

## ABSTRACT

YALCINKAYA, ALIN RABIA. Creative Data Literacies with Personal Data Crafting and Storytelling Through Drawing (Under the direction of Dr. Shiyang Jiang).

The continuous growth of data, driven by technological innovations, has resulted in an exponential increase in the amount of shared data available to the public (Bhargava & D'Ignazio, 2015). However, data literacy remains a significant gap, particularly among high school students who are at a crucial stage of their education, bridging the gap between foundational knowledge and future pursuits (Germeijs & Verschueren, 2006; Mortimer et al., 2002; Ruijter et al., 2018). To address this gap and foster data literacy skills among high school students, this study employs the theoretical framework of "creative data literacy" (D'Ignazio, 2017) along with complementary frameworks of "data feminism" and "data humanism" (D'Ignazio & Klein, 2020). It is crucial to tailor teaching approaches to meet the specific developmental needs and abilities of high school students (Littledyke, 2008; Piaget, 1969; Vygotsky, 1978). The aim of this study is to explore high school students' processes of crafting personal data for telling data stories about climate change and to examine the creative data literacy practices and creative data literacy skills they demonstrate. The research questions guiding the study are: 1) What are the practices that describe high school students' processes of crafting personal data for telling stories about climate change? and 2) What kinds of creative data literacies do high school students demonstrate in the practices of crafting personal data for telling stories about climate change? To investigate these questions, 8 mix-grade high school students, with little to no prior experience in data drawing, were involved in the study. The activities were held online and included four Zoom sessions, each focusing on a different data literacy skill and climate theme. Data were

collected through Zoom and student screen recordings, pre- and post-surveys, field notes, student artifacts, and semi-structured student interviews. The collected data were analyzed using open coding (Creswell, 2013) and interaction analysis methods (Derry et al., 2010; Jordan & Henderson, 1995). The findings of this study revealed unique creative data literacy practices and skills demonstrated by the participating high school students. While some of these findings align with existing literature on data collection, interpretation, visualization, and storytelling, this study introduces new discoveries that extend beyond the current understanding. By contributing to the existing literature, this study provides insights for future research and practical implications in the field of data literacy and data science education, aiming to empower high school students to engage critically and creatively with data in meaningful ways.

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Creative Data Literacies with Personal Data Crafting and Storytelling Through Drawing

by

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## **DEDICATION**

To my mom and dad,

For believing in me unwaveringly,

For your constant prayers and support,

For reminding me that I am a Gemini with limitless potential,

And for providing ideas and encouragement even when unaware of my work.

This dissertation is dedicated to you, the pillars of my strength and the source of my determination. Thank you for your constant love and belief in my abilities.

## BIOGRAPHY

Alin’s rebellion against the traditional education system began during high school, when she questioned the approach of merely “depositing knowledge and withdrawing.” Her avid curiosity clashed with an educational system that emphasized memorization rather than true understanding and despite her successful academic life, her dream of becoming a psychiatrist was shattered when she faced failure in the national college entrance exam.

However, as time passed, Alin had a moment of realization. She discovered that she had been carrying others’ dreams and expectations as her own and that the perceived failure was not the end but a pathway to her true dream. She understood that her journey should not be defined by conforming to societal standards, but by pursuing her own passions and aspirations.

She reluctantly pursued her parents’ dream and enrolled in Cumhuriyet University to study secondary school math. Although she excelled in math and all other subjects throughout high school, she was drawn to this path due to the “benefits” offered to female teachers. However, from the very first day of school, she sensed that this was not her true calling, and the realization that she was following someone else’s dreams became increasingly apparent.

At Cumhuriyet University, she was confronted with the task of memorizing lengthy theorems and proofs that held little meaning to her. Her constant questioning of “why” went unanswered, leaving her feeling frustrated. It took two additional years for her to come to terms with the situation and learn to accept it. However, a stroke of luck came her way when she was presented with an opportunity to study abroad in Italy. This experience was truly eye-opening for her. It solidified her determination to continue her studies and pursue a career in academia.

Upon graduating as a secondary school math teacher, Alin ventured into tutoring K-12 students, which proved to be an enjoyable experience as she could teach what she truly loved:

problem-solving. However, teaching similar subjects could not meet her enthusiasm for learning more and more and left her unsatisfied. It was at this point that she reminisced about her dreams and yearned to delve deeper into the world of academia, desiring to expand her knowledge and pursue her passion.

Motivated by her aspirations, Alin embarked on a master's degree in Differential Geometry at Erzincan University. Yet, she once again confronted the disheartening reality of having to memorize theorems and proofs. As she contemplated whether to continue or seek a different path, an opportunity arose that would alter the course of her journey—a scholarship for graduate studies abroad. This chance not only offered financial support but also granted her the possibility to change her academic focus.

Thus, Alin embarked on a new chapter in her life in the United States, pursuing a master's degree in digital media design for Learning at New York University—an experience that far exceeded her expectations. Being part of a world-renowned university situated in a vibrant city like New York, she discovered her profound affinity for visual design, although she was yet to realize the true extent of its significance.

In the spring semester of 2020, as a Ph.D. student in the Learning Design and Technology program at North Carolina State University, Alin embarked on a pivotal moment in her career when she enrolled in the Data Visualization course. This course became a significant stepping-stone for her professional journey. It was during this time that she experienced a profound discovery—she realized just how much she enjoyed the art of visualizing data, particularly through unconventional and innovative approaches. Finally, she had found her true passion.

During this transformative period, Alin's advisor, Dr. Shiyan Jiang, played a crucial role in guiding her toward her newfound passion. With excellent mentorship and guidance, Dr. Jiang

facilitated Alin’s exploration and provided invaluable support in her journey of “finding her true passion.” The mentorship she received from Dr. Jiang was instrumental in shaping her path and nurturing her enthusiasm for data visualization.

Immersing herself in the world of data visualization, Alin eagerly enrolled in online courses offered by renowned designers in the field. This experience not only honed her skills but also connected her with a vibrant community of individuals who shared her desire and passion for the craft. Inspired by these experiences, she made the resolute decision to forge a career as a data visualization designer and artist.

Throughout the process of her thesis dissertation, Alin witnessed the remarkable impact of data and data visualization on student engagement and learning. Recognizing the enjoyment and excitement it brought to students, she became determined to refine her methods further, aiming to harness the power of data to tell compelling stories. With an unwavering belief in the potential of data, she envisions a future where everyone possesses the ability to effectively communicate and interpret data—a world where everyone speaks the language of data.

## ACKNOWLEDGMENTS

Pursuing a Ph.D. is a lifelong commitment to expanding knowledge, conducting research, and gradually building upon existing foundations within a specific field. It is akin to embarking on a voyage across uncharted waters, navigating through darkness, and with that, I would like to express my heartfelt appreciation to my advisor, Dr. Shiyan Jiang. She has been a guiding lighthouse illuminating my path, providing invaluable mentorship and support. Dr. Jiang's influence on my academic and personal growth extends far beyond that of a mere advisor. She has been a true role model, offering unwavering guidance that allowed me to develop my own research interests and gain diverse experiences through various projects. I hold immense admiration for her exceptional leadership and innovative mindset. I am truly grateful for her constant encouragement, motivation, and nurturing of my scholarly pursuits over the course of the past four years.

I am filled with immense gratitude towards Dr. Angela Wiseman, who holds multiple roles in my academic journey as my advisor, committee member, and an esteemed expert in qualitative research studies. Her unwavering support and deep reservoir of knowledge have been instrumental in guiding me toward a clear path of discovery. Throughout these years, I have consistently felt fortunate to have her by my side, providing not only academic support but also invaluable emotional encouragement. Her presence has been a source of strength and reassurance as I navigate the challenges of my doctoral studies.

I would like to extend my heartfelt appreciation to my esteemed committee members, Dr. Kevin Oliver and Dr. Christopher Parnin. Their invaluable contributions to my dissertation journey have opened new doors of knowledge and understanding for me. Through their

insightful questions and feedback, they have challenged me to delve deeper into my research and provided valuable guidance along the way.

I am particularly grateful for their unwavering support, even during the summer months. I would like to express my deep gratitude to Dr. Parnin, who made a tremendous effort to attend my defense despite being in a completely different time zone. Their dedication and commitment have truly made a difference in shaping the outcome of my work, and I am sincerely thankful for their time, expertise, and unwavering support.

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Special mentions go to Dr. Cansu Tatar, who radiates positivity and has been a constant source of good vibes during our numerous coffee shop work sessions. I also want to express my heartfelt thanks to Dr. Samira Syal, who has always cherished our friendship and though we had to resort to Face Timing over breakfast or lunch since she moved to New York, her presence is deeply missed.

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And, of course, my dear family—my mom, dad, brother, and our newest family member, Berna, my aunts and uncles, and my grandma—your unwavering love and support have been instrumental in making my dream come true. Your presence in my life fills every moment with warmth and joy. The exchanges we have on social media, particularly with my brother and Berna, never fail to bring a smile to my face. Brother, I deeply appreciate your dedicated efforts to provide a diagnosis from overseas. Now, with two doctors in the family, I find humor in the fact that I may not be the diagnosing one. Together, we have overcome challenges and celebrated successes, creating cherished memories that will last a lifetime.

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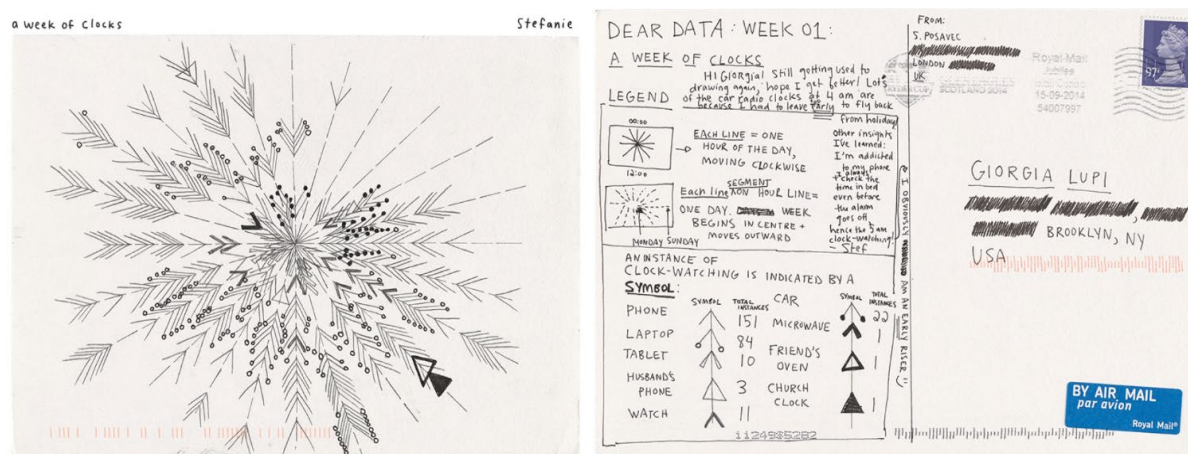
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## CHAPTER 1 - INTRODUCTION

**Figure 1.1**

*A week of clocks from the Dear Data Project (Lupi & Posavec, 2016)*



On a daily basis, a significant amount of data is generated, with approximately 2.5 quintillion bytes<sup>1</sup> being produced. This includes over 8.5 billion Google searches, around 65 billion WhatsApp messages, over 870 million tweets, and 95 million Instagram posts (Petrov, 2022; Wise, 2022). Additionally, substantial financial transactions occur regularly, such as \$67k spent on Instacart, \$283k on Amazon shopping, and \$304k sent through Venmo (DOMO, 2022), contributing further to the vast expanse of Big Data. Our existence is not only intertwined with a data-driven world, but every aspect of our lives, from our social media activities to our dietary choices and exercise routines, is meticulously tracked, recorded, and digitalized—turning us into data subjects, making us increasingly “datafied” (boyd & Crawford, 2012; Pangrazio & Sefton-Green, 2019; Yau, 2011, p. 15). Therefore, the vast amount of personal data generated every day can provide valuable insights, but realizing their true potential requires individuals to possess the skills and knowledge to interpret and understand their own data (Huang et al., 2015).

<sup>1</sup> 2.5 quintillion bytes is  $2.5 \times 10^{18}$  bytes.

In the early 2000s, as digital recording and modernization became prevalent with the introduction of new technologies, the concept of Big Data remained relatively unfamiliar to the general public. It was not until the United States embraced the open data movement, followed by other countries and organizations like UNdata and Data.gov.uk, that awareness began to spread (Cukier & Schönberger, 2013; Yau, 2011, p. 15). The open data movement aimed to unlock the potential of the rapidly expanding data landscape by publishing and sharing raw data, therefore involving citizens in the emerging data-driven society (Atenas et al., 2015). However, despite the developing technologies and tools, and expectations of active citizen engagement and participation in the movement, the initial launch fell short of true success due to the absence of foundational groundwork. Citizens' limited technical and data literacy skills impeded their meaningful engagement (Gray et al., 2018; Shadbolt et al., 2012). Despite the government's transparency policies, the lack of citizens' data handling skills hindered the movement from attaining its intended impact (Janssen et al., 2012; Sturges & Gastinger, 2010; Weerakkody et al., 2016).

Data literacy skills play a crucial role in enabling individuals to actively engage with and interpret data (Bhargava et al., 2015), empower them to question the methods of generating and collecting data and foster their ability to become democratic participants in society (Philip et al., 2013; Wise, 2020). Bhargava and D'Ignazio (2015) define data literacy as "the capacity to read, work with, analyze, and critically engage with data." Research indicates that as our world becomes increasingly data-driven, the need for data literacy skills intensifies (Bhargava et al., 2015; Gebre, 2022; Wolff et al., 2016). The Organization for Economic Co-operation and Development (OECD) Future of Education and Skills 2030 report (2019) highlights these skills as indispensable, encompassing both technical and social dimensions, and fostering student

engagement with real-world problems and community issues (Atenas et al., 2015). Moreover, this study adopts the concept of “creative data literacy,” coined by D’Ignazio (2017), which recognizes the need to provide pathways for learners from diverse backgrounds, including technical and non-technical ones, to develop their data literacy skills.

When confronted with global issues like climate change, the sharing of data becomes increasingly prevalent among researchers and experts as the impact of global warming and increasing carbon emissions were recognized by researchers (Keeling, 1961; Le Treut et al., 2007). In this context, the collection and analysis of climate data play a crucial role in tracking changes, identifying root causes, and raising public awareness to inspire action, particularly for future generations who may confront the catastrophic consequences of climate change (Farber, 2020).

Furthermore, the development of data literacy skills is especially pertinent for high school students, who are at a crucial stage of their education bridging the gap between foundational knowledge and future pursuits. As they prepare to navigate the complexities of the data-driven world and make informed decisions, equipping high school students with data literacy skills becomes essential (Germeijs & Verschueren, 2006; Matuk et al., 2020; Noushad et al., 2022).

## **Problem Statement**

The continuous growth of data, driven by technological innovations, has resulted in an exponential increase in the amount of shared data available to the public. However, despite this abundance of data, there remains a significant gap in data literacy skills (Ruijter et al., 2018; Ruijter & Meijer, 2019; Weerakkody et al., 2017). This gap becomes particularly crucial for high

school students who are at a transitional stage, preparing to enter adulthood and make informed decisions about their lives (Germeijs & Verschueren, 2006; Mortimer et al., 2002). Imagine this: in 1999, 1 gigabyte of data was considered large (IT Chronicles, nd), yet today, we find ourselves amidst a knowledge revolution (Cukier & Schönberger, 2013), witnessing the emergence of yottabytes<sup>2</sup> (Ramachandramurthy et al., 2015). Consequently, it has become critical to develop approaches that facilitate data literacy skills not only for data scientists but also for laypeople who are increasingly becoming producers and consumers of data (D’Ignazio, 2017; Sander, 2020; Wise, 2020). Efforts to promote data literacy skills among a broader audience, including high school students, have been limited and require more attention (D’Ignazio, 2017; Sander, 2020). Therefore, it is crucial to prioritize data literacy education initiatives that empower high school students to become competent and responsible data users, enabling them to make informed decisions in their personal and professional lives (D’Ignazio & Bhargava, 2015).

### ***Data Visualization as a Way to Reduce Power Inequality***

Data experts and scientists often collect data for research purposes but presenting it in ways that are accessible to a broader audience can be challenging (D’Ignazio, 2017; D’Ignazio & Klein, 2020; Wise, 2020). The availability of extensive raw data through the open data movement is not sufficient on its own; it needs to be organized and structured in a manner that unlocks its true meaning for a wider range of individuals (Li, 2020, p. 17). To address this gap, scholars have introduced the concepts of “Data feminism” and “Data humanism” as frameworks

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<sup>2</sup> 1 yottabyte is  $10^{24}$  bytes.

that emphasize inclusivity, ethical considerations, and social implications in data practices (D'Ignazio & Klein, 2020; Lupi, 2021).

Motivated by the challenges and opportunities presented by data practices, my research is deeply rooted in the principles of data feminism and data humanism. I recognize the limitations of traditional approaches in making data accessible and meaningful to a broader audience (D'Ignazio & Klein, 2020; Lupi, 2021). Data feminism emphasizes the significance of challenging power imbalances and promoting social justice within the data landscape, recognizing its potential to shape and reinforce social structures. Complementing this perspective, data humanism focuses on the human-centered aspects of data practices, acknowledging that data unveils the hidden layers of daily life, providing insights into the complexities of human experiences and societal dynamics.

In alignment with the research context, the combination of data feminism and data humanism plays a crucial role in empowering high school students to uncover power imbalances, biases, and inequities within data practices. Data feminism emphasizes the significance of promoting social justice and addressing power imbalances in the data landscape, while data humanism focuses on the human-centered aspects of data, unveiling the complexities of human experiences and societal dynamics. By incorporating the principles of data feminism and data humanism into the educational framework, high school students are equipped with the tools to challenge existing biases, advocate for inclusivity, and contribute to more equitable outcomes in data analysis and interpretation. This approach fosters a sense of agency and empowers students to critically engage with data, uncover hidden information, and make informed decisions about their lives and future pursuits. By bridging the gap between data literacy and social impact, this

research strives to support high school students in becoming active participants in shaping a fairer and more inclusive society.

Furthermore, integrating data visualization into the framework of data feminism and data humanism holds great relevance for empowering high school students in their data exploration. Data visualization serves as a powerful tool that can bridge the gap between complex data and its meaningful interpretation, enabling students to derive insights and make informed decisions (Bhargava et al., 2015; boyd & Crawford, 2012). However, it is crucial to acknowledge that existing data visualization tools often cater to technical users, creating a distinction that leaves non-technical or novice learners, like high school students, at a disadvantage and perpetuates power imbalances within the field of data (Bhargava & D'Ignazio, 2015; D'Ignazio & Klein, 2020).

In contrast to data collected for professional purposes and publicly shared, the responsible utilization of personal data derived from individuals' lived experiences becomes critical. Empowering individuals to have control over their own information aligns with the principles of data humanism, which recognizes the value of personal experiences and agency in the context of data (Markham, 2018; Lupton, 2017; Pangrazio & Selwyn, 2018). By integrating the principles of data feminism and data humanism into my research, I aim to contribute to the development of inclusive and ethically grounded data practices that empower high school students, ensuring that their voices are heard and fostering social justice in the realm of data. Through the incorporation of data visualization techniques that cater to their specific needs and abilities, students can actively engage with data, gain insights, and participate in meaningful decision-making processes, ultimately shaping a more equitable and socially conscious society.

## *Drawing to Visualize Data*

In recent years, the emergence of new data-related professions, such as data visualization designer, data engineer, and data artist (Bhargava et al., 2015; Segel & Heer, 2010), has brought forth a fresh dimension to data visualization from an artistic standpoint. This has led to the adoption of non-traditional visualization methods, including the use of programming languages, crafting tools, and even traditional drawing techniques (Lupi & Posavec, 2016; Matuk et al., 2021). For example, when visually representing a dataset, individuals may employ different colors, shapes, sizes, or arrangements of variables, similar to how artists interpret the same landscape and emphasize distinct elements (Matuk et al., 2021). Furthermore, drawing with pen and paper eliminates the need for digital tools, enabling a more hands-on approach to learning and visualization.

Similarly, when learning, especially abstract concepts like science, students are encouraged to draw their own visualizations to explain what they have learned, as this approach proves more effective than working with pre-existing drawings that may not align with their interests (Ainsworth et al., 2011). Furthermore, learning data science through the collaboration of art, science, and visualization creates a powerful tool for delivering information to a broader audience, while also enabling learners to reason with data and gain deeper insights into the learning content (Areljung, 2021; Leenaars et al., 2012; Quillin & Thomas, 2015; Samsel, 2013). In this context, drawing serves as an integral part of the artistic and creative process, allowing individuals to express their understanding and interpretations of data through unique features such as color, shape, and scale (Alamalhodaie et al., 2020; Matuk et al., 2021). Therefore, to teach data science effectively, it is essential to foster a collaborative approach that merges art and visualization. Addressing this need, the current study investigates the impact of students' data

collection and drawing activities on the development of their creative data literacy skills through centering a complex scientific concept, climate change.

### ***High School Youth and Climate Change***

As students grow, their cognitive abilities change, and educational interventions must adapt to meet their evolving needs (Vygotsky, 1978). Therefore, the focus on high school youth in this study is driven by the recognition that teaching approaches should be tailored to their specific developmental needs and abilities. High school students typically demonstrate a greater capacity for critical thinking, abstract reasoning, and data analysis compared to their younger counterparts (Littleddyke, 2008; Piaget, 1969).

Additionally, there is a significant gap in teaching climate change within the curriculum and integrating it across disciplines (Eilam, 2022). The traditional compartmentalization of subjects limits students' opportunities to develop a comprehensive understanding of climate change and its interconnectedness with various aspects of society. By targeting high school youth, this study can employ teaching strategies and activities that align with their cognitive abilities, facilitating a more nuanced exploration of creative data literacy through drawing and personal data. This approach acknowledges the unique learning needs of high school students and allows for the implementation of more sophisticated techniques to enhance their understanding of climate change and data visualization, fostering their creative expression skills while preparing them for higher education and future endeavors.

Furthermore, the specific choice of climate change as the context for teaching creative data literacies in this study is motivated by its relevance, urgency, and potential impacts on high school youth. Climate change is a critical global issue that directly affects the lives and futures of

young individuals (Bandura & Cherry, 2019; O'Brien et al., 2018; Treichel, 2020). By focusing on climate change, students not only engage with complex scientific phenomena but also develop a profound understanding of the environmental challenges they will face as they transition into adulthood. This contextualization enables students to grasp the significance of data analysis, visualization, and interpretation within the broader context of real-world problems.

The inclusion of high school students in this study goes beyond their cognitive abilities; it recognizes their role as future leaders and their inherent motivation to address pressing global issues. High school students have been at the forefront of movements like the Fridays for Future strikes, demonstrating their awareness and activism regarding the future of the planet (Thunberg, 2020). Their engagement and consciousness make them an ideal target audience for educational interventions that aim to enhance their understanding of climate change and empower them with creative data literacy skills.

By tailoring educational interventions to high school students' cognitive abilities, addressing the gaps in climate change education, and focusing on the urgency and relevance of climate change, this study aims to empower high school students with the knowledge, skills, and motivation to become informed global citizens capable of contributing to ongoing efforts to address climate change and its consequences.

### **Purpose Statement and Research Questions**

This qualitative study aims to obtain a comprehensive understanding of high school students' practices in drawing and visualizing data to develop their creative data literacies. Specifically, the study explores how students engage in the creation of personal data, draw data visualizations, and construct data narratives related to climate change. It further examines the

ways in which these processes facilitate the development of creative data literacies while enhancing their comprehension of the factors contributing to climate change. The study is guided by the following research questions:

- RQ1: What are the practices that describe high school students' processes of crafting personal data for telling stories about climate change?
- RQ2: What kinds of creative data literacies do high school students demonstrate in the practices of crafting personal data for telling stories about climate change?

### **Significance of the Study**

The present study aims to promote data literacy among high school students from diverse backgrounds by exploring the benefits of involving them in data visualization practices using their personal data. Through hand-drawn visualizations, students are expected to develop creative data literacy skills while understanding the complexities of climate change, drawing on the theoretical framework of *creative data literacy*, and the complementary frameworks of *data feminism* and *data humanism*. By investigating how students approach and perceive data in their daily lives, particularly in relation to climate change, this research seeks to broaden their understanding that data can be represented in various forms limited only by their imagination, regardless of the data scale.

Moreover, engaging citizens and society, in this case, high school youth, in data collection plays a vital role in creating a fairer community, improving service quality, and enhancing overall life quality. Individuals can derive valuable insights and benefits from this data, fostering a mutually beneficial relationship between society and its members. Therefore, it

is crucial to introduce data literacy education from an early age as a fundamental subject alongside other essential learning areas. This approach ensures accessible data literacy for all individuals and encourages practical application, empowering them to understand and effectively utilize data, thus fostering a more equitable and informed society.

Additionally, data science holds great significance in high school education. In today's data-driven world, where information is abundant and complex, data science skills are becoming increasingly essential for students. Introducing data science concepts and practices in high school equips students with the ability to analyze, interpret, and draw insights from data (Bhargava et al., 2015; Boyd & Crawford, 2012). By engaging in data-driven projects, students develop critical thinking, problem-solving, and decision-making skills that are crucial for their future academic and professional endeavors. Furthermore, data science education in high school prepares students to be active participants in the ever-evolving digital landscape, enabling them to navigate and make sense of the vast amount of information they encounter. By incorporating data science into the high school curriculum, we empower students to become data-savvy individuals, ready to tackle the challenges and opportunities of the data-driven world they will enter as they progress in their educational and professional journeys.

### **Positionality Statement**

As a data visualization artist and instructional designer, my journey into the world of data and data literacy began during my participation in a data visualization course in the spring of 2020. This experience highlighted the significance of data and its role in shaping our understanding of the world. However, it was during my internship with Social Explorer, a web-based mapping and data visualization tool, that my passion for this field truly blossomed.

Through creating educational learning modules and engaging data visualizations, I witnessed firsthand the power of visual storytelling and its ability to make complex information accessible and meaningful.

In the summer of 2021, I had the opportunity to contribute to the Data VIZion project, a collaboration between North Carolina State University and the University of Miami, where I served as a graduate assistant. The program aimed to provide high school students with a free summer program to learn about the D3.js programming language and create dynamic data visualizations and tell data stories about climate change. My role involved collecting, managing, and analyzing the data, as well as providing support to the high school students during their learning activities. Observing the students as they coded data visualizations allowed me to understand the challenges they faced, further deepening my understanding of the practical aspects of data visualization and the specific hurdles encountered by high school students. This experience solidified my commitment to exploring data visualization as a vital area of study and inspired me to pursue my dissertation research in this field.

Living in an era defined by data-driven decision-making, I am acutely aware of the importance of active citizenship and its profound impact on society. As individuals, we not only produce and consume data on a daily basis but also bear the responsibility of understanding and managing our personal information to counteract misinformation. In this regard, the concepts of data feminism and data humanism resonate strongly with me. These perspectives advocate for inclusive, human-centered approaches to data practices and emphasize the need to challenge power imbalances in the data realm.

Furthermore, through taking several online courses on data visualization and data drawing, as a data artist, I believe in transcending the limitations of coding and digital tools, empowering individuals to freely and creatively visualize data. These online courses shaped my design of learning activities in the dissertation. Also, by embracing the principles of data humanism, I aim to make data more accessible and comprehensible to a broader audience, including non-experts. This approach aligns with the goals of the dissertation study, as it encourages an inclusive approach to data literacy and visualization in the context of climate change education for high school students.

Moreover, throughout the study, I adhered to ethical procedures following the IRB protocols, ensuring that all data collected were obtained with the informed consent of the participating students. However, I acknowledge that my enthusiasm for data empowerment and my advocacy for data humanism and feminism may have influenced my expectations of the students' artifacts and interventions during the workshop. To ensure the integrity of the research process, I actively engaged in self-reflection, taking notes to improve future sessions, and seeking guidance from mentors and peers.

### **Definition of Key Terms in the Dissertation**

In this dissertation, several key terms are central to understanding the research and its findings. Here, I provide comprehensive and precise definitions of these key terms, ensuring that readers have a solid foundation of understanding as they delve into the complexities and implications of the research presented in this dissertation:

- *Data literacy*: Data literacy is defined as “the capacity to read, work with, analyze, and critically engage with data” (Bhargava & D’Ignazio, 2015).

- *Creative data literacy*: It refers to the recognition that individuals who are not necessarily from technical backgrounds may require alternative pathways to engage with and understand data (D'Ignazio, 2017).
- *Data feminism*: Data feminism is a framework rooted in intersectional feminism that examines the intersection of data science and ethics. It sheds light on how conventional practices in data science can perpetuate and exacerbate existing inequalities in society. By challenging these norms, data feminism seeks to create a more inclusive and equitable data landscape (D'Ignazio & Klein, 2020).
- *Data humanism*: Data humanism is an approach that emphasizes the human-centered aspects of data. It recognizes the value of individuals' personal experiences and agency in their data and seeks to uncover the hidden layers of daily life through data analysis. Data humanism promotes a holistic understanding of human impacts on various phenomena and encourages inclusive and ethical data practices that empower individuals and foster social justice (Lupi 2017 & 2021).
- *Data visualization*: Edward Tufte (2001), a prominent expert in data visualization, defines data visualization as “the representation of information through visual forms.” He emphasizes the importance of clear and effective visual design in presenting data, enabling viewers to understand complex information, patterns, and relationships.
- *Carbon footprint*: Wiedmann and Minx (2008) defined carbon footprint as “*a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities.*”
- *Decomposition in nature*: Cotrufo et al. (2010) define decomposition as “*the process through which dead organic material is broken down into particles of progressively*

*smaller size until the structure can no longer be recognized, and organic molecules are mineralized to their prime constituents: H<sub>2</sub>O, CO<sub>2</sub>, and mineral components.”*

- *Sustainability*: Morelli (2011) emphasizes the connection between human actions and the environment, defining sustainability as “*meeting human needs without compromising the health of the ecosystem.*”

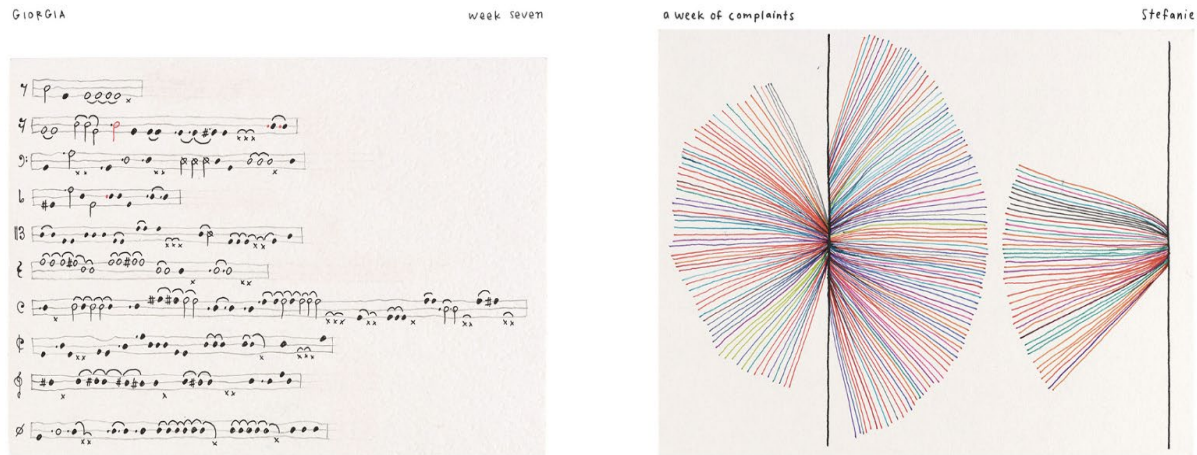
## **Organization of the Dissertation**

This dissertation comprises five chapters, each addressing different aspects of the study. Chapter 1 offers an overview of the research, including the study’s purpose, problem statement, and the role of data visualization in data science education. Additionally, it explores the relevance of data science education for high school students, the rationale behind choosing climate change as the study’s theme and includes a positionality statement. In Chapter 2, a comprehensive literature review is presented, focusing on data science and data literacy implementations in K-12 education. Chapter 3 delves into the study's context, detailing information about the students and the methods employed to address the research questions. Chapter 4 presents the research findings with specific examples from students, while Chapter 5 concludes the dissertation by discussing the implications of the findings for future research and practice.

## CHAPTER 2 - LITERATURE REVIEW AND THEORETICAL FRAMEWORK

**Figure 2.1**

*A week of complaints from The Dear Data Project (Lupi & Posavec, 2016)*



“The greatest value of a picture is when it forces us to notice what we never expected to see,” says the pioneer of exploratory data analysis John Wilder Tukey (1977). Looking through his lens, today’s data visualizations can be considered more than just charts and graphs; they serve as powerful tools for conveying data stories and making sense of complex information. By effectively communicating with readers through thoughtful design elements, data visualizations make data more accessible to people from all backgrounds. The increasing use of public and personal data representations in our data-driven world has underscored the need for data literacy. It is defined as the ability to read, work with, analyze, and argue with data (D’Ignazio & Bhargava, 2015), and has become one of the most essential skills of the 21st century, particularly for democratic and socially just civic engagement (Huijboom & van den Broek, 2011; OECD, 2019; Philip et al., 2013; Philip et al., 2016).

However, the instructional methods for teaching data literacy skills are not evolving at the same pace as the data itself, resulting in a growing gap between individuals' existing skills and the skills needed (D'Ignazio, 2017; Gebre, 2018; Gebre, 2022; Lupton, 2017; Miller, 2014). This gap poses significant challenges for individuals in understanding and critically engaging with the vast amounts of data that surround them. While traditional approaches to data literacy have primarily focused on statistics and data analysis, it is crucial to incorporate data visualization and explore new approaches to address fostering data literacy skills in K-12 settings.

This chapter delves into the research on data literacy implementations in K-12 learning settings, beginning with early implementations, and tracing the evolution of research from statistics and data analysis to data visualization. It highlights the importance of data literacy in today's world, particularly in the face of pressing global issues like the climate crisis. The climate crisis presents complex challenges that require a deep understanding of data related to environmental patterns, climate facts, and mitigation strategies. Data literacy equips K-12 students with the necessary skills to navigate and interpret this data, empowering them to contribute to informed decision-making and advocacy for sustainable solutions (Matuk et al., 2020).

Moving forward, I will introduce the theoretical framework of creative data literacy (D'Ignazio, 2017) as the foundation of this study. Creative data literacy emphasizes the use of imaginative and participatory approaches to engage learners in data exploration and storytelling activities. By incorporating creative and artistic elements, such as hand-drawn data stories, learners can develop a deeper connection with data and express their insights in unique and compelling ways to diverse audiences.

In addition to creative data literacy, this study incorporates the frameworks of data feminism (D’Ignazio & Klein, 2020) and data humanism (Lupi, 2017) to further support and enrich the theoretical framework. Data feminism advocates for a feminist perspective in data science and data visualization, challenging existing power structures and biases inherent in data practices, while data humanism emphasizes the ethical and human-centered aspects of data, emphasizing the significance of empathy, context, and narrative in data interpretation and communication, as well as recognizing subjectivity in data science practices. These complementary frameworks offer critical lenses through which to examine the development of creative data literacy skills and explore the potential for fostering more inclusive, ethical, and empowering data practices in K-12 learning settings.

### **Early Implementations of Statistics and Data Analysis in K-12**

In 1977, Tukey initiated a new era in statistics through his groundbreaking exploratory data analysis (EDA) methods, which included innovative data representation techniques like box and whisker plots and stem-and-leaf displays. This seminal work served as a wake-up call for educators and researchers, highlighting the significance of statistics in comprehending the world fairly, while also underscoring the existing gap in statistical instruction, particularly at pre-college levels (Konold & Higgins, 2003; Makar & Rubin, 2009). Previous studies have revealed that formal learning settings often provided insufficient instruction, placing excessive emphasis on procedural knowledge rather than fostering learners’ understanding and reasoning abilities in data and statistics (Garfield & Ahlgren, 1988; Garfield & Gal, 1999). As a result, there arose a need for new methods and guidelines to address this gap and involve individuals beyond formal

learning settings, including a broader audience, in data science education (Konold & Higgins, 2003; Scheaffer & Jacobbe, 2014; Wallman, 1993).

Implementing data science education in limited class periods is a challenge (Vahey et al., 2012), and recognizing the limitations in traditional statistical instruction, particularly at pre-college levels, there is a need for new methods and guidelines to address this gap (Konold & Higgins, 2003; Scheaffer & Jacobbe, 2014; Wallman, 1993). Early research brought attention to the limited understanding of students' statistics and data competencies and the challenges in effectively developing them within the K-12 curriculum when integrating statistics and data analysis (Ben-Zvi & Arcavi, 2001; Hancock et al., 1992; Konold & Higgins, 2003; Lehrer & Schauble, 2007; Makar & Rubin, 2009). In response, numerous studies have aimed to address these concerns by providing meaningful and relevant learning experiences that incorporate real-world data.

Recognizing the limitations of focusing solely on technical skills in statistics and data analysis (Allmond & Makar, 2010; Garfield & Ahlgren, 1988; Konold & Higgins, 2003; Schwartz & Martin, 2004), it has been emphasized that raw data alone is insufficient unless it is transformed into a meaningful form. This notion is supported by Cobb and Moore's assertion that "Data are not just numbers; they are numbers with a context" (1997, p. 801). Additionally, Bakker (2004) highlighted that students often learn statistics as a set of techniques without grasping their practical application. To address these concerns and promote a deeper understanding of statistical concepts, researchers have conducted studies that incorporate real-world contexts into statistics education.

For example, Lehrer and Romberg (1996) conducted a study where fifth-graders posed research questions and developed a survey to collect data using documents about Colonial America. This approach allowed students to engage with statistical concepts in the context of historical information. Similarly, Enyedy and Mukhopadhyay (2007) integrated mathematics with real-life concepts by having high school students build community maps. This hands-on activity enabled students to explore spatial data and apply statistical reasoning to understand patterns within their own communities. Another study by Allmond and Makar (2010) incorporated real-world data into elementary students' learning experiences. Through posing statistical questions, analyzing data, and drawing meaningful conclusions, students developed improved skills in investigation, reasoning, and making inferences. These studies highlight the importance of presenting statistical and data science competencies within real-world contexts. By connecting statistical concepts to meaningful and relevant situations, learners can develop effective reasoning, questioning, and problem-solving abilities. This approach enhances their understanding of statistical techniques and promotes the application of statistical thinking in various domains (Bhargava et al., 2015; Konold & Pollatsek, 2002; Lehrer & Schauble, 2004).

The evolution of statistical instructions and continuous improvements in data and data tools have prompted a shift towards a more process-oriented approach in research and education (Sorto, 2006). This approach goes beyond numerical computations and procedural knowledge and emphasizes the reification and utilization of data to foster skills such as investigative questioning, statistical reasoning, data exploration, trend identification, and data-based predictