improve reasoning skills. Furthermore, drawing rational conclusions, justifying explanations, explaining or portraying thoughts using models, data, or representations, and employing patterns to examine problems are strategies to improve reasoning. The following skills are necessary for students as they proceed to higher grades. They should be able to conclude from graphs, validate their reasoning, discover links between different variables, apply inductive and deductive reasoning, create mathematical statements, and evaluate the validity of mathematical arguments in developing reasoning skills. All of the tasks mentioned above may be associated with thinking and reasoning skills, and this skill involves thinking about mathematical information and concluding based on one's thinking and reasoning. Thinking and reasoning skills aid in developing mathematical knowledge (Ilhan et al., 2019; Pugalee, 1999).

- *Argumentation:* This skill involves understanding mathematical proofs, knowing the difference between proofs and other types of mathematical reasoning, and how to develop and assess mathematical statements and arguments. Guzman (2002) points out that it is challenging in mathematics to link diverse theoretical parts (for example theorems, proofs and statements) using only logical approaches, and visuals are handy tools in such scenarios. Visuals aid in understanding various tasks associated with mathematical theory comprehensively. It is also great for getting thoughts across quickly and making connections. Because visual features are included in all actions of the mathematician, including the presentation of theorems and problem solving, it will be advantageous to train one's visual capacity and introduce it to those who are learning mathematics (Guzman, 2002). This skill calls attention to one's capacity for using diagrams to grasp proofs, mathematical statements, arguments and how visuals relate to mathematical proofs and also underlines the need for teaching students to build those skills.
- *Communication:* Communication skills require the ability to express verbally, visually, and in writing, and also to comprehend the work of others. Communication involves having mathematical conversations and discussions requiring people to reason about the mathematics they employ (Pugalee, 1999). This aids in developing mathematical knowledge and conceptual thinking, and such communication promotes mathematical

understanding (Pugalee, 1999). Mathematical conversations and discussions may be incorporated into teaching to enhance mathematical understanding.

- *Modelling:* Modelling involves explaining, justifying, criticizing, assessing mathematical models, thinking and laying out the subject to be modelled, and reflecting on the modelling process. Interpreting mathematical problems and transforming problems and scenarios into mathematical models are also tasks associated with mathematical modelling. Kaiser and Willender (2005) state that modelling is a primary skill involved in mathematical literacy. Mathematical concepts and procedures have numerous visual connections that can be modelled in various ways. For instance, distance is an example of a basic concept related to measurement that can be modelled as a visual (Guzman, 2002) by drawing a line and stating the measurement. Visuals help to deepen the connection between mathematics and actuality and encourage long-term learning (Ilhan et al., 2019). Konyalıoğlu et al. (2012) point out that visual models are physical manifestations of abstract ideas and symbols. Mathematics is an abstract topic, and the link between visuals and mathematical concepts transforms it into tangible, concrete and observable (Ipek, 2003). Students' grasp of mathematical concepts and processes are improved by converting complex and abstract mathematical topics into observable and understandable forms (Liang & Sedig, 2010; Murphy, 2011; Naidoo, 2012). By providing a framework for understanding the information, the model reflecting the concept aids in cognitive processing (Dunlap & Lowenthal, 2016). Research suggests that appropriate usage of visuals can help students learn new concepts, especially if they do not already have a model of the notion in mind (Dunlap & Lowenthal, 2016).

- *Problem Posing and Solving:* Problem posing and solving requires modelling the problem, formulating, following the strategies or steps that lead to finding solutions, and employing multiple ways to solve problems. According to Pugalee (1999), problem-solving is the primary reason for studying mathematics, and it entails applying existing knowledge and skills to solve problems that have no obvious answer. Visualization, which involves developing diagrams to portray the situation explained in the problem, may be employed in every phase of the mathematical problem-solving process (Pachemska et al., 2016). Yin (2010) states that mathematical problem solving relies heavily on the capacity to reason visually. Regarding mathematical problem solving, reasoning and visual reasoning skills are required because of the use of diagrammatic representations in mathematics (Celik, 2019).
- *Representation:* Representation requires the ability to decode, encode, and understand various representations, know the relationships between various representations, and interpret information from different representations. According to Pugalee (1999), representation is the building block of mathematical inquiry and a requisite to be mathematically literate. Furthermore, understanding representations that are presented in any form and transforming representations or models into different forms (For example, equations, graphs, and forms) is a crucial aspect of representation (Pugalee, 1999). Visual representations make math learning easier and increase the desire to learn (Trifunov et al., 2019). Based on the studies conducted by Naidoo (2012), expert teachers employed visuals in mathematics teaching to make it easier to recall the mathematical concepts and to make the learning experience fascinating and enjoyable. Another aim of visuals was to make the mathematical teaching tangible, relatable and understandable. The use of visual

aids encourages active student participation, and visual tools may be employed to promote mathematics instruction and learning (Naidoo, 2012). Learners' knowledge and comprehension improve when they employ visual representations or methodologies to study mathematics, as compared to learning that is only based on text (Murphy, 2011; Naidoo, 2012). Yildrim (2016) points out that visuals are one of the most basic forms of presenting information, and visuals can be used to emphasize specific information with minimal explanation. For instance, in math, graphs can present specific information and convey lots of information (Yildrim, 2016). Visuals perform the best when the layout is well-organized and arranged, revealing connections between concepts and the underlying narrative (Dunlap & Lowenthal, 2016). According to Guzman (2002), visuals aid in problem-solving subtly, developing holistic knowledge and the rapid sharing of ideas.

- *Symbols:* This competency necessitates using operations and symbols to represent, manipulate mathematical statements for calculation, and use technical language. Manipulation entails accurately performing operations and procedures to improve one's mathematical comprehension (Pugalee, 1999).
- *Tools and Technology:* The ability to use tools and technology when it is needed is a necessary skill to become mathematically literate. Pugalee (1999) points out that a mathematically literate person must be able to examine mathematical ideas and solve problems using technology tools. The use of technology in generating visualizations makes the presentations appealing and accessible (Trifunov et al., 2019). Technological advancements could have made it easier and faster to edit or update visuals as needed, the ease with which visuals can be manipulated or moved around on a computer rather than on pen and paper, and the shareability of visuals on online platforms.

According to Ojose (2011), to be mathematically literate, individuals must gain all of these competencies to varying extents, along with a level of comfort to apply these competencies and confidence in their ability to use mathematics.

### 3.3 Overlap Between Visual and Mathematical Literacy Competencies

This discussion is mainly based on the works of Ojose (2011) and Avgerinou (2009) for the following reasons. Both Avgerinou (2009) and Ojose (2011) give instructional perspectives on visual and mathematical literacy and explain the competencies from an educational standpoint. Avgerinou (2009) relates visual literacy to education, whereas Ojose (2011) links mathematical literacy to education and this link to education is in line with my literature review section's explanation of the significance of mathematical and visual literacy in learning, two major topics covered in this literature review.

Ojose (2011) provided an in-depth discussion about mathematical literacy, citing studies from various sources. Furthermore, the competencies were created based on what mathematical concepts must be learned to become mathematically literate; this makes it easier for educators to connect mathematical concepts to mathematical literacy competencies. Avgerinou (2009) conducted a substantial study (Avgerinou 2003, 2007) on visual literacy and defined visual literacy competencies based on her findings and information from other researchers. Her insights and research on visual literacy and how it pertains to young people in the digital age, especially in education, were pertinent to the topics in this literature review. According to Avgerionou (2009), young people should be able to observe critically, think about, and extract meaning from images, rather than being partial and passive recipients of visual messages. This is very important in education and daily lives. Based on the publications of Ojose (2011) and Avgerinou (2009), visual literacy and mathematical literacy competencies play distinct roles. However, the following description shows some overlap between visual and mathematical literacy competencies, and the competencies complement one another.

- Both mathematical and visual literacy competencies involve constructing meaning from visuals. In mathematics, information is comprehended from graphical, geometrical and other mathematical forms, whereas visual literacy involves comprehending information from visuals.
- Both mathematical and visual literacy competency involves communicating and expressing through visual representations.
- Knowledge of mathematical symbols and correct use of operations aid in building mathematical literacy whereas knowledge of visual vocabulary and conventions aids in developing visual literacy.
- Knowledge about the associations between various mathematical representations and identifying such associations is a mathematical literacy competency. This mathematical association is comparable to visual association, a visual literacy competency, where visual images with a common theme are associated to decode meaning.
- Mathematical reasoning and thinking entail asking questions about mathematics, being aware of mathematical assertions, and comprehending mathematical concepts. Visual thinking entails critically considering images, forming thoughts, and grasping the information communicated by the image. Both of these competencies involve critical thinking and reasoning to comprehend the information.

Thus, it may be stated that there is some overlap between visual and mathematical literacies, and visual and mathematical literacy competencies complement each other. Therefore, visual and mathematical literacy competencies may be required to analyze, comprehend and link visuals to mathematics. Celik (2019) explains that visually literate individuals are more successful in becoming mathematically literate and to link mathematics to everyday life; visuals are vital in building connections to everyday life.

# Chapter 4. Mathematical Visualization: Benefits in Education

The role of visualization in mathematics learning, different visualization methods in mathematical visualization, and the advantages of visualization in learning mathematics, such as improving reasoning and comprehension, conveying concrete concepts to abstract concepts, and developing creativity, is explained. Also, data visualizations are defined with an example of a small and large-scale data visualization, how to extract information from data visualization, characteristics of a good data visualization, reasons for using data visualization, and an explanation of data visualization from a mathematical standpoint is covered.

## 4.1 What is Visualization in Mathematics?

Creating images mentally, through sketching or with technology and then utilizing these images for mathematical inquiry is referred to as visualization in mathematics (Pachemska et al., 2016). Visualization appears to be a natural and complex process that involves the human brain's structure (Guzman, 2002). Utomo et al. (2018) refer to visualization in mathematics as a mental process that assists in creating information and ideas. According to Celik (2019), mathematical visualization is the ability to comprehend a mathematical problem by employing a diagrammatic representation and solving the problem. According to Yin (2010), in mathematics, visualization takes different roles in the following areas,

- problem-solving: visuals can be developed to find connections between different elements in the problem
- simplifying the problem using visual representations
- visualizing the connection to another related problem
- developing visuals to streamline each student's learning preferences
- visuals may be developed as a substitute for calculation

- verify and visually express the solution using visual representations

Utomo et al. (2018) explain mathematical visualization as a cognitive activity involving various visualization methods such as visual creation, examination, surveying, and modification. Utomo et al. (2018) emphasize that mathematical visualization is not a sequential process but more about how people connect each visualization element. These explanations are consistent with the points made by Rivera et al. (2014) and Guzman (2002) that these factors influence how each person conceptualizes visualization and develops mathematical thinking. The following description explains how problem-solving is applied to visual creation, examination, surveying, and modification. Exploring data from the provided information in a problem, developing a visual representation with algebraic symbols and making connections between visual ideas generated from the visual representation and existing knowledge are the processes in the visual creation method. The visual examination method entails analyzing and devising a problem-solving strategy based on visual notions. Representing or replicating parts or all of a problem and simplifying it is part of the visual surveying method. Manipulating visual representations, for example, by performing transformations such as rotation, reflection, translation, and enlargement to discover the solution can be considered a visual modification method. Visual thinking and making associations between different elements of the visual and mathematical concepts are involved in visualization. Utomo et al. (2018) point out that visualization can increase one's creativity through the projection of thoughts and reflections.

From a mathematical standpoint, data visualization relates to understanding number sense, measurement and approximation, proportions, fractions, ratios, percentages, probability and statistics (Reyna et al., 2009). In math, visualization is required for problem-solving (Arcavi, 2003; Ho, 2010; Konyalıoğlu et al., 2012; Utomo et al., 2018), proving and reasoning (Arcavi, 2003). Mathematical visualization enables individuals to comprehend mathematical concepts (Guzman, 2002). However, to comprehend the message in the visuals with mathematical representation, readers must be able to read the type of communication from the visual or figure correctly (Guzman, 2002). The following explanations by researchers point out that comprehension depends on the unique ways in which each individual makes connections and interprets information. Readers' minds are committed to looking at specific ways that enable the creation of required mathematical knowledge when observing a visual (Rivera et al., 2014). Similar explanations were put forth by Guzman (2002); each person's mental framework will impact how they conceptualize and develop mathematical thoughts. This could imply that the knowledge development from visualization is dependent on one's thoughts, how they create associations, and how they put together the different elements from their thinking, and this might vary depending on the learners.

### 4.2 Benefits of Visualization

This section looks at the benefits of visualization in education, and the following discussion provides supporting explanations based on research about the connection between visualization and the development of different skills in learning. Visualization plays a significant role in the development of cognition, logical comprehension, and the transition from concrete to abstract thinking, all of which are important in solving arithmetic tasks (Lavy, 2006). Visualization enables us to understand mathematical concepts (Guzman, 2002; Ho, 2010; Rahim & Siddo, 2009). Appropriate mathematics exercises that promote comprehension include thinking about mathematics and making mathematical links to facts and real-world math applications (Guzman, 2002). Visual justification includes the comprehension of mathematical concepts using representations and operations depicted in diagrams, computer graphics programs and object models. According to Rahim and Siddo (2009), visual justification is required to learn mathematics. It could be said that visual justification employs visualization due to the use of visual representations, which are developed to enhance comprehension along with other benefits.

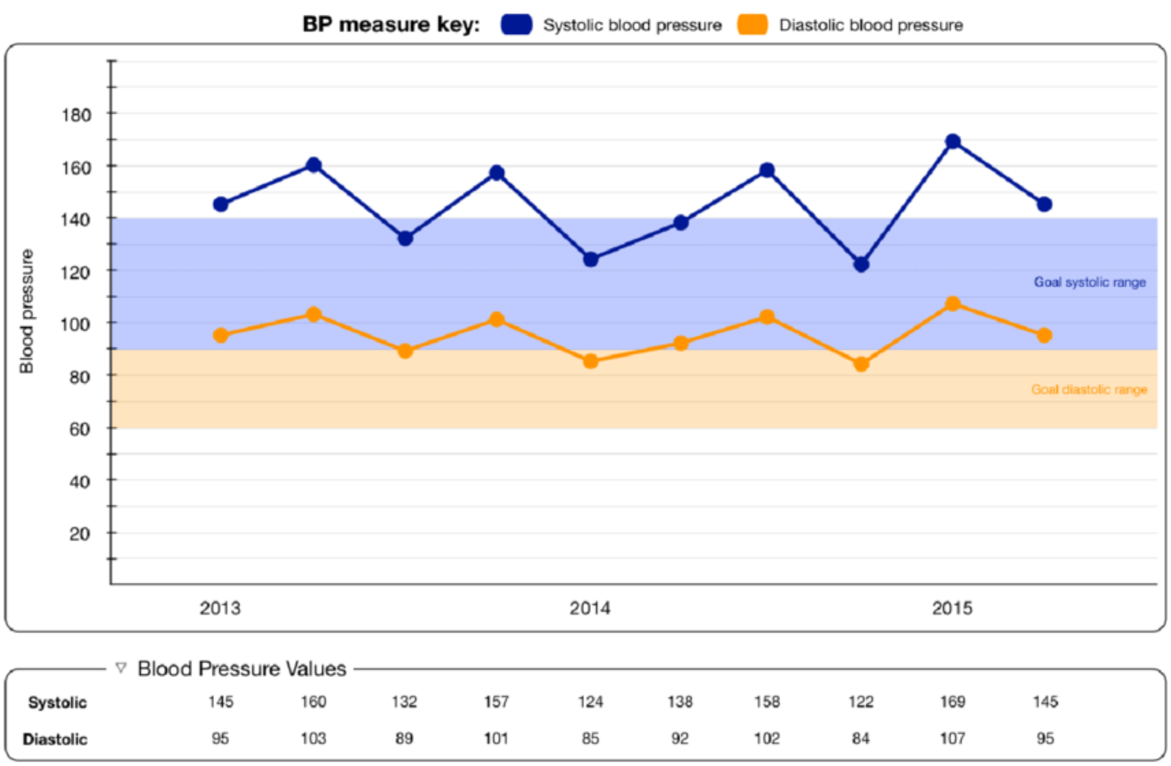
Visualization, according to research, helps people understand complex concepts, increases critical and analytical thinking and improves communication (Aisami, 2015; Bamford, 2003; Botha et al., 2019; Felton, 2010; Murphy, 2011). Students are capable of making the transition from concrete to the abstract while developing visual pictures or representations of a concept (Murphy, 2011). Moving from the concrete (quantitative aspects that can be observed, numbered or measured) to the abstract (what can be envisioned, interpreted and grasped) involves visualization (Murphy, 2011). According to Presmeg (2002), since mathematics uses symbols and diagrams to represent abstract concepts, visualization is involved, and visuals and spatial patterns are easier to remember (Presemeg, 2020). According to Pachemska et al. (2016), visualization plays a prominent role in geometry, and visualization is the only way to simplify a problem and get directions on how to solve the problem from an image (Pachemska et al., 2016). Concepts are comprehended more thoroughly and permanently using geometric educational software that aids visualization (Pachemska et al., 2016).

**4.3 Data Visualization**

Data visualization is transforming data in any form into visuals (Bikakis, 2018: Li, 2020) which could be graphs, charts, scatter plots, waveforms, simulations, or tables (Li, 2020). Data visualization translates data into a simple graphic that allows the observer to translate the numerical information into meaningful information, enabling more efficient communication than raw data (Li, 2020). Data visualization improves the comprehension of large and small-scale data, enabling users to generate logical statements or conclusions about the data set (Li, 2020). According to Cui and Liu (2021), data visualizations reduce large amounts of numerical data into more miniature, more understandable visual representations. According to Krum (2014), data visualizations are vital tools that designers frequently employ to express their message visually. Data visualization tools are software applications that create data visualizations and can be used for small-scale and large-scale data (Bikakis, 2018). The following diagram in Figure 4.1 is an example of data visualization for small-scale data.

**Figure 4.1**

*Small Scale Data Visualization Showing Blood Pressure Variations Over Time*

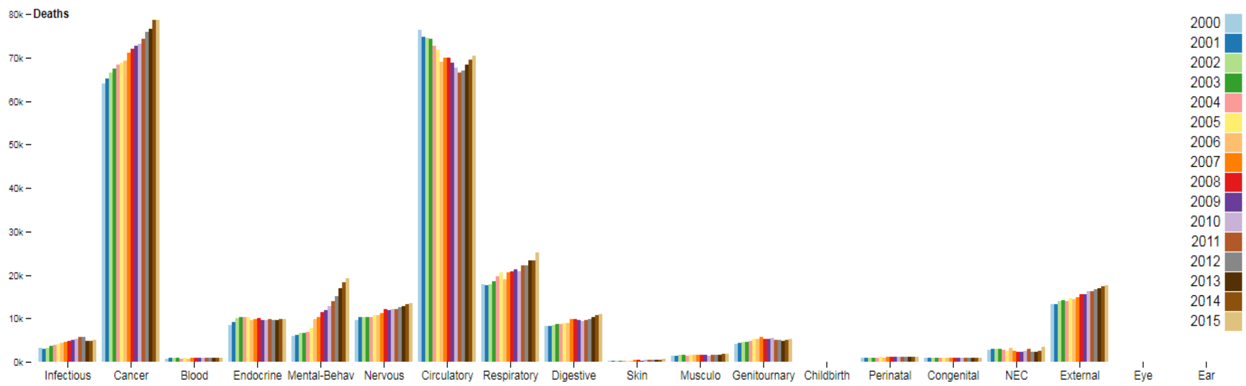



*Note:* Sourced from Shaffer et al. (2018).

In Figure 4.1, the observer can compare systolic and diastolic blood pressure levels and find patterns over time using data visualization.

**Figure 4.2**

*Large Scale Data Visualization Showing the Number of Deaths due to Various Illnesses*




*Note:* Sourced from Government of Canada (2017).

From 2000 to 2015, the above data visualization depicts the number of deaths due to various ailments, allowing the viewer to study and draw conclusions about the data. Vast amounts of data are presented concisely in this visualization allowing the user to conclude by viewing a single chart.

According to Li (2020), readability, recognizability, and meaning are three fundamental characteristics of a good data visualization. Readability describes how information is presented clearly and how simple it is to comprehend data from a visualization. The term recognizability relates to the capacity to recognize the data visualization's features, background information about the visualization, and existing content-related knowledge. Meaning encompasses the ability of data visualization to convey information and the process of concluding it. Readability, recognizability, and meaning influence an observer's ability to create new associations, logical interpretations, and perceptions (Li, 2020). Different strategies can be employed to extract information from data visualizations. These strategies include finding the mean or average of data, finding outliers and determining the range (difference between highest and lowest values in a data set), finding correlation in scatter plots or identifying trends, and categorizing data into subgroups or clusters (Szafir et al., 2016).

Based on the study by Borkin et al. (2013), the reasons for using data visualization are as follows.

- To create visualizations that distinctly represent data.
- To summarize a significant amount of quantitative data in the form of a diagram such as charts, maps, or graphs and to develop data representations that convey a message.
- To analyze the quantitative information and formulate hypotheses.
- To direct a statistical examination of data and ensure its authenticity.

Bikakis (2018) highlights the following reasons for using data visualization

- To explore and analyze data to generate an understanding
- To spot interesting trends and patterns
- To identify any unknown information or outliers
- To establish associations between different elements presented in the visualization
- To make logical judgements
- To determine any underlying reasons that may have caused the data to be drawn

The above-stated reasons for using data visualization by Bikakis (2018) and Borkin et al. (2013) imply the significance of critically observing and analyzing a visual to determine what the data means, represents and concludes. When a user reads or examines a visual display, the human cognitive system interprets the image to comprehend meaningful information (Li, 2020). While analyzing a visual, numerous visual aspects of the image are freely added to the mind, and this is by making associations with the existing schema (understanding the topic), which produces new information. (Borkin et al., 2013). Making linkages and associations with the current schema to produce new information can be deduced as a way of meaning production.

According to Liang and Sedig (2010), mathematical information rapidly develops in amount and complexity. Learners will be expected to master more complicated topics faster and at a younger age soon. The ability to envision conceptual and relationships is crucial to mathematical thinking and, as a result, learning, and this is generally challenging for young learners (Liang & Sedig, 2010). Liang and Sedig (2010) explain that visualization on paper or board provides limited exploration opportunities since students must visualize and manipulate visuals in their minds. This draws attention to new possibilities with visualization tools in education. Interactive visualization tools are external entities that help enhance thinking and make sense of the data presented through visual means (Liang and Sedig, 2010). According to Liang and Sedig (2010), the following are some of the advantages of utilizing interactive visualization tools:

- Information is displayed in the form of visual representations or visualizations.
- They allow students to edit or interact with these visuals through the use of a human-computer interaction and operate as a medium to supplement learning.
- Students can control the pace and direction of their study and gauge the time as needed since the visualization is digitally accessible.
- The presentation and interactive features of visualization tools enhance comprehension, learning and encourage student engagement.
- The inclusion of interactive visualization enables students to construct representations, formulate and test hypotheses, analyze their findings, interpret and make sense of their findings, and draw their conclusions.

## Chapter 5. Mathematical Visualization in Education: A Look at Infographics

The benefits of mathematical visualization for education brought my attention to pedagogical tools that could use visualizations and infographics as instructional tools. The emphasis of this section is on infographics, including types of infographics, storytelling features of infographics, and a study of three common infographics. The ability of infographics to convey information through storytelling and how to develop infographics to convey information through storytelling are discussed. The analysis of three general infographics will show what details to look for in the context of reading infographics and how it will help the reader comprehend the narrative. It is also examined whether the data provided is sufficient to support the message given by the infographic and how critical questions should be asked about it.

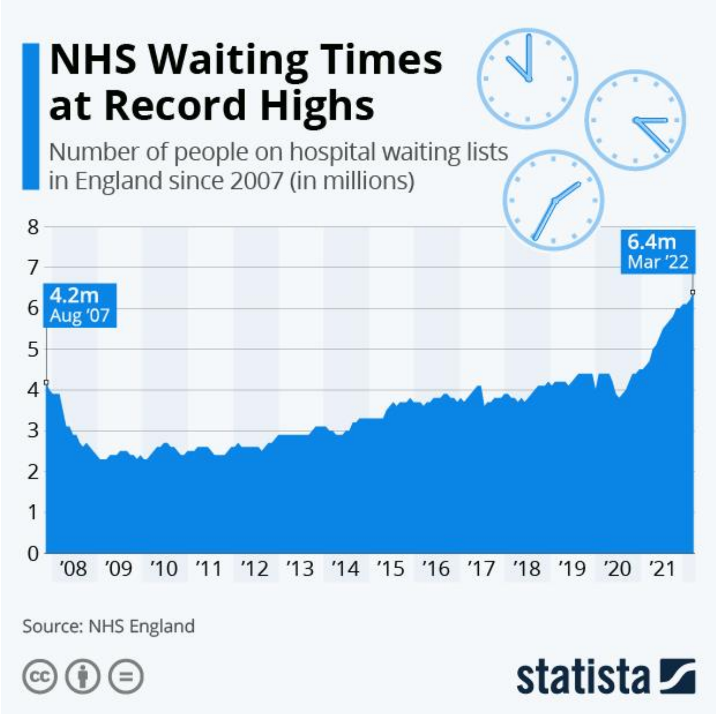
### 5.1 What are Infographics?

Infographics are visual representations of data that use signs, pictures, maps, graphics, charts, text or a combination of such elements to convey complex information clearly, quickly and in a logical manner (Abilock & Williams, 2014; Afify, 2018; Naparin & Saad, 2017; Siricharoen, 2013; Yildrim, 2016). Flowcharts, narratives, visuals, or a combination of these elements can be used in infographics to communicate messages (Naparin & Saad, 2017). Infographics could employ various visual elements such as images, illustrations, typography, and maps to convey information (Dur, 2014). According to Dur (2014), an infographic may include a single data visualization or several data visualizations and are designed to provide an organized and clear visual presentation of complicated and irregular information. Infographics are becoming more widely used and commonly seen in commercial and educational settings (Yildrim, 2016) to businesses, news and social media sites (Naparin & Saad, 2017). Infographics can also be seen in medical clinics, schools, government websites, and personal websites, demonstrating their ubiquitous use.

There are four varieties of infographics described by Siricharoen (2013). These include statistical based, timeline based, process based, and geography based infographics. Infographics can also include a combination of these varieties such as statistical based, timeline based, process based, or geography based. Siricharoen (2013) distinguished the varieties based on what context they are conveying as well as the visual approaches that are most relevant. Statistical based infographics include diagrams, charts, graphs, tables, lists or a combination of these elements to present facts and figures (Siricharoen, 2013). For example, the infographic of National Health Service (NHS) waiting times depicted in Figure 5.1 is considered statistical based because it presents statistical data and a graph depicting the number of individuals (in millions) on England's hospital waiting lists since 2007.

**Figure 5.1**

*Statistical Based Infographic*

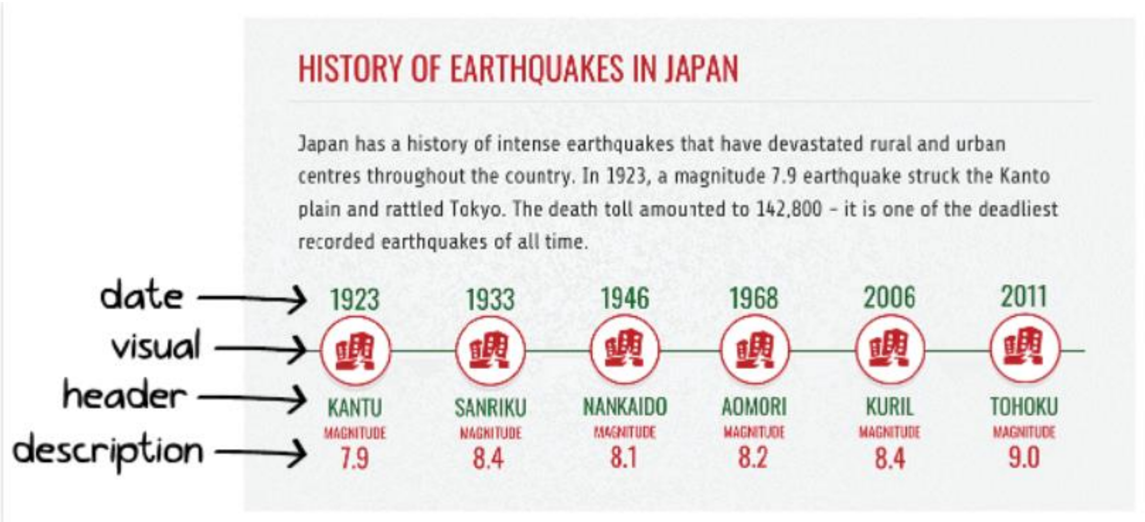



*Note:* Sourced from NHS England (n.d.).

Timeline Based Infographic shows a course of events in chronological order (Siricharoen, 2013). An example of a timeline based infographic is shown in Figure 5.2. This infographic shows the occurrences of earthquakes and magnitude in Japan from 1923 to 2011. The date, visual, header and description point out the details associated with the occurrence of earthquakes.

**Figure 5.2**

*Timeline Based infographic*

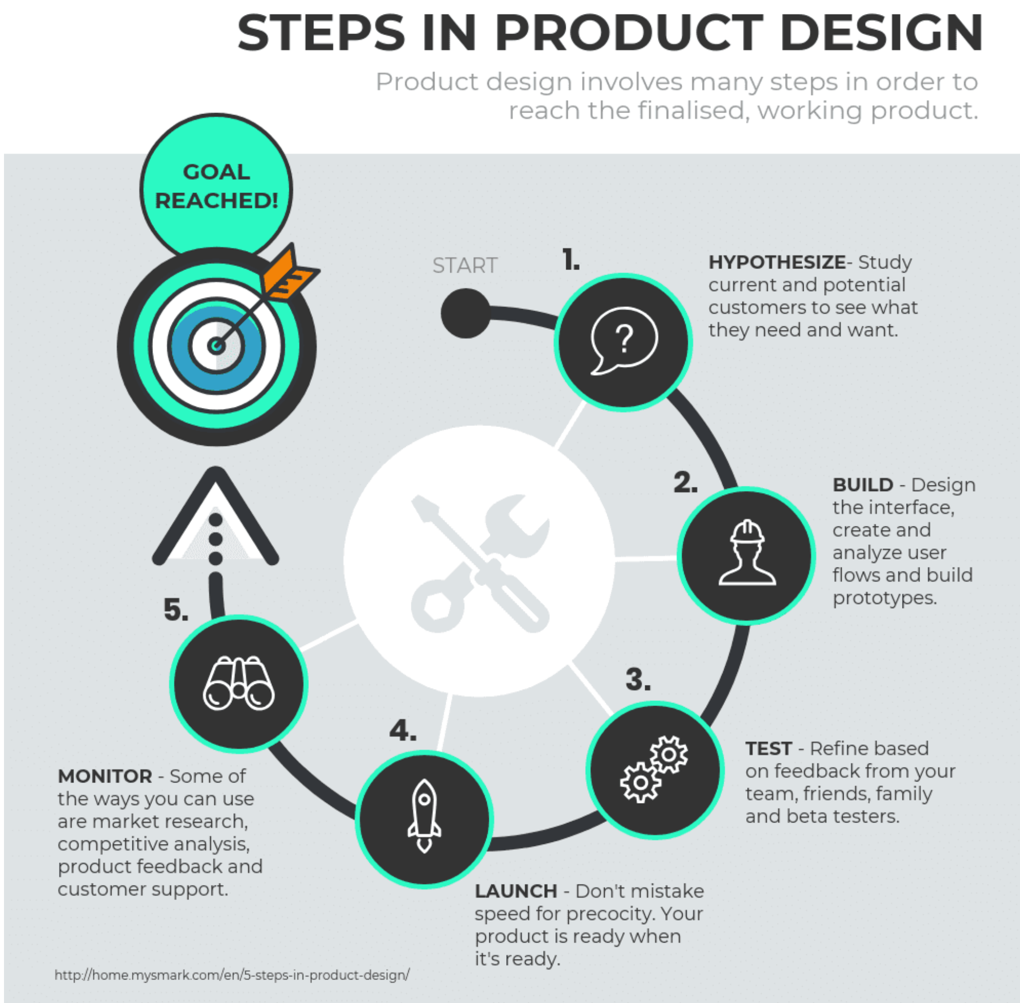



*Note:* Sourced from Vennagage (2022).

Process based infographics explain processes which help the reader understand them (Siricharoen, 2013). The infographic in Figure 5.3 shows the multiple processes involved in product design. The five processes of product design, hypothesize, create, test, launch, and monitor are explained in this example infographic. The picture also depicts the development of processes, beginning with hypothesizing and progressing through the phases to reach the goal.

**Figure 5.3**

*Process Based Infographic*

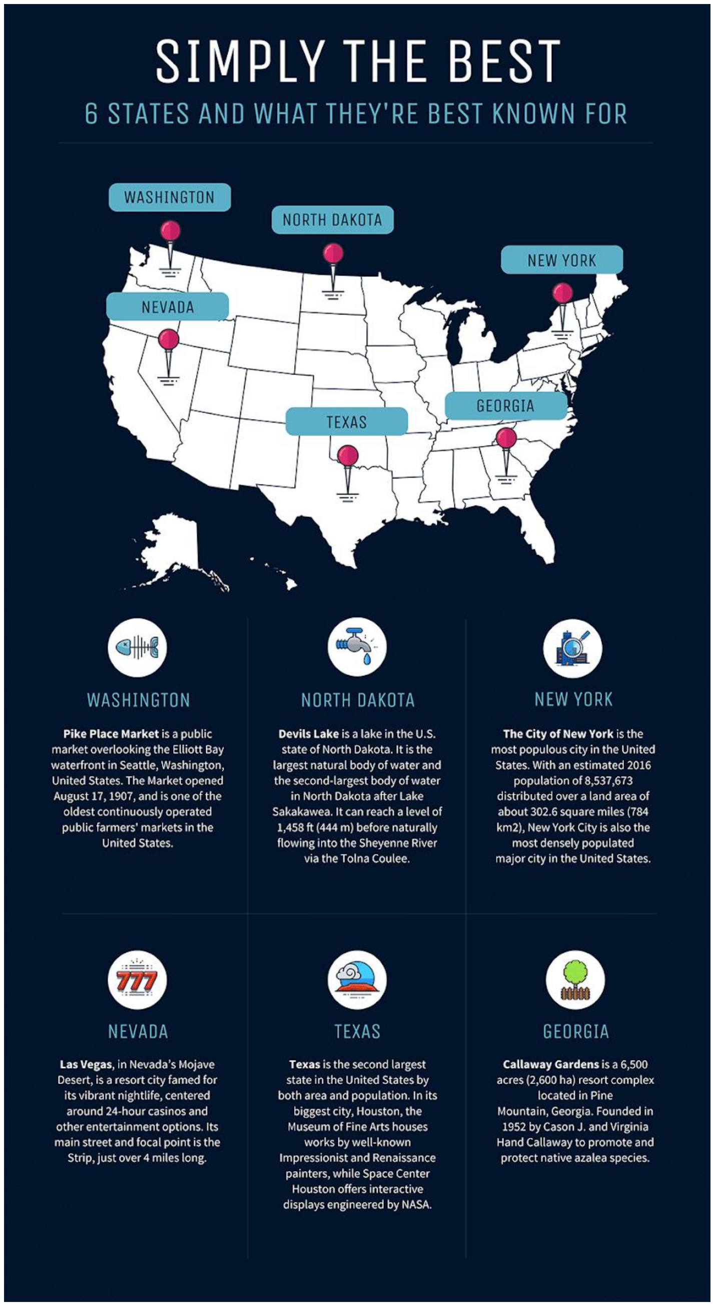



*Note:* Sourced from Vennagage (2022).

Geography based infographics show location or geography to display landmarks, and maps (Siricharoen, 2013). Figure 5.4 shows an example of a geography based infographic. In the infographic in figure 5.4, the map of the United States of America is shown pointing out six states and a general description of a landmark is provided.

**Figure 5.4**

*Geography Based Infographic*




*Note:* Sourced from Vennagage (2022).

### 5.2 Storytelling Feature of Infographics

Much of today's information is delivered in narrative form, so understanding narrative frameworks are critical to comprehending the information presented through visuals (Dunlap & Lowenthal, 2016; Williams, 2019). Infographics convey information by concisely telling a story (Davidson, 2014; Dur, 2014; Islamoglu et al., 2015; Smiciklas, 2012). Naparin and Saad (2017) explain that many infographics include a three-part story framework: an introduction, key message, and conclusion. Infographics narrate a story cohesively using visuals and text and integrating data visualization and graphic design (Naparin & Saad, 2014). According to Dur (2014), infographics can cover a wide range of topics and tell a more complete story than a single data visualization by incorporating different visual forms such as pictures and maps into the visual story presentation. Storytelling entails employing rhetorical tactics such as contrasts, comparisons and analogies to illustrate and convey the story's ideas (Islamoglu et al., 2015; Krum, 2014).

Abilock and Williams (2014) explain how to develop an infographic using a *storyframe* to organize important events, portray the events, show their progression and point out the relationships between specific events in the constrained area of an infographic. An infographic *storyframe* uses a combination of *storyboarding* and *wireframing*. A storyboard is a series of squares used to organize ideas or visuals, such as the pictures in a video, photo session, multimedia news article, puppet show, or other forms of storytelling. Sticky notes on paper can be used to create an infographic *storyframe* that shows the different events. Lines, arrows, circles, and other symbols can be used to depict the link between events. A *wireframe* shows how an infographic can be created digitally and graphically maps the image on a webpage. A *wireframe* represents a page's layout that focuses on the allocation of content space, the placement of various elements according to priority, and displays how different elements interact. According to Abiliock and Williams (2014), students may be allowed to utilize *storyframes* to design their infographics. They may experiment by rearranging their *storyframes* multiple times to see which presentation best meets their learning objective.

## 5.3 Analyzing Infographic Stories

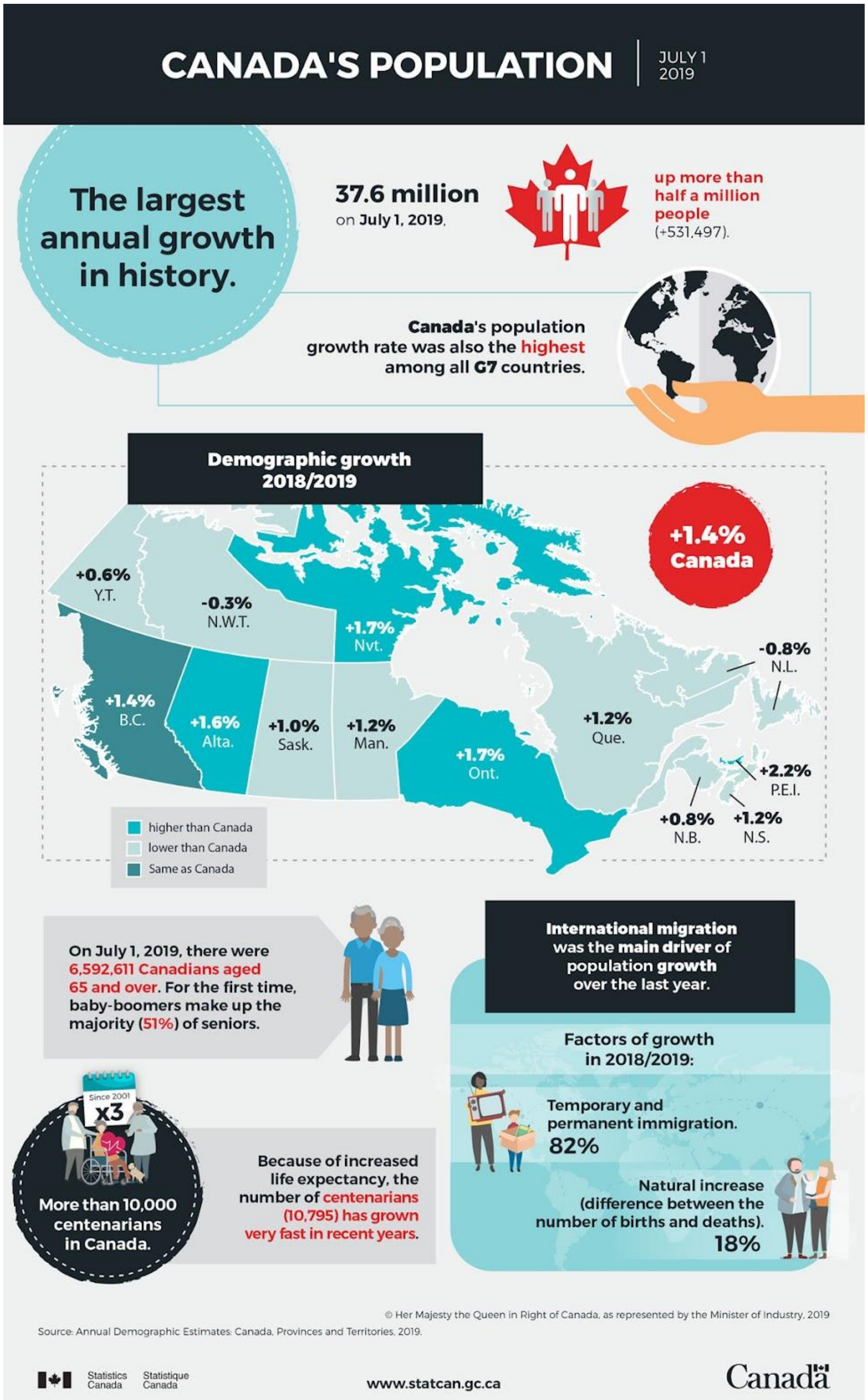
Three general examples of infographics are chosen and analyzed in this section. This analysis will demonstrate what information to search for in the given context when reading infographics and how it will aid in understanding the story.

### *5.3.1 Infographic 1: Canada's Population*

Statistics Canada published the infographic in Figure 5.5 about the Canadian population in 2019 and the factors that led to the most significant annual growth in population in history.

**Figure 5.5**

*Canada's Population*




*Note:* Sourced from Statistics Canada (2019).

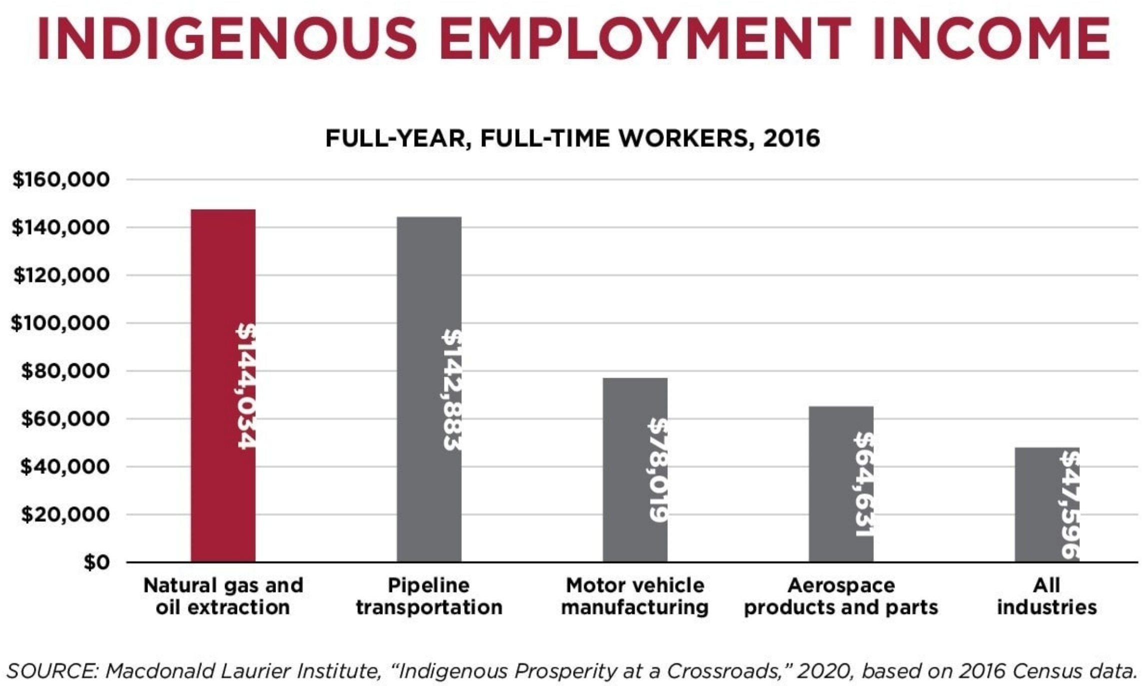
The demographic growth of Canada is visualized in this infographic using the map of Canada. The percentage of population growth in each province and territory is presented clearly and orderly, allowing for easy reading and comprehension. The information shows how each province's demographic growth influenced annual population increase and which provinces are growing faster, slower, or at the same rate as Canada overall. The specificity and clarity of information presentation allow viewers to perceive new information and visually recognize the new data, in this case, the percentage increase in population for each province and territory. The title relates to this message conveyed, and the textual information, which includes the facts presented, adds necessary supporting information to complement the numerical data (increase in population) presented in the map of Canada. Hence, the infographic's textual and visual content complement one another in understanding the story it conveys. Thus, the information and visualization aid in conveying the message behind the data, which is to inform the readers that the annual population growth resulted from increasing population rates across Canada.

### *5.3.2 Infographic 2: Indigenous Employment Income*

Macdonald Laurier Institute published the infographic in Figure 5.6 based on 2016 census data. The infographic depicts the Indigenous employment income from employees who worked full-time in 2016.

**Figure 5.6**

*Indigenous Employment Income*




*Note:* Sourced from Macdonald Laurier Institute (2020).

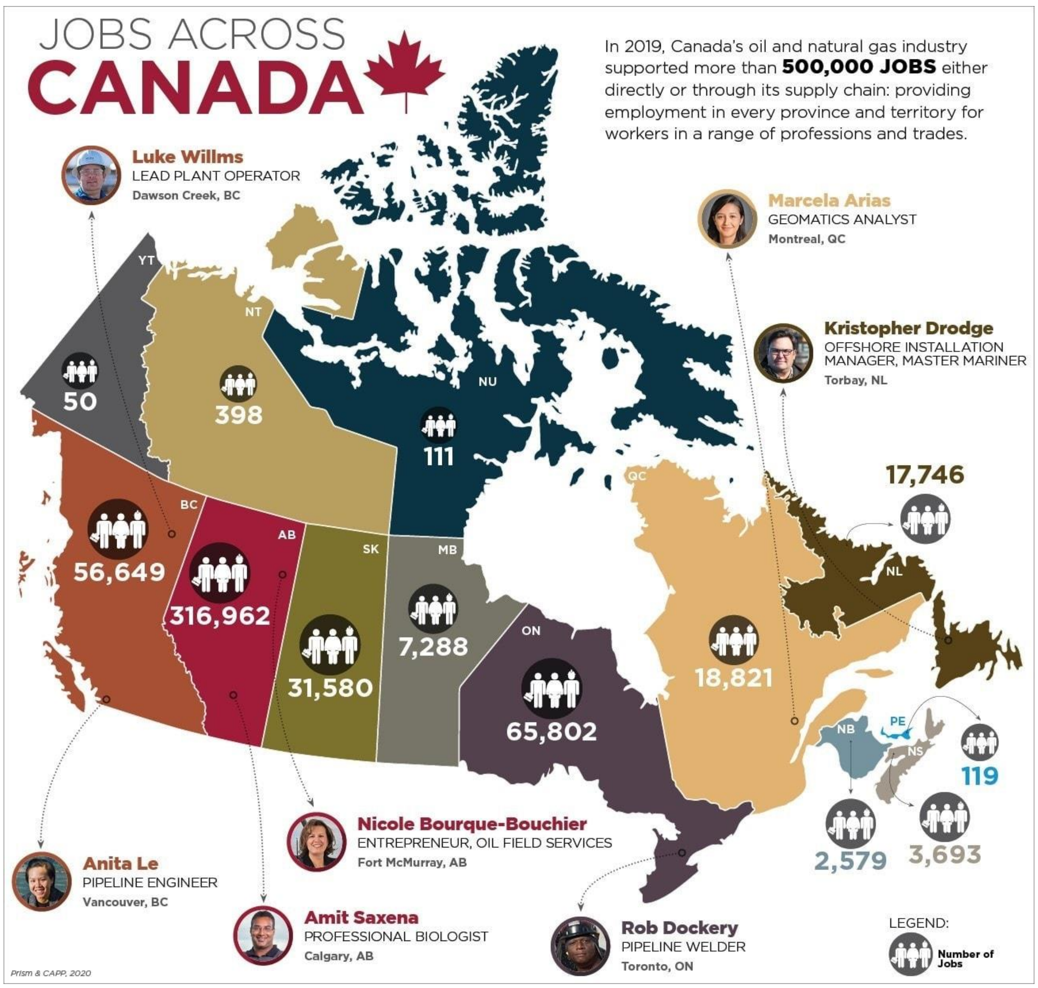
The infographic in figure 5.6 gives the indigenous employment income for individuals who worked in natural gas and oil extraction in comparison with pipeline transportation, motor vehicle manufacturing, aerospace products and parts, and all industries. This data is visualized using a bar graph. It may be noted that the difference in income from natural gas and oil extraction ($144, 034), and pipeline transportation ($142, 883) is $1151 which is not a notable difference. Furthermore, why is data represented in multiple different colours? Even though there is not a significant difference, the income from natural gas and oil extraction is highlighted in red while the other incomes are highlighted in gray, and this adds an emphasis on the data presented using the red bar. This also draws attention to the visual aspects of this infographic particularly the choice of two different colours, red and gray and as a result there is a lack of consistency in how the bars are portrayed. Additionally, to enhance readability and for easier reading, the revenues might be positioned in the middle of the bar graph rather than towards the margin. Furthermore, data gives the impression that full-time employees who worked in such industries earned high incomes. However, the graph does not state the number of full-time workers which is important for generating a valid justification about the data. It is possible that only a small number of people earned the amounts shown in the graph. Knowing this number will assist the reader in determining how many indigenous people earn the above-mentioned income in each sector. To build a comparison analysis and to generate a rational interpretation, more information is needed. As a result, the infographic in Figure 8 is deficient in essential information and lacks fair display of data due to non uniformity in bar colors. The narrative that the infographic is trying to convey is that full time employees from the Indigenous community working in the natural gas and oil extraction industry earned the highest income in comparison to the other sectors as shown in Figure 5.6. However, the question that is left unanswered is how many employees earned the specified incomes in each industry? This number is important for all of the industries specified in the infographic as this helps to make a meaningful judgment based on data from all industries. This is missing from the infographic and this information is critical in making the conclusion that full time employees from the Indigenous community working in the natural gas and oil extraction industry earned the highest income.

### *5.3.3 Infographic 3: Jobs in the Oil and Gas Industry*

Prism and the Canadian Association of Petroleum Producers (CAPP), (2020) published the following infographic in Figure 5.7, which states the number of jobs supported by the oil and gas sector across Canada.

**Figure 5.7**

*Jobs Across Canada*




*Note:* Sourced from Prism & CAPP (2020).

In figure 5.7, the data about jobs in the oil and gas industry is visualized on the map of Canada. It is reported that the oil and gas industry supported over 500,000 jobs in total, giving the impression that the industry generated many jobs. This raises the following questions: Are all 500,000 jobs full-time positions? Is part-time, temporary, and casual employment included in the 500,000 jobs? Data on the number of full-time, part-time, temporary, long-term, short-term, casual positions and seasonal work is required to develop a rational interpretation and to substantiate the statement. Therefore, the infographic in figure 9 lacks the necessary information to make a meaningful interpretation.

The analysis of the three infographics in Figures 5.5, 5.6 and 5.7 illustrates the importance of posing critically minded questions about the story being conveyed by the infographic and whether or not the data presented is adequate to support that message. As shown in Figures 5.6 and 5.7, infographics may be developed to portray information in a misleading manner and convey certain intended narratives, such as by obscuring or excluding relevant data. The ability to critically observe visuals, assess data, and spot questionable or incomplete information is necessary. The information offered in the form of numbers, facts, or assertions and how they are depicted in the visualization can help assess whether data is misrepresented; therefore, it is crucial to look at infographics with a critical eye and consider whether further information is necessary to make a meaningful interpretation. Furthermore, it is also essential that viewers are not misled by the narrative conveyed. In the next section, I explore the educational applications of infographics in the classroom and how they can be used to help students develop critical thinking abilities.

## Chapter 6. Educational Benefits and Developing Infographics for Education

This section explains how infographics may aid in learning and how to develop infographics for educational purposes. I organize this section into two parts:

- How infographics aid in learning
- Developing infographics for educational purposes

### 6.1 How Infographics aid in Learning

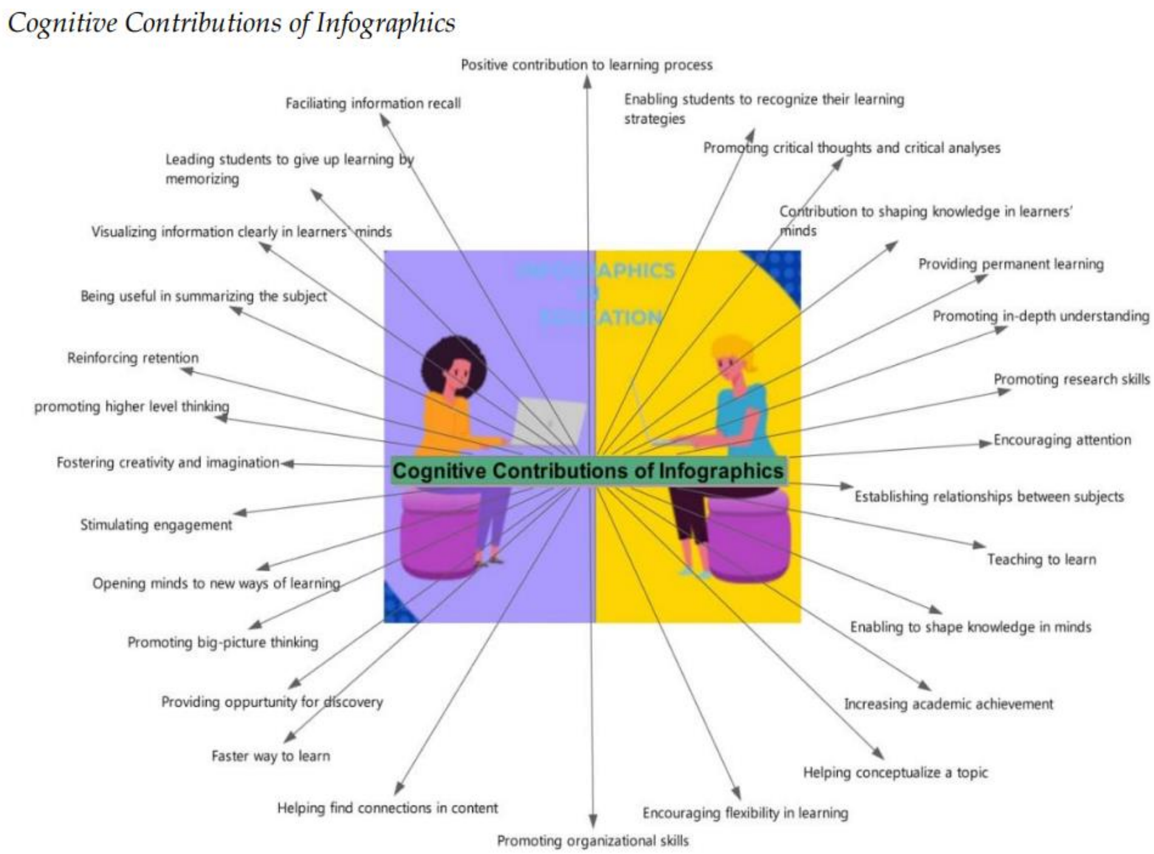
This section discusses research literature which examines how infographics have been used to facilitate learning. Infographics lower cognitive load by delivering information clearly and succinctly. Infographics aid in comprehending information, specifically abstract and complex information, and this is due to the ability of infographics to incorporate text and visual communication elements. Furthermore, infographics also aid in memory and recall of information which can be attributed to the design features. The following discussion will explore how infographics assist learners in cognition, comprehension, and memorability.

#### *6.1.1 Cognitive Benefits of Using Infographics*

The study by Elaldı and Çifçi (2021) gives an overview of the cognitive contributions of infographics. They conducted a meta-analysis of 12 empirical research between 2016 and 2021 about the influence of infographics on academic performance, and based on the analysis, employing infographics in education improves academic performance by promoting conceptual understanding, research skills, critical thinking, organizational skills, creativity, aiding in memory and recall of information, enhancing attention and engagement, and facilitating a faster way to learn. This draws attention to an overview of the benefits in the cognitive domain of using infographics in teaching and learning. This is shown in Figure 6.1 and is retrieved from the article by (Elaldı & Çifçi, 2021).

**Figure 6.1**

*Cognitive Benefits*




*Note:* Sourced from Elaldı & Çifçi (2021, p. 105).

Yildrim (2016) addresses the instructional power of infographics and the infographics' structure, design, reader approaches, and preferences when used for teaching and learning by the study's participants. According to Yildrim (2016), infographics are instructional tools that can be used to teach a topic. The primary objective of infographics is to convey information, and infographics can be used to present a wide range of information comprehensively. Due to this concise presentation of information, learners need to spend less time and effort reading and comprehending the content, which lowers their cognitive load as opposed to reading through data from multiple pages. Researchers suggest that infographics can be used to communicate content concisely in a limited space (Dunlap & Lowenthal, 2016; Elaldı & Çifçi, 2021) while still conveying essential information (Yidrim, 2016).

Dunlap and Lowenthal (2016) conducted a study investigating the factors that make a good infographic. The article emphasizes the power of visuals and infographics to teach and suggests recommendations on how to use infographics in education. According to Dunlap and Lowenthal (2016), it is possible to harness the power of visuals and use visualization to teach by incorporating images into infographics. Infographics' ability to explain information succinctly and reduce cognitive load can be complemented by the ability of visuals to instruct. Additionally, when a new concept is introduced and learners are unfamiliar with it, images are beneficial since they help students become aware of the idea (Dunlap & Lowenthal, 2016). Infographic visualization reduces cognitive load because learners do not have to put as much effort into creating their own visualization because it is already offered in the infographic (Yildrim, 2016). However, non-instructional images and unnecessary aesthetic graphics may be avoided from infographics because they may increase the cognitive burden (Yildrim, 2016). This may be because such aspects might reduce the readability of information and divert readers' attention from the vital information. Through visuals, infographics facilitate communication and comprehension of new topics and reduce the cognitive load (Dunlap & Lowenthal, 2016).

### *6.1.2 Comprehension of Information*

Dunlap and Lowenthal (2016) explain how infographics can be used to convey abstract and complex information, and this is by incorporating visual representations that show the context in its entirety. Whether the context is to explain a process, story, summary or to compare and contrast, it may be presented in a manner that enables the reader to visualize the context completely. For example, a process-based infographic, as shown in Figure 5, may be used to present the sequential progression of processes. This diagram depicts the processes and the different steps involved and may be presented linearly if there is a linear progression. Such presentations can aid in the efficient, accurate, and unambiguous expression of abstract ideas and complex content in infographics that would otherwise demand a lengthy narrative.

Another factor that aids in comprehension is the structure of graphics in infographics. The pictures in infographics operate the best when the layout is well-organized and ordered, displaying links between different components and as this helps in comprehending the underlying narrative or plot (Dunlap & Lowenthal, 2016). Researchers suggest that a compelling visual represents the relationships between distinct elements of the whole, how they connect and convey the information in its entirety, and data may be presented in this manner in infographics to enhance comprehension (Alshehri & Ebaid, 2016; Dunlap and Lowenthal, 2016; Yildrim, 2016). Furthermore, to convey information in its entirety, images and critical concepts that align with the learning objective may be chosen (Yildrim, 2016). Also, the key concepts must be well-organized so that the reader can make connections and associate the content with the visuals to frame a complete message (Yildrim, 2016). According to Yildrim (2016), such links enable students to make new associations that add new data to existing schemas (knowledge/understanding about the topic), which helps to develop new schemas. Such new schemas aid in building a more profound knowledge about the presented topic and lead to new learning (Yildrim, 2016).

The study by Alshehri and Ebaid (2016) examines how interactive infographics, including features such as visuals, video, audio and animation, support delivering abstract and complex information in mathematics. The study's objective was to develop a paradigm for instructional design using interactive infographics to teach mathematics in primary schools.

Another goal was to evaluate how effectively mathematics is taught in elementary schools using the interactive Infographic. The study used a semi-experimental methodology with two groups: 15 students in the experimental group learned using interactive infographics. In contrast, 17 students in the control group learned using a standard method focused on text. Pre and post-exams were administered for two groups. Based on the study findings, the group of students who studied with interactive infographics performed better than those who studied using traditional teaching methods. Alshehri and Ebaid (2016) point out that conventional text-based teaching methodologies, especially in the early stages of teaching mathematics, increase the abstract nature of mathematics and could generate student reluctance.

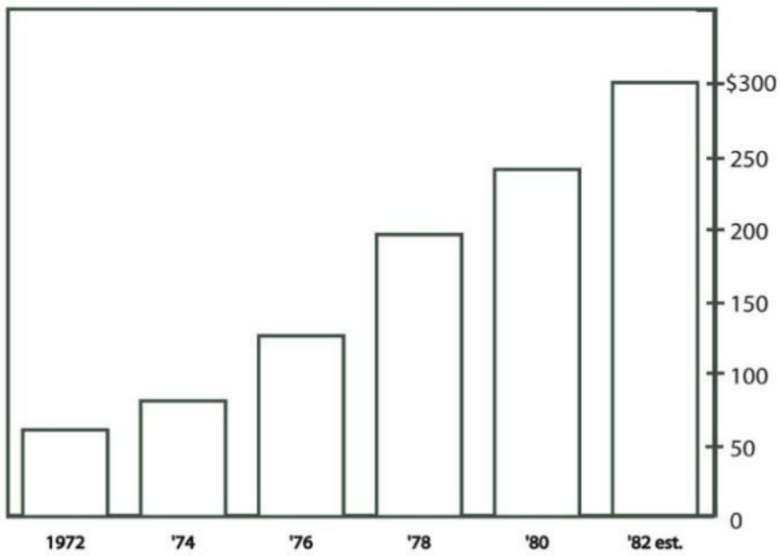
Alshehri and Ebaid (2016) and Smiciklas (2012) shared the features of interactive infographics and how they aid learning. Interactive infographics incorporate visuals, visual interactive activities, and multimedia elements to graphically express information. Interactive infographics promote learner engagement, and the visuals, text, videos, and animation capture the learner's visual attention. Videos and animation make learning more realistic, dynamic and engaging, increasing the desire to learn and explore. According to Yildrim (2016), when infographics use audio and visuals, it aids in the learning process because it activates the brain's audio and visual channels. Madar and Buntat (2011) found that interactive multimedia improved students' arithmetic learning by increasing the interaction with the instructor and visual graphics. According to the study by Alshehri & Ebaid (2016) and Madar & Buntat (2011), interactive multimedia can improve the effectiveness of mathematics teaching and learning. Furthermore, Alshehri and Ebaid (2016) draw attention to the intriguing structure of infographics, which incorporates text, visuals, and other interactive aspects, and how this increases learners' enthusiasm and motivation to study while improving their math skills.

### *6.1.3 Memorability*

Another aspect of infographics is aiding information recall and highlighting design elements that help in memorability. Researchers suggest that infographics assist readers in remembering the information presented, and this was mainly because of the power of visuals to teach and convey information. (Alshehri & Ebaid, 2016; Borkin et al, 2013; Dunlap and Lowenthal, 2016; Yildrim, 2016). Based on the study's findings by Yildrim (2016), participants could remember the information communicated through infographics. According to Yildrim (2016), this could be due to the inclusion of pictures and text, which activates the brain's aural and visual channels. Furthermore, organizing information in an orderly and unambiguous manner by emphasizing essential topics also aids memorability (Yildrim, 2016). The study by Bateman et al. (2010) examined how aesthetics and design features affect graphical interaction in terms of interpretation accuracy and memorability. The study used 20 charts, and the data from the charts were presented as an enhanced version (with visual embellishments such as non-essential imagery and decorations) and a simple version. Figure 6.2 represents an example of an enhanced version and simple version of a graph which depicts a rise in expenses, and the diagrams are retrieved from the article by Bateman et al. (2010).

**Figure 6.2**

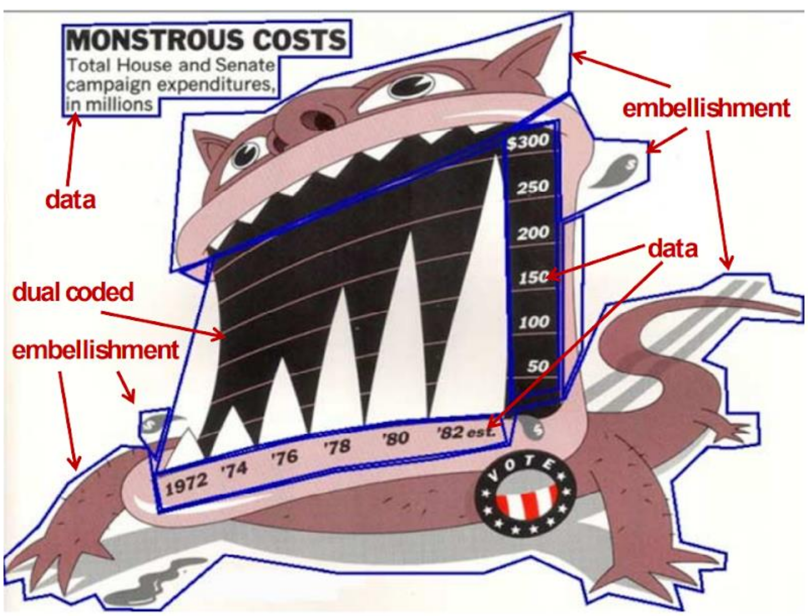
*Simple Version of the Graph*




*Note:* Sourced from Bateman et al. (2010, p.2573).

**Figure 6.3**

*Enhanced Version of the Graph*




*Note:* Sourced from Bateman et al. (2010, p.2578).

In Figure 10, the enhanced graph version included cartoon images and visuals that connect to the context. For instance, the shape of the monster's mouth and teeth signifies rising expenses. Based on the study's findings by Bateman et al. (2010), participants demonstrated the same accuracy in describing embellished graphs as the simple version of the graph. However, the ability of the participants to remember information after 2-3 weeks was much higher for the embellished graphs. The participants retained the theme and nuances of the embellished graphs, and they preferred the embellished graphs more than the simple version of graphs (Bateman et al., 2010).

In line with Bateman et al. (2010), Borkin et al. (2013) conducted a similar study, which investigated the various modes of visualization and their link to memory levels. The study comprised 2,070 single-panel visualizations, which are stand-alone visualizations with one panel, do not have an accompanying article or paper and are thus solely responsible for telling the entire story through the visualization. Examples of single-panel visualizations are graphics containing single visualizations or representations (single chart or graph). The study samples were gathered from various sources, including news media, government publications, scholarly articles, and infographic providers. Figure 6.3 shows an example of visualizations from infographic providers arranged in the order of highest to lowest memorability.

**Figure 6.4**

*Visualizations From Infographic Providers*


*Note:* Sourced from Borkin et al. (2013, p. 9).

In this study, hundreds of infographics samples recorded their memorability scores, and the findings revealed that viewers have a constant preference for which visualizations they remember and which they forget. Based on the results of the study by Borkin et al. (2013), the following aspects explain what makes visualizations memorable and a visualization's capacity to retain information in an observer's mind. People tend to remember visuals identifiable to humans, such as scenes, objects, and people. The natural appearance of visualizations and rounded characteristics of visuals aid memorability. Memorability scores for pictorial, grid/matrix, trees and networks, and diagrams were much higher than for conventional graphs like circles, area, points, bars, and lines (Borkin et al., 2013). The presentation of mathematical concepts by connecting them to everyday applications also enables students to organize the information in their memory and recall it later (Alshehri & Ebaid, 2016). How people tend to remember objects/scenes/real-world applications in infographics could be correlated to how connecting abstract and complex information to real-world applications and presenting it as a visual in infographics aids comprehension. According to studies by Bateman et al. (2010) and Borkin et al. (2013), representations with more clutter and embellished information were more recalled than visualizations with fewer visuals. This explanation is contrary to Yildrim's (2016) claim that aesthetic graphics and non-instructional images might raise the cognitive load, which may be because it reduces readability and diverts readers' attention from the critical information. Maintaining the correct balance between the relevant material on which readers should concentrate, and the clutter, embellished information, non-instructional visuals, and attractive graphics is crucial. This can call for meticulous organization and planning.

Infographics convey information to students in a way that is easier and faster to understand than standard text techniques (Alshehri & Ebaid, 2016; Smiciklas, 2012; Naparin & Saad, 2014; Siricharoen, 2013; Yidrim, 2016). Learners exercise less cognitive effort to comprehend infographics information than text-based learning or traditional teaching methods (Alshehri & Ebaid, 2016; Yildrim, 2016) and interactive infographics outperform standard text-based teaching strategies (Alshehri & Ebaid, 2016). Davidson (2014) pointed out that when infographics were used to teach, students connected more profoundly with infographics than with text or PowerPoint presentations and were engaged in learning. Using infographics in teaching and learning promoted student engagement (Alshehri & Ebaid, 2016; Davidson, 2014). Researchers suggest that infographics can be used to deliver abstract lessons in a concrete, clear and understandable manner (Alshehri & Ebaid, 2016; Dunlap & Lowenthal, 2016; Naparin & Saad, 2017; Smiciklas, 2012). Borkin et al. (2013) point out that learning using infographics aids in memorability and realizing what makes a graphic memorable is merely the first step toward creating excellent data visualizations. The most crucial components of the data or trend should be remembered, not simply any part of the representation (e.g., chart garbage, which refers to unnecessary visuals or visual embellishments). However, a more memorable image does not always imply that it is more understandable (Borkin et al., 2013). Critical observation, critical thinking skills, and reasoning are necessary to understand and interpret visuals, as discussed in the earlier section about visual literacy. It may be stated that infographics serve as a medium through which the learner is presented with information concisely, clearly and in a manner that is easier to understand. The intriguing structure of infographics that mixes text and pictures aid in comprehension. Also, well-chosen images and the design of infographics aid in memorability and recall.

**6.2 Developing Infographics for Educational Purposes**

The information in this section could assist educators in determining the factors to consider while developing infographics or searching for pre-made infographics for teaching and learning. The potential of infographics to promote critical thinking skills, the elements that influence the instructional power of infographics, design aspects and reader preferences are discussed. Infographics entail a form of reading and viewing experience that stimulates critical thinking and reasoning (Dunlap & Lowenthal, 2016; Naparin & Saad, 2017). The article by Mamolo and Ibeh (2021) focuses on harnessing the capacity of infographics as a tool to encourage students to apply their critical understanding of mathematics to unravel information from raw data or visual representations. Asking questions and using critical thinking skills to unpack mathematical and nonmathematical content in the stories will assist in making logical interpretations (Mamolo & Ibeh, 2021). Instructors can leverage the capability of infographics to teach critical thinking and reasoning abilities to students.

Davidson (2014) explains how students in her science class developed infographics to carry out a research project. As part of the project, students created infographics to present their findings, and Davidson explained how she facilitated the lesson. Initially, students were asked to search for three to five infographics about a topic and evaluate them to find the best infographic. Students were asked to defend their choices and present their findings to the rest of the class. Davidson asked guiding questions to identify how the images relate to the content and how images and content align with the learning objective. Discussions were conducted about what constitutes a good infographic, and the class collaborated to develop a template with specifications which outline factors to consider when developing infographics. The example of the specification sheet from the article is shown in Figure 6.5; students used the template in Figure 6.5 to construct their own infographic. According to Davidson (2014), through this project, students learned how to organize data, use critical reasoning to evaluate information, select what is relevant to support their point of view, and develop infographics.

**Figure 6.5**

*Specification Sheet*

FIGURE 3

**Specification sheet for coffee cup project.**

| Features to Include on K-Cup Infographic | Present, Missing or Needs Improvement |
| --- | --- |
| Shows creativity | |
| Tells a story | |
| Presents a position on the issue | |
| The information flows in an organized manner | |
| The information is clear and concise | |
| Uses charts, graphs, and statistics to present numerical information | |
| Addresses: What are K-Cups? | |
| Addresses: What are K-Cups made of? | |
| Addresses: What problems are caused by K-Cups? | |
| Addresses: How are K-Cups changing coffee consumption? | |
| Addresses: How can K-Cups be recycled? | |
| All information and images contribute to the message of the infographic | |
| Uses and cites multiple credible sources | |
| The title stands out and fits the contents and message | |
| The text can be read easily and contrasts with the background | |
| The amount of white space is appropriate | |
| Images are clear, relevant, original or copyright free, and credited | |
| Fonts, shapes, and colors are consistent throughout | |

*Note:* Sourced from Davidson (2014, p. 37).

According to Davidson (2014), the features of infographics include the presentation style infographics, which incorporates aesthetic elements such as colour contrast with the background and maintaining a consistent font, colour, and form. A title that stands out and is appropriate for the content, information clarity, the relevance of images and how they match with the content, and the choice of copyright-compliant pictures may be considered while developing infographics. Naparin and Saad (2017) point out that analyzing, evaluating, and designing are all necessary steps while creating infographics. An infographic should precisely reflect the facts, convey data visualization, and the overall design should be appealing and clear. Furthermore, information structure, content depth, and functionality may be focused on aesthetics while developing infographics.

Based on the findings of the study by Yildrim (2016), the components determining the instructional power of infographics are information-visual adaptation, information quality, visualization quality, visual quality, and design approach. Among these components, the essential component is information-visual adaptation, which is the reconstruction of information and images to line with the objective. The objective is the most significant element of an infographic, as it determines the scope of information presented. Information and images may be considered as parts of a whole and must fit together to convey the message or, in other words, to meet the objective in an infographic. Information quality and visualization are the other components influencing an infographic's instructional power. Yildrim (2016) points out that readers tend to look at the title and visuals before reading the content; therefore, images play an essential role in grabbing the reader's attention. High-quality images and colour choices influence the visualization and the quality of infographics. The design aspects include, following a consistency in layout and font, organizing information and visuals, and avoiding distractors and non-instructional information. These factors may be considered while developing infographics for teaching and learning. The quality of information, visuals, multimedia elements and layout are vital components that determine the quality of infographics (Yildrim, 2016).

Yidrim (2016) used a case study approach to find features of infographics that are preferred in learning. Based on the study's findings, participants considered infographics instructional tools that aid understanding, and they preferred infographics to plain text in education. Furthermore, digital infographics, interactive infographics and infographics with vertical layouts were preferred in teaching and learning. Yildrim (2016) states that may be due to the simplicity of use and the dynamic structure of digital infographics. Furthermore, participants favoured vertically oriented infographics. Yildrim (2016) explains vertically oriented infographics enable easy navigation. Infographics that take a long time to read are not preferred in learning. According to Yildrim (2016), this may be because readers prefer quick and effective communication over reading extensive texts.

Naidoo (2012) points out that teachers shall consider the instructional goal and learning outcome when selecting visual tools for teaching and learning. Furthermore, educators could develop infographics that can reduce the cognitive load, improve comprehension and aid memorability. Moreover, the characteristics that determine the educational capacity of infographics and design aspects and reader preferences for infographics in education could help educators create or select effective instructional infographics.

## Chapter 7. An Analysis of Three Infographics

This section analyzes three infographics using visuals with mathematical representations. To do so, I draw on research findings concerning visual literacy, mathematics literacy, and the benefits infographics may provide to teaching and learning. I organized the discussion based on the necessary visual and mathematical literacy skills and critical thinking skills required to analyze the story from the infographic. I organized this discussion into two parts based on specific mathematical and visual literacy competencies and the necessary thinking skills needed to analyze each infographic.

- Visual and mathematical literacy competencies: This section will analyze the mathematical and visual literacy competencies required to analyze the information in the infographics. These competencies were discussed in Chapters 2 and 3. It may be noted that the infographics in this analysis feature visuals with mathematical representations. The specific visual and mathematical literacy competencies are discussed, and I examine how the competencies can aid in deciphering the presented narrative. The competencies required differ depending on the graphic, with some requiring a broader range of skills and others requiring less. The discussion also covers mathematical concepts that can be taught utilizing the infographic.
- Critical thinking skills: This section focuses on how making sense of the infographic draws upon critical thinking and reasoning. This discussion begins with unpacking data from the infographic, including analyzing the visualization in depth to extract information. Furthermore, making associations between different elements such as numerical data, facts, graphs, charts, and visual aspects aids in developing a meaningful interpretation. Moreover, such associations also aid in identifying misleading

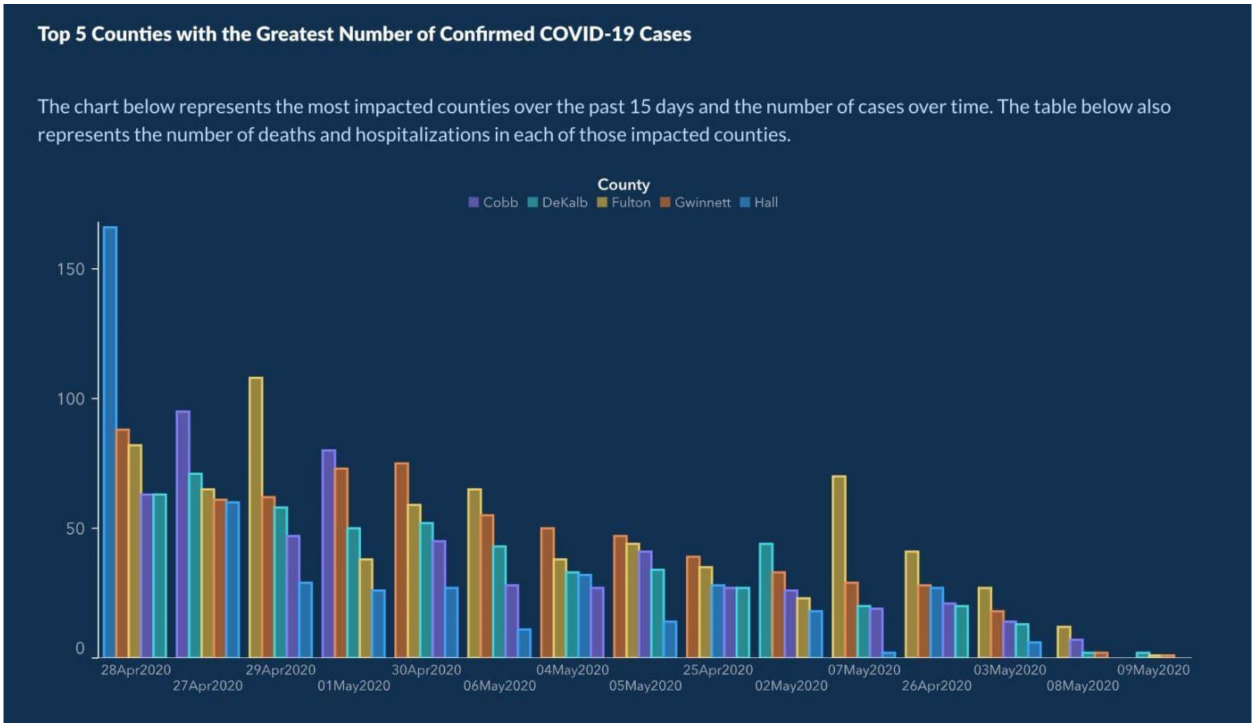
representations and the potential reasons that may have resulted in a misleading representation. Such an in-depth analysis aids learners in constructing meaning from the infographics by considering the evidence provided in the infographic. My analysis considers how teachers could use each infographic to encourage students to think critically about data and the narratives conveyed by their respective visual representations.

### 7.1 Infographic 1: The Top Five Counties with the Most COVID-19 Cases

The infographic in Figures 7.1 and 7.2 represents the top five counties with the most COVID-19 cases. The data visualization used in this infographic is a bar graph. Each county is represented by different coloured bars, with each bar representing the COVID-19 cases for the corresponding date. Since there are five counties, there are a group of five bars for each date. Figure 7.1 represents data over 15 days, and Figure 7.2 illustrates the data over 14 days. Data is succinctly presented through these infographics using a bar graph. As such, it makes it easier to visualize the information without going over vast amounts of data. The US Georgia Department of Public Health published the infographic in figure 7.1, which sought to display the top five counties with the greatest COVID-19 instances from April 25, 2020, to May 9, 2020.

**Figure 7.1**

*COVID-19 Cases From April 25, 2020, to May 9, 2020*




*Note:* Sourced from Georgia Department of Public Health (2020).

Figure 7.1 depicts a decrease in COVID-19 cases, shown by the decreasing height of multicoloured bars for each date. Thus, the visualization shows a decreasing trend.

- Visual and mathematical literacy competencies: The following visual literacy competencies are necessary to analyze this infographic:
    - Critical viewing (Avgerinou, 2003, 2007, 2009) is required in extracting information from this infographic. It may be noted that the dates under the bars are not in chronological order; instead, the dates between April 25th, 2020, and May 9th, 2020, are interleaved. Moreover, counties are not always depicted in the same order for each date but in case-by-case order, based on highest to lowest COVID-19 cases. For instance, in the first cluster of bar graphs on April 28th,

2020, the counties were arranged in the order Hall, Gwinett, Fulton, Cobb and DeKalb, whereas in the second cluster of bar graphs, the order of counties is Cobb, DeKalb, Fulton, Gwinett and Hall. The third cluster has the counties in order, Fulton, Gwinett, Dekalb, Cobb and Hall.

- Visual thinking and visualization are required to analyze the visual and generate meaning. Learners need to think and ask questions about the graphic to create ideas (Avgerinou, 2003, 2007, 2009; Aisami, 2015; Bamford, 2003; Botha et al., 2019; Felton, 2010; Murphy, 2011). A crucial question to ask is what the decreasing heights of bars on all dates mean for the data. Finding an answer to the above-mentioned question aids in developing the visual's narrative.
- Visual association and constructing meaning (Avgerinou, 2003, 2007, 2009) help the learner to develop meaningful and accurate interpretations from this infographic. In Figure 7.1, identifying visual elements that share a common theme is essential. Making visual associations between factors that have common ideas aid in generating meaning (Avgerinou, 2003, 2007, 2009). In this case, the commonality of the visual element is the decreasing height of bars for each date which conveys the message that COVID-19 cases are diminishing.

Critical viewing, visual thinking, visualization, association and constructing meaning contribute to understanding the information presented. The lack of consistency in dates and county representation is worth noting. This critical examination is necessary as it could lead the learner to question why the dates are not in chronological sequence, and the counties are not placed consistently in the representation. How does this layout affect the way data is presented? Such questions could help the student think critically about the topic.

- The following mathematical literacy competencies are necessary to analyze the infographic:
  - Representation skills are necessary to analyze this infographic (Ojose, 2011; Pugalee, 1999). In this case representation of the bar graph is analysed. The bar graph is missing labels for the X-axis and Y-axis, and this is a required detail. From the earlier explanation about visual literacy skills, it is understood that graph lack consistency in dates and county arrangement. Knowledge about representations, in this context, about graphs will enable the reader to understand that the lack of inconsistency in dates and county arrangement impact how data is presented and leads to a misleading presentation as shown in Figure 7.1.
  - Communication skills are required to comprehend the content presented (Ojose, 2011; Pugalee, 1999). Reading the type of communication from the visual or figure and making mathematical connections about the information from the graphic is required to develop meaning (Guzman, 2002). Figure 7.1 shows that the cases are diminishing, which is shown by the decreasing height of the bars for each date and reading this visual information may be considered as part of communication.
  - Thinking and reasoning skills are required when readers need to ask questions related to mathematics (Ilhan et al., 2019; Ojose, 2011; Pugalee, 1999) and, in this case, about why the dates and counties are represented inconsistently? How does this affect the data and the story that the data is conveying? The answers to these questions would help the readers conclude information from the graph and validate their reasoning.

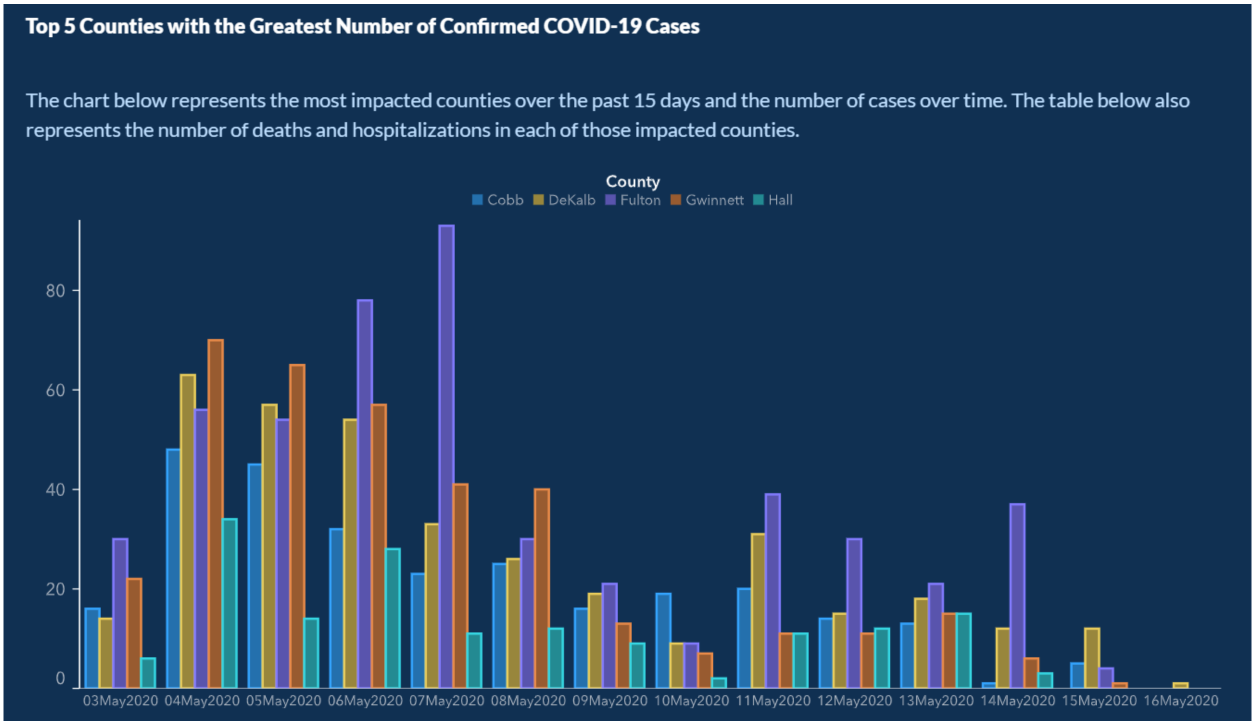
- Modelling is necessary to assess the visual model, which is the bar graph. Modelling involves explaining, justifying, and criticizing and evaluating the mathematical models or graphs (Kaiser & Willender 2005; Konyalıoğlu et al., 2012; Ojose, 2011). Such tasks could enable readers to identify if data is presented correctly and if the visual accurately represent data. Explaining information from the graph, and justifying the information based on critical thinking can be employed in this example as explained in the earlier sections. Criticizing and evaluating the graph to check if the information is misleading and if the graph is drawn accurately is a task associated with modelling. Such an in-depth analysis could aid in finding answers to questions related to the visuals and generate a logical interpretation based on evidence from the visuals.
- Tools and Technology assist learners in developing representations (Ojose, 2011). Students could redraw the graph by arranging the dates chronologically and counties consistently and observe the new visualization. Developing this proper model will enable the learner to assess and compare the new mathematical model to Figure 7.1. To do this raw data is required and, this could be provided to the learners.

Teachers can use the infographic in Figure 7.1 to teach misleading representations. Students may be taught how to use mathematical and visual literacy skills to extract information from the infographic and to check for misleading information. Teachers can use the visualization in the infographic to teach about graphs.

- Critical thinking skills: To explore the critical thinking skills required to interpret the information, Figure 7.2 is used. Figure 7.2 shows a proper version of the graph with dates and counties arranged consistently. This graph was released for the dates from May 3rd, 2020, to May 16th, 2020; this is depicted in Figure 7.2. It may be noted that the counties were arranged consistently for each date in the order Cobb, DeKalb, Fulton, Gwinett and Hall for each cluster and the dates are arranged chronologically.

**Figure 7.2**

*COVID-19 Cases From May 3, 2020, to May 16, 2020*




*Note:* Sourced from Georgia Department of Public Health (2020).

Figure 7.2 depicts highs and lows in the visual representation. Therefore, the visualization does not show an increasing or decreasing trend but a fluctuation in COVID-19 cases. Figure 7.1 and Figure 7.2 show data from May 3, 2020, to May 8, 2020, and some overlap exists. Comparing the graph for those days makes the graphs appear differently for the same data. Figure 7.1 shows a steady decline in cases and gives the impression that COVID-19 cases are steadily decreasing, whereas Figure 7.2 shows that COVID-19 cases fluctuate. Figures 7.1

and 7.2 depicted contrasting storylines, and teachers could use this example to teach students how to examine visuals critically. Unless the observer scrutinizes the visuals to detect the inaccuracy in the date and county arrangement, Figure 7.1 implies that the peaks are getting shorter for each date, giving the impression that COVID-19 cases are decreasing. This is a misrepresentation of the actual occurrences over time and can be used to teach about misleading visual representations.

The infographics in Figures 7.1 and 7.2 have a visually appealing aspect with the choice of colours and their contrast with the background. However, students must be taught to draw conclusions based on critical reasoning of facts, statistics, and graphics rather than on their aesthetic appeal. For instance, if students take the information provided in Figure 7.1, the narrative conveyed is that COVID-19 cases are decreasing. In contrast, if students analyze the visual representation and critically think about the graphic, they will be able to understand the flaws in the representation. Furthermore, Figures 7.1 and 7.2 can be used to portray how contrasting storylines are represented by visuals using the same data. This could also draw attention to viewing through a critical lens when analyzing visuals.

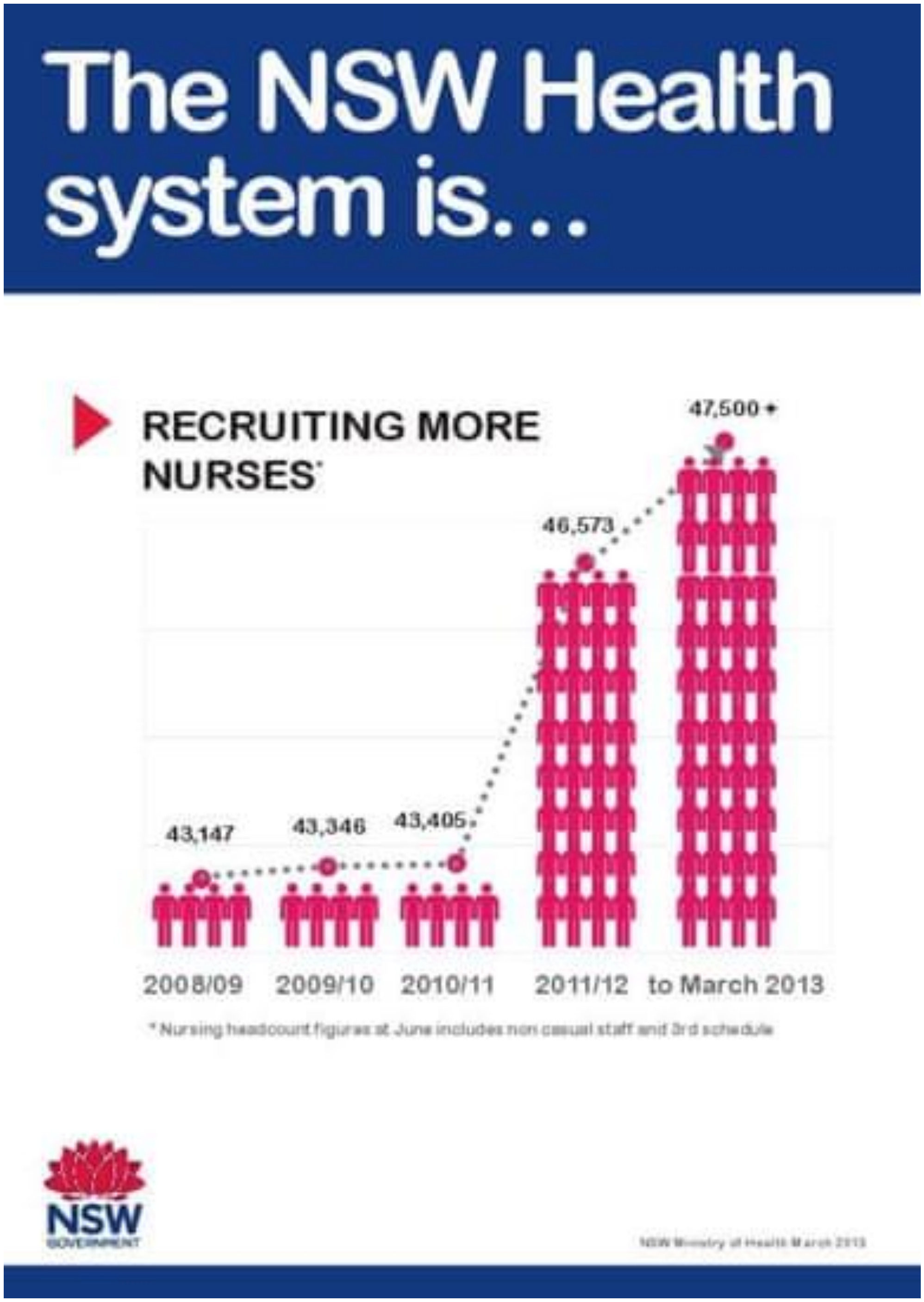
Teachers can use this infographic to teach students how to associate data with visual representations. Teachers should utilize examples of infographics to explain how to construct linkages between underlying content and pictures (Elaldı & Çifçi, 2021). Teachers could provide raw data and the infographic and ask students to associate the data with the visual representation. By using Figures 7.1 and 7.2, teachers could ask students to identify which infographic is a fair representation of data and to explain their reasoning. Guiding questions may be asked to encourage students to think critically about the data and associate it with the visual representation to develop logical interpretations.

### 7.2 Infographic 2: NSW Health Hires More Nurses

The Ministry of Health in New South Wales (NSW) released the following infographic in Figure 7.3 about nurse recruitment. From 2008/09 to March 2013, the data illustrates the number of employments created in nursing and the data is concisely presented through the infographic. The data visualization used in this infographic is a chart which includes numerical data and a visual representation which portrays the jobs created in nursing from 2008 to March 2013. The colourful presentation and the inclusion of icons () add to the aesthetic feature of the infographic in Figure 7.3.

**Figure 7.3**

*Recruitment of Nurses From 2008 to March 2013*




*Note:* Sourced from NSW Government (2013).

The statistics in this infographic tell the story that the number of nurses hired in 2011/12 and 2012/March 2013 increased considerably since 2008.

- Visual and mathematical literacy competencies: The following visual literacy competencies are necessary to analyze the infographic:
    - Critical viewing and visual discrimination skills are required to analyze the visual in Figure 7.3 and the following description explains how those skills can be applied. There is a sudden spike in the number of jobs generated for 2011/12 compared to the previous years. The visual stimuli or impulse from observing the sudden increase in data could make the observer curious to know more about what led to the sudden increase? Visual discrimination skill is the ability to receive a sensory response from observing a visual (visual stimuli), which aids observers in further analyzing the graphic to make insightful interpretations (Avgerinou, 2003, 2009).
    - Visual thinking and visualization are necessary to analyze a graphical representation (Avgerinou, 2009). In this case, thinking about the sudden spike in the visualization and doing a comparative analysis with other years will aid in developing a deeper understanding of the visual.
- The following mathematical literacy competencies are necessary to analyze the infographic:
    - Thinking and reasoning skills are required to make interpretations of this infographic. This skill requires asking questions related to mathematics and an understanding mathematical concept (Ojose, 2011). The question in this scenario could be if the data is represented correctly. To figure this out the reader may

extract information from the visual and apply mathematical understanding to make interpretations. The reader's critical understanding of mathematics helps to make logical interpretations, as explained by Mamolo and Ibeh (2021). The following explanation describes how to extract information and apply critical understanding of mathematics to make interpretations. To present the information from the infographic, I created a table as shown in Table 7.1. Information such as the year, number of jobs generated, and number of icons () are obtained from the infographic, and the unit ratio is calculated, and this is shown in Table 7.1. The unit ratio refers to the number of jobs represented by one icon and is calculated using the following formula:

Unit ratio = Number of jobs created for each year ÷Number of icons representing the jobs.

**Table 7.1**

*Unit Ratio Calculation*

| Year | Number of jobs created each year | Number of icons representing the jobs | Unit ratio (Calculation is shown in the brackets) |
|---|---|---|---|
| 2008/09 | 43147 | 4 | 1: 10787 (43147 ÷ 4 = 10787) |
| 2009/10 | 43346 | 4 | 1: 10896.5 (43346 ÷ 4 = 10836.5) |
| 2010/11 | 43405 | 4 | 1: 10851.25 (43405 ÷ 4 = 10851.25) |
| 2011/12 | 46573 | 32 | 1: 1455.4 (46573 ÷ 32 = 1455.4) |
| 2012/ March 2013 | 47500+ | 40 | 1: 1187.5+ ([47500+] ÷40 = 1187.5+) |

The data from Table 7.1 is used in the following analysis to do calculations.

- Problem posing and solving skills are required to interpret the extracted data from Table 7.1 and apply it in further calculations to determine if the visual representation represents the data correctly. Problem-solving entails using existing knowledge and skills to solve problems without apparent answers

(Pugalee, 2019). According to Ojose (2011), problem-solving involves formulating, following the strategies or steps that lead to finding solutions and employing multiple ways to solve problems. In this case, the problem is the sudden spike in data and whether this an accurate representation of the data. In this analysis I am digging deep to analyze the representation by applying mathematical understanding. I include three different mathematical methods or approaches to find whether the data is accurately presented.

1. By comparing unit ratios: Based on the results from Table 7.1, the unit ratio differs for each year, and this lack of consistency impacts how the data is portrayed, resulting in a misleading representation. For example, one icon represented 10787 jobs in 2008/09, whereas the same icon represented 1455.4 jobs in 2011/12 and about 1187 jobs in 2012/March 2013. This lack of consistency resulted in an exaggeration in 2011/12 and 2012/March 2013. As a result, the visual shows a sudden spike for those years, leaving the impression that there was a sudden increase in jobs.
2. By calculating the percent increase in data: The following formula can be used to compute the percentage increase in data from 2008/09 to 2011/12.

   $$\text{Percent Increase} = \frac{\text{Final Value - Initial Value}}{\text{Initial Value}} \times 100\%$$

   The final value is the number of jobs for 2011/12, which equals 46573, and the initial value is the number of jobs for 2008/09, which equals 43147.

   $$\text{Percent increase in data} = \frac{46573 - 43147}{43147} \times 100\% = 7.94\% \text{ increase}$$

There is an increase of 7.94% jobs from 2008/09 to 2011/12 based on mathematical calculation. However, for 2011/12, the representation does not depict an increase of 7.94% instead it shows a rise of 700% (From the infographic, for 2011/12 there are 8 rows of 4 icons and for 2008/09 there is 1 row of 4 icons. Therefore 2011/12 is showing an increase by 7 times or an increase by 700%).

3. By using visual reasoning: This method employs using visual reasoning to find a solution. To interpret the diagrammatic illustrations in mathematics, reasoning and visual reasoning skills are required (Celik, 2019). The number of icons from the chart in Figure 7.1 is used in this method. For 2008/09, 2009/10 and 2010/11, each icon represents approximately 10,000 jobs, as shown in Table 7.1. Following this rule, approximately five icons can represent 46573 jobs in 2011/12. Instead, in the visual, 32 icons were used to represent 46753 jobs in 2011/12. This means that the data for 2011/12 is inflated, resulting in a misleading representation.

Any method explained above can be used to teach students how to identify the misleading representation. Furthermore, ratios and proportions, proportional reasoning, deceptive graphical representations, and numerical and percentage calculations may all be taught using the visualization in this infographic. This infographic can be used to draw attention to the significance of analyzing images before making interpretations. Teachers could use this infographic to facilitate discussions about the importance of mathematical and visual literacy skills.

- Critical thinking skills: The earlier analysis of visual and mathematical literacy competencies explored how to apply critical thinking to analyze visuals. Teachers can use the infographic in Figure 7.3 to draw students' attention to critical thinking skills that are required to analyze the information.

The infographic in Figure 7.3 is a misleading representation and the following are some pedagogical strategies that can be used in teaching. The lesson's goal is for students to point out that the infographic contains misleading information. The following description explains how to use Figure 7.3 to guide students to identify that the presentation is misleading. This could be done in different ways as explained below and the role of the teacher is to facilitate the discussion.

- One strategy is to show the infographic, and the teacher can ask students to observe the visual and ask what their thoughts or questions about the representation are.
- The teacher can ask students to look for the visual cues (e.g., the number of icons for each year), and students may be asked to compare the data between different years and generate an interpretation.
- Students could work in small groups to analyze the infographic and explain what they understood from this infographic and their reasoning.

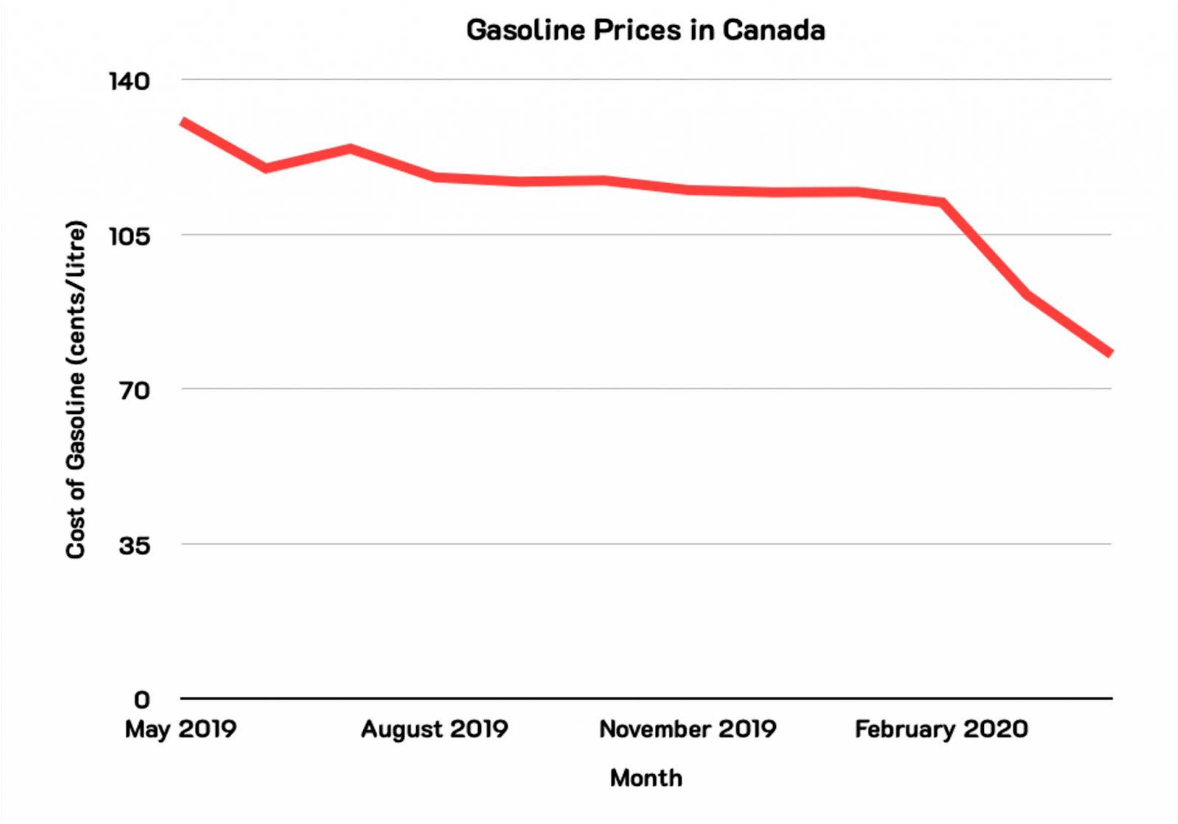
Based on the responses, teachers can ask guiding questions to elicit thoughts, encourage learners to think about the visual and create connections between numerical data and the picture in the infographic. Learners can identify the misleading representation from this infographic if they apply visual and mathematical literacy competencies and critical thinking. Though the underlying narrative in this infographic is to show an increase in nursing jobs, observing the data through a critical lens will enable learners to understand that the representation is misleading.

### 7.3 Infographic 3: Gasoline Prices in Canada

The infographic in Figures 7.4 and 7.5 displays the gas prices in Canada. The visual was retrieved from the Toronto Metropolitan University Press Books website. The infographics employ a line graph to show the trend in gasoline prices. The graph may appear to be a simple representation, but to uncover the intricacies of the representation, close analysis is necessary. Figure 7.4 is first examined and analyzed in this discussion, and Figure 7.5 is introduced after. Figure 7.4 shows the gasoline prices in Canada from May 2019 to April 2020, and the line graph shows a downward trend in gasoline prices.

**Figure 7.4**

*Downward Trend in Gasoline Prices in Canada*



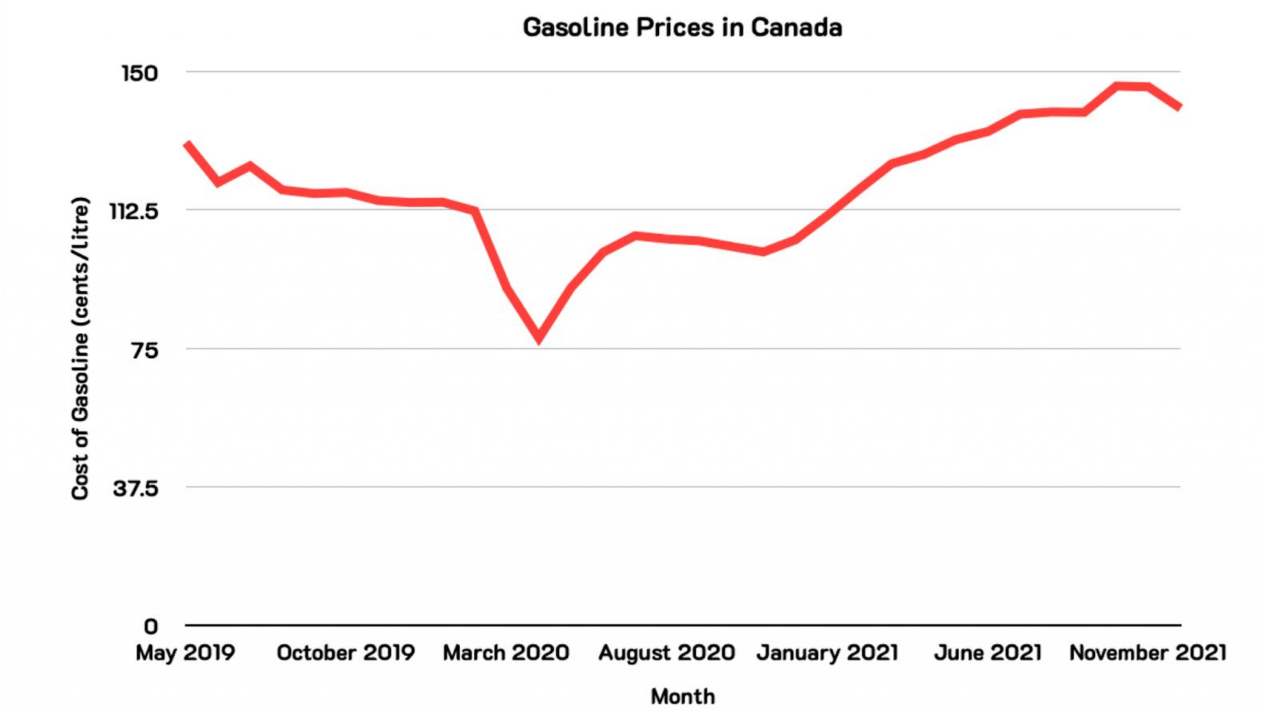

*Note:* Sourced from Pressbooks (n.d.). Infographic is from the Toronto Metropolitan University Press books based on the information retrieved from Statistics Canada Website.

- Visual and mathematical literacy competencies: The following visual literacy competencies are necessary to analyze the infographic:
    - *Critical viewing* (Avgerinou, 2003, 2007, 2009) is required to observe and read visuals. In Figure 7.4, X-axis uses a shorter time frame.
    - *Visual association* is required to relate between the shorter time frame and the line graph. Such association enables learners to make connections between the data on the X-axis and the trend of the graph, which is showing a declining trend. Reading information from visuals and making connections are required to interpret the information from this visual. Reading visuals/pictures and making visual associations are all part of visual learning skills (Avgerinou & Pettersson, 2010)
- The following mathematical literacy competencies are necessary to analyze the infographic:
    - *Thinking and reasoning* skills are required to understand why the graph is showing a declining trend. Readers need to ask questions to extract information from the infographic, such as why the graph shows a declining trend? and does the shorter time frame affect the graph?
    - *Representation* skills are required to decipher information from the infographic. In this case, understanding graphs and how the values on the X and Y axis can affect a representation will enable readers to figure out that a shorter time frame affects the visual representation. Representation requires the ability to decode, encode, and understand various models (Ojose, 2011). This includes knowing the relationships between various representations and interpreting information from different types of representations (Ojose, 2011).

Teachers could use Figure 7.4 to teach how the values on the X-axis affect the line graph. This means that choosing a shorter time frame, limiting the number of values, or omitting specific data values can lead to a misleading representation. The example in Figure 7.4 can be used as an example of a misleading representation and students may be asked to analyze the infographic, and the teacher facilitates the discussion. Teachers could also introduce Figure 7.5 which is a modified version of Figure 7.4.

**Figure 7.5:**

*Upward Trend in Gasoline Prices in Canada*




*Note:* Sourced from Pressbooks (n.d.). Infographic is from the Toronto Metropolitan University Press books based on the information retrieved from the Statistics Canada Website.

Figure 7.5 includes more data collected over a more extended period, from May 2019 to November 2021. Figure 7.5 shows more data inclusion portrayed an upward trend in gasoline prices. Figure 7.5 is a more accurate graph than Figure 7.4 and can be used to portray how the inclusion of more data produced a graph showing a rising trend in gasoline prices. Teachers can use the infographics in Figures 7.4 and 7.5 to teach how the choice of data values on the graph's x-axis affected the line graph. Teachers can use the infographic in Figures 7.4 and 7.5 to teach about graphs and the factors to look for when interpreting information from the graph.

- Critical thinking skills: When comparing the two data representations in Figures 7.4 and 7.5, they each tell a different story. Figure 7.4 shows a declining trend when using a shorter time frame. This is due to the careful selection of data that communicates a specific trend, in this case, data that shows gasoline prices are falling. On the other hand, Figure 7.5 shows a rising trend when using a longer time frame which included more data. The inclusion of more data resulted in a graph that shows lows and highs, as well as an upward trend from January 2021 onwards, indicating that gasoline prices are increasing. Such critical thinking is required to make an in-depth analysis.

Teachers can ask students to compare the infographics in Figures 7.4 and 7.5 and identify which graph is a misleading representation. This could be done as a think/pair/share activity or as a small group activity. This activity encourages students to think critically about the infographics and explain their reasoning. Using the infographic in Figure 7.4, teachers can draw attention to the content and design decisions that favour a specific objective or convey an intended trend (in this case gasoline prices are decreasing). It is important to teach students that before ingesting the information "as is," it is critical to analyze and evaluate information presented through infographics.

The infographics from Figures 7.1, 7.2, 7.3, 7.4 and 7.5 require visual and mathematical literacy competencies and critical thinking skills to interpret the narrative conveyed through the infographic. Furthermore, it is vital to analyze a visual representation utilizing these skills to spot misleading information and understand the data completely and accurately.

# Chapter 8. Limitations, Further Research and Conclusion

## 8.1 Limitations

This literature review addressed the research questions which intended to gain an in-depth understanding of visual and mathematical literacy as well as the skills needed to be visually and mathematically literate, to examine the advantages of infographics in learning and to comprehend the educational benefits of infographics with mathematical representations. However, there were few limitations. Based on research material, this literature review explored different perspectives and explanations about visual and mathematical literacy and how it impacts learning. Several studies experimented the effectiveness of visual representations in mathematics learning. Though there are research articles which explain the benefits of infographics in learning, the number of articles that present experimental research is limited. Therefore, my suggestions are theoretical rather than evidence based. This research review would have benefitted from having more research articles that discuss teachers' educational experiences using infographics in teaching. Conducting a systematic review might have generated more research articles than the approach I adopted which was more of a narrative literature review. Furthermore, I could have created infographics and developing few grade-specific infographics with mathematical representations would have been beneficial. This would allow me to include specific mathematical concepts that are appropriate for a grade level. Then my analysis of infographics would focus on grade-specific objectives along with visual and mathematical literacy competencies and critical thinking skills which would have benefited educators teaching those grades.

### 8.2 Further Research

- Based on my review, I found a need for further studies that focused on developing ways to enhance learners' visual and mathematical literacy skills, which would benefit students in K-12 grades.
- The limited research that investigated students' mathematical learning with infographics suggests a need for further research in this direction. In particular, research that investigates the instructional potential of infographics and how they may be harnessed to teach mathematics could help shed light on how educators can use infographics in teaching.
- Research may be conducted to study how using infographics in teaching impacts learners' visual and mathematical literacy skills and critical thinking skills.
- This literature review highlights some ways teachers can use infographics to teach key mathematical concepts, and further research into the educational uses and benefits of such an approach is relevant. The research reviewed suggests that infographics can reduce cognitive load, convey complex and abstract information and aid in memorability. The instructional capacity of infographics to teach mathematical concepts needs to be researched. Research on how infographics impact mathematical learning in different grade levels may be conducted. Exploring different strategies to teach mathematical concepts may benefit learners. However, this needs to be researched to understand its effectiveness. Furthermore, such research findings could encourage educators to try innovative ways to teach mathematics.
- The educational benefits of infographics need to be further explored. Some ideas for further research include how can infographics be developed to teach mathematical

concepts to students in k-12 grades? And how can infographics be created to connect mathematics to real-world applications?

- Another area of research is regarding how infographics can be used to make data more memorable. Furthermore, how can infographics be developed to improve visual memory? Does this have an impact on people suffering from memory loss? Identifying the factors that can improve memorability and incorporating those into developing infographics may be researched.

### 8.3 Conclusion

This literature review focussed on visual and mathematical literacies and the competencies required to be visually and mathematically literate. As discussed in the research, visuals can be complex, and an in-depth analysis of visuals may be necessary to decipher information from visuals. While observing visuals, a viewer needs to consider different aspects of the visuals, and associations need to be made between other parts of a visual representation to generate a meaningful interpretation. Based on my analysis of the overlap between visual and mathematical literacy competencies, visual and mathematical literacy competencies complement each other. Comprehending information from visuals with mathematical representation is contingent on the reader's mathematical literacy abilities to interpret the facts and figures from the representation and their visual literacy skills in critically observing and analyzing the visual. In mathematics, students must be able to understand the information conveyed through different visual representations such as illustrations, flowcharts, graphs, scatterplots, and tables. Researchers have emphasized the educational benefits of mathematical visualization, and this drove my attention to exploring instructional tools that convey information through visualizations. I chose to explore infographics, which are instructional tools that use visualizations, images, and text to convey information through storytelling.

How infographics convey information is discussed, along with an analysis of infographic stories. The analysis focuses on interpreting information from the infographics, and the following are the key findings:

- Visual literacy competencies and critical thinking skills are required to interpret information from infographics.
- If there are mathematical representations, then mathematical literacy competencies and mathematical understanding are also required to interpret messages.
- Critical viewing plays a significant role in spotting outliers, identifying any relevant information that is missing and finding misleading representations. Identifying such aspects of an infographic is key to understanding and evaluating the narrative conveyed through infographics.

My analysis emphasizes a mathematical literacy skill (Ojose, 2011) required to interpret information from these infographics: thinking and reasoning. Thinking and reasoning involve asking questions to extract information from the visualizations and applying mathematical knowledge to generate interpretations. For example, the infographic in Figure 7.3 shows a misleading representation, and this is because of the inconsistency in unit ratio for each year in the representation. Therefore, in the visual representation, some years depict data accurately, whereas other years depict data inaccurately, as shown in the infographic in Figure 7.3. Readers may be misled unless they thoroughly analyze the content to spot the deception. My analysis contributes insight into how mathematical and visual literacy skills are crucial for thoroughly analyzing such distorted mathematical representations and coming to a logical conclusion.

The educational benefits of using and developing infographics for educational purposes were also covered. The research reviewed suggests that infographics facilitate information presentation concisely, reducing the cognitive load. Furthermore, the capacity to integrate visualizations, text and interactive elements can aid in conveying abstract and complex concepts in a way that aids in memorability and recall of information. My research suggests that the instructional power of infographics and the capacity of infographics to facilitate learning may be significant. However, harnessing the teaching potential of infographics relies on how educators develop or choose infographics for teaching and how they are applied in education.

# REFERENCES


Abilock, D., & Williams, C. (2014). Recipe for an infographic. *Knowledge Quest*, *43*(2), 46-55. https://link.gale.com/apps/doc/A392478321/AONE?u=ko_acd_uoo&sid=bookmark-AONE&xid=3d83aba1

Afify, M. K. (2018). The effect of the difference between infographic designing types (static vs animated) on developing visual learning designing skills and recognition of its elements and principles. *International Journal of Emerging Technologies in Learning*, *13*(9), 204–223. https://doi.org/10.3991/ijet.v13i09.8541

Aisami, R. S. (2015). Learning styles and visual literacy for learning and performance. *Procedia - Social and Behavioral Sciences*, *176*, 538–545. https://doi.org/10.1016/j.sbspro.2015.01.508

Alshehri, M., & Ebaid, M. (2016). The effectiveness of usıng interactive infographic at teaching mathematics in elementary school. *British Journal of Education*, *4*(3), 1–8. https://www.eajournals.org/wp-content/uploads/The-Effectiveness-of-Using-Interactive-Infographic-at-Teaching-Mathematics-in-Elementary-School.pdf

Arcavi, A. (2003). The role of visual representations in the learning of mathematics. *Educational Studies in Mathematics*, *52*, 215–241. https://doi.org/10.1023/A:102431232107731

Avgerinou, M. D. (2003). A mad-tea party no-more: Revisiting the visual literacy definition problem. *Turning trees*, 29-41.

Avgerinou, M. D. (2007). Towards a visual literacy index. *Journal of Visual Literacy*, *27* (1), 29-46, https://doi.org/10.1080/23796529.2007.11674644

Avgerinou, M. D. (2009). Re-viewing visual literacy in the ‘Bain d’images’ era. *TechTrends, 53,* 28–34. https://doi.org/10.1007/s11528-009-0264-z

Avgerinou, M. D., & Pettersson, R. (2011). Toward a cohesive theory of visual literacy. *Journal of Visual Literacy, 30*, 1–19. https://doi.org/10.1080/23796529.2011.11674687

Bamford, A. (2003). *The visual literacy white paper* [Online]. Art and Design University of Technology. https://library.wit.edu/ld.php?content_id=17702378

Bateman, S., Mandryk, R. L., Gutwin, C., Genest, A., McDine, D., & Brooks, C. A. (2010). Useful junk?: the effects of visual embellishment on comprehension and memorability of charts. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2573-2582. https://doi.org/10.1145/1753326.1753716

Bateman, S., Mandryk, R. L., Gutwin, C., Genest, A., McDine, D., & Brooks, C. A. (2010). *Monstrous costs* [Online Image]. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2573-2582. https://doi.org/10.1145/1753326.1753716

Beauchamp, D. G., Braden, R. A., & Baca, J. C. (1994). Visual literacy in the digital age. *Proceeding of 25th Annual Conference of the International Visual Literacy Association* (pp. 13-17). Rochester, New York, United States. https://files.eric.ed.gov/fulltext/ED370602.pdf

Bekdemir, M., & Duran, M. (2012). Development of a visual math literacy self-efficacy perception scale (VMLSEPS) for elementary students. *Ondokuz Mayis University Journal of Faculty of Education, 31*(1), 89-115. https://www.researchgate.net/publication/272876498_Development_of_a_visual_math_literacy_self-efficacy_perception_scale_VMLSEPS_for_elementary_students

Benoît, G. (2016). The 'beautiful' in information: thoughts about visual literacy and aesthetics. *Journal of Visual Literacy, 35*(1), 60-78. https://doi.org/10.1080/1051144X.2016.1205831

Bikakis N. (2018). Big Data Visualization Tools. In S. Sakr, & A. Zomaya (Eds.), *Encyclopedia of Big Data Technologies*. Springer. https://doi.org/10.1007/978-3-319-63962-8_109-1

Blackwell, A. F., & Green, T. R. (1999). Does metaphor increase visual language usability? *Proceedings 1999 IEEE Symposium on Visual Languages*, 246-253. https://www.semanticscholar.org/paper/Does-metaphor-increase-visual-language-usability-Blackwell-Green/d6c85780eddcce8677c7b470d8ff0a6b97098e0c

Borkin, M. A., Vo, A. A., Bylinskii, Z., Isola, P., Sunkavalli, S., Oliva, A., & Pfister, H. (2013). What makes a visualization memorable? *IEEE Transactions on Visualization and Computer Graphics*, *19* (12), 2306–2315. https://doi.org/10.1109/TVCG.2013.234

Borkin, M. A., Vo, A. A., Bylinskii, Z., Isola, P., Sunkavalli, S., Oliva, A., & Pfister, H. (2013). *Fig. 9. The top ten most memorable visualizations for each of the four visualization source categories* [Online Image]. *IEEE Transactions on Visualization and Computer Graphics*, *19* (12), 2306–2315. https://doi.org/10.1109/TVCG.2013.234

Borgo, R., Abdul-Rahman, A., Mohamed, F., Grant, P. W., Reppa, I., Floridi, L., & Chen, M. (2012). An empirical study on using visual embellishments in visualization. *IEEE transactions on visualization and computer graphics*, *18*(12), 2759–2768. https://doi.org/10.1109/TVCG.2012.197

Botha, H., van Putten, S., & Kundema, I. (2019). Enhancing visual literacy in the mathematics classroom: the case of Dar es Salaam. *Perspectives in Education*, *37*(2), 110-123. https://doi.org/10.18820/2519593X/pie.v37i2.8

Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of*

*Sciences of the United States of America, 105*(38), 14325–14329. https://doi.org/10.1073/pnas.0803390105

Celik, H. C. (2019). Investigating the visual mathematics literacy self-efficacy (VMLSE) perceptions of eighth grade students and their views on this issue. *International Journal of Educational Methodology, 5*(1), 165-176. https://doi.org/10.12973/ijem.5.1.177

Cimen, E. E., & Ayguner, E. (2018). An analysis of eighth grade students' self-efficacy perception of visual mathematics literacy and their actual performance. *Elementary Education Online, 17*(2), 675-696.

Clark, R. C., & Lyons, C. (2010). *Graphics for Learning: Proven guidelines for planning, designing and evaluating visuals in training materials.* Pfeiffer.

Cui, L., & Liu, Z. (2021). Synergy between research on ensemble perception, data visualization, and statistics education: A tutorial review. *Attention, Perception, & Psychophysics, 83*(3), 1290–1311. https://doi.org/10.3758/s13414-020-02212-x

Curtiss, D.P. (2004). The oldest literacy, *Journal of Visual Literacy, 24* (2), 121-128, https://doi.org/10.1080/23796529.2004.11674608

Davidson, R. (2014). Using infographics in the science classroom: Three investigations in which students present their results in infographics. *The Science Teacher, 81*, 34–39. http://crisp.southernct.edu/wp-content/uploads/2016/08/Infographics-NSTA.pdf

Davidson, R. (2014). *Figure 3 specification sheet for coffee cup project* [Online Image]. *The Science Teacher*, *81*, 34–39. http://crisp.southernct.edu/wp-content/uploads/2016/08/Infographics-NSTA.pdf

Dunlap, J. C., & Lowenthal, P. R. (2016). Getting graphic about infographics: Design lessons learned from popular infographics. *Journal of Visual Literacy, 35* (1), 42-59. https://doi.org/10.1080/1051144X.2016.1205832

Dur, B. I. (2014). Data Visualization and infographics in visual communication design education at the age of information. *Journal of Arts and Humanities, 3*, 39-50.

Duran, M., & Bekdemir, M. (2013). Evaluation of visual math literacy self-efficacy perception with visual mathematics accomplishment. *Pegem Journal of Education and Instruction, 3*(3), 27-40. https://doi.org/10.14527/C3S3M3

Elaldı, Ş. & Çifçi, T. (2021). The effectiveness of using infographics on academic achievement: A meta-analysis and a metathematic analysis. *Journal of Pedagogical Research, 5*(4), 92-118. https://doi.org/10.33902/JPR.2021473498

Elaldı, Ş. & Çifçi, T. (2021). *Cognitive contributions of infographics* [Online Image]. *Journal of Pedagogical Research, 5*(4), 92-118. https://doi.org/10.33902/JPR.2021473498

Georgia Department of Public Health. (2020). *Top five counties with the greatest number of confirmed COVID-19 cases* [Online image]. Voxmedia. https://www.vox.com/covid-19-coronavirus-us-response-trump/2020/5/18/21262265/georgia-covid-19-cases-declining-reopening

Georgia Department of Public Health. (2020). *Top five counties with the greatest number of confirmed COVID-19 cases* [Online image]. Insider Inc. https://www.businessinsider.com/graph-shows-georgia-bungling-coronavirus-data-2020-5

Government of Canada. (2017). *Mortality by year* [Online image]. https://health-infobase.canada.ca/datalab/mortality-blog.html?=undefined&wbdisable=true

Guzman, M. (2002). *The role of visualization in the teaching and learning of mathematical analysis* [Paper Presentation]. *Proceedings of the International Conference on the Teaching of Mathematics (at the Undergraduate Level)*. Hersonissos, Crete, Greece.

Höfer, T., & Beckmann, A. (2009). Supporting mathematical literacy: Examples from a cross-curricular project. *International Journal on Mathematics Education, 41*(1), 223–230. doi: 10.1007/s11858-008-0117-9

Ilhan, A., Tutak, T., & Çelik, H. C. (2019). What is the Predictive Power of Visual Mathematics Literacy Perception and Its Sub-dimensions for Geometry Success? *Eurasian Journal of Educational Research. 80,* 1-23.

Inbar, O., Tractinsky, N., and Meyer, J. (2007). Minimalism in information visualization - Attitudes towards maximizing the data-ink ratio. Proceedings of the 14th European Conference on Cognitive Ergonomics: invent! Explore!, 185-188. https://doi.org/10.1145/1362550.1362587

Ipek, I. (2003). Computers, visual design and visual learning strategies. The Turkish Online Journal of Educational Technology, 2(3), 68-76.

Islamoglu, H., Ay, O., Ilic, U., Mercimek, B., Donmez, P., Kuzu, A. & Odabasi, F. (2015). Infographics: A new competency area for teacher candidates. *Cypriot Journal of Educational Sciences, 10,* 32–39. https://www.semanticscholar.org/paper/Infographics%3A-A-new-competency-area-for-teacher-Islamoglu-Ay/81a788d79e2f044bb35842febe15dbcf7ab97f42

Kaiser, G., & Willender, T. (2005). Development of mathematical literacy: Result of an empirical study. Teaching Mathematics and Its Applications, 24 (2-3), 48-60.

Kibar, P. N. & Akkoyunlu, B. (2017) Fostering and assessing infographic design for learning: the development of infographic design criteria, *Journal of Visual Literacy, 36* (1), 20-40. https://doi.org/10.1080/1051144X.2017.1331680

Konkle, T., Brady, T. F., Alvarez, G. A., & Oliva, A. (2010). Conceptual distinctiveness supports detailed visual long-term memory for real-world objects. *Journal of Experimental Psychology: General*, *139*(3), 558–578. https://doi.org/10.1037/a0019165

Konyalioğlu, A. C. & Aksu, Z. & Şenel, O. E. (2012). The preference of visualization in teaching and learning absolute value. *International Journal of Mathematical Education in Science and Technology. 43*, 613-626. https://doi.org/10.1080/0020739X.2011.633627

Krauss, J. (2012). Infographics: More than words can say. *Learning and Leading with Technology, 39*, 10–14.

Krum, R. (2014). *Cool infographics: Effective communication with data visualization and design.* John Wiley & Sons.

Lavy, I. (2006). Dynamic visualization and the case of 'Stars In Cages'. In Novotná, J., Moraová, H., Krátká, M. & Stehlíková, N. (Eds.). *Proceedings 30th Conference of the International Group for the Psychology of Mathematics Education, 4,* (pp. 25-32). Prague. https://www.emis.de/proceedings/PME30/4/25.pdf

Liang, H., & Sedig, K. (2010). Can interactive visualization tools engage and support pre-university students in exploring non-trivial mathematical concepts? *Computers & Education, 54* (4), 972-991. https://doi.org/10.1016/j.compedu.2009.10.001

Li, Q. (2020). *Overview of Data Visualization.* Springer. https://doi.org/10.1007/978-981-15-5069-0_2

Madar, A. & Buntat, Y. (2011). *The effect of using visual graphics via interactive multimedia on learning of mathematics (Straight Line) at secondary school*. Journal of Technical, Vocational & Engineering Educational, *3*, 94-103.

Mamolo, A. & Ibeh, N. (2021). Infographics: A remixing approach. *Ontario Association for Mathematics Gazette.*, *60* (1).

Macdonald Laurier Institute (2020). *Indigenous employment income* [Online Image]. Canada's Oil & Natural Gas Producers. https://context.capp.ca/infographics/2020/infographic_indigenous-income/

Murphy, S. J. (2011). The Power of visual learning in secondary mathematics education: How does visual learning help high school students perform better in mathematics? *Research into Practice Mathematics*, *16* (2), 1-8. https://assets.savvas.com/asset_mgr/current/201033/VisualLearningResearch.pdf

Naidoo, J. (2012). Teacher reflection: The use of visual tools in mathematics classrooms. *Journal of the Association for Mathematics Education of South Africa*, *33*(1), 1-9. https://doi.org/10.4102/pythagoras.v33i1.54

Naparin, H. & Saad, A. B. (2017). Infographics in education: Review on infographics design. literacy. *The International Journal of Multimedia & Its Applications* (IJMA), *9* (4/5/6), 1-24. https://doi.org/10.5121/ijma.2017.9602

NHS England (n.d.). *NHS waiting times at record highs* [Infographic]. Statista. https://www.statista.com/chart/27447/nhs-hospital-waiting-times/

NSW Government (2013). *The NSW Health System is…*[Infographic]. http://static.guim.co.uk/sys-images/Guardian/Pix/pictures/2013/8/1/1375343461201/misleading.jpg

Ojose, B. (2011). Mathematics Literacy: Are we able to put the mathematics we learn into everyday use? *Journal of Mathematics Education, 4* (1), 89-100. https://www.researchgate.net/publication/228874128_Mathematics_Literacy_Are_We_Able_To_Put_The_Mathematics_We_Learn_Into_Everyday_Use

Ontario Ministry of Education. (2014). *Leading math success: Mathematical literacy grades 7–12. The report of the expert panel on student success in Ontario.* http://www.edu.gov.on.ca/eng/document/reports/numeracy/numeracyreport.pdf

Organization for Economic Cooperation and Development. (1999). *Measuring student knowledge and skills: A new framework for assessment.* OECD. https://www.oecd.org/education/school/programmeforinternationalstudentassessmentpisa/33693997.pdf

Organization for Economic Co-operation and Development. (2003). *The PISA 2003 assessment framework – mathematics, reading, science and problem-solving knowledge and skills.* http://www.oecd.org/

Ozdamli, F., Kocakoyun, S., Sahin, T. & Akdag, S. (2016). Statistical reasoning of impact of infographics on education. *Procedia Computer Science, 102*, 370-377. https://doi.org/10.1016/j.procs.2016.09.414

Ozgen, K., & Bindak, R. (2011). Determination of self-efficacy beliefs of high school students towards math literacy. *Educational Sciences: Theory and Practice, 11*(2), 1073-1089.

Pachemska, T. A., Gunova, V., Lazarova, L. K., & Pachemska, S. (2016). Visualization of the geometry problems in primary math education (Needs and Challenges). IMO-Istrazivanje matematickog obrazovanja, *8* (15). 33-37.

Pressbooks (n.d.). *Figure 2.13 Gasoline prices in Canada Figure* [Infographic]. https://pressbooks.library.ryerson.ca/criticaldataliteracy/chapter/misleading-data-visualizations/#return-footnote-198-5

Pressbooks (n.d.). *Figure 2.14 Gasoline prices in Canada* [Infographic]. https://pressbooks.library.ryerson.ca/criticaldataliteracy/chapter/misleading-data-visualizations/#return-footnote-198-5

Prism & CAPP (2020). *Jobs across Canada* [Infographic]. Context Energy Examined. https://context.capp.ca/infographics/2018/infographic_jobs-across-canada/

Pugalee, D. K. (1999). Constructing a model of mathematical literacy. *The Clearing House, 73* (1), 19-22. https://doi.org/10.1080/00098659909599632

Rahim, M. H., & Siddo, R. (2009). The use of visualization for learning and teaching mathematics. *Research in Mathematical Education, 14*(3), 496-500.

Reyna, V. F., Nelson, W. L., Han, P. K., & Dieckmann, N. F. (2009). How numeracy influences risk comprehension and medical decision making. *Psychological Bulletin, 135* (6), 943–973. https://doi.apa.org/doiLanding?doi=10.1037%2Fa0017327

Rivera, F. D., Steinbring, H., & Arcavi, A. (2014). Visualization as an epistemological learning tool: an introduction. *ZDM Mathematics Education*, *46* (1), 1–2. https://doi.org/10.1007/s11858-013-0552-0

Shaffer et al. (2018). Sample data visualization tool [Image]. Patient judgments about hypertension control: The role of variability, trends, and outliers in blood pressure data

(Preprint). *Journal of medical Internet research, 21*(3). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6454346/

Siricharoen, W. V. (2013). Infographics: The new communication tools in the digital age. [Paper presentation]. *International Conference on E-Technologies and Business on the Web* (pp. 169–174). http://sdiwc.net/digital-library/infographics-the-newcommunication-tools-in-digital-age

Smiciklas M. (2012). *The Power of Infographics: Using Pictures to Communicate and Connect with Your Audiences.* Pearson Education, Inc. http://ptgmedia.pearsoncmg.com/images/9780789749499/samplepages/0789749491.pdf

Statistics Canada (2019, September). *Canada's population* [Infographic]. https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2019061-eng.htm

Steen, L. A. (2001). *Mathematics and democracy: The case for quantitative literacy.* National Council on Education and the Disciplines.

Szafir, D. A., Haroz, S., Gleicher, M., & Franconeri, S. (2016). Four types of ensemble coding in data visualizations. *Journal of Vision,16* (5), 1-19. https://doi.org/10.1167/16.5.11

Trifunov, Z., Zenku, T. J., Karamazova, E. & Pachemska, T. A. (2019). Importance of visualization in math problems at the universities. *South East European Journal of Sustainable Development, 3* (1). 17-23. https://www.researchgate.net/publication/344594495_Importance_of_Visualization_in_Math_Problems_at_the_Universities

Utomo, E. S., Juniati, D., & Siswono, T. Y. E. (2017). Mathematical visualization process of junior high school students in solving a contextual problem based on cognitive style. *AIP Conference Proceedings 1868* (pp. 1-14) https://aip.scitation.org/doi/pdf/10.1063/1.4995138

Vande Moere, A., Tomitsch, M., Wimmer, C., Christoph, B., & Grechenig, T. (2012). Evaluating the effect of style in information visualization. *IEEE Transactions on Visualization and Computer Graphics*, *18*(12), 2739–2748. https://doi.org/10.1109/TVCG.2012.221

Vennagage (2022). *History of earthquakes in Japan* [Infographic] https://venngage.com/blog/how-to-create-a-timeline-infographic-in-6-steps/

Vennagage (2022). *Steps in product design* [Infographic] https://venngage.com/templates/infographics/5-step-cycle-8f3ab343-255e-4d50-b974-2c6dfd040c32

Vennagage (2022). *Simply the best 6 states and what they're best known for* [Infographic] https://venngage.com/templates/infographics/best-of-the-state-geographic--0796a0d2-b789-4cc7-bd62-a7a09a1d092c

Vermeersch, L. & Vandenbroucke, A. (2015) Kids, take a look at this! Visual literacy skills in the school curriculum, *Journal of Visual Literacy, 34* (1), 106-130. http://dx.doi.org/10.1080/23796529.2015.11674725

Williams, W. R. (2019) Attending to the visual aspects of visual storytelling: Using art and design concepts to interpret and compose narratives with images, *Journal of Visual Literacy, 38* (1-2), 66-82, https://doi.org/10.1080/1051144X.2019.1569832

Yildirim, S. (2016). Infographics for educational purposes: Their structure, properties and reader approaches. *TOJET: The Turkish Online Journal of Educational Technology, 15*(3), 98-

110. http://search.proquest.com.uproxy.library.dc-uoit.ca/scholarly-journals/infographics-educational-purposes-their-structure/docview/1833764580/se-2?accountid=14694

Yildiz, M., Cieslak, M. & Holmes, G. (2019). Visualization in teacher education: Storytelling with data. In K. Graziano (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 639-647). Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/primary/p/207710/

Yin, S. H. (2010). Seeing the value of visualization. *National Institute of Education.* https://repository.nie.edu.sg/bitstream/10497/4380/1/SingTeach-2010-22-HoSiewYin.pdf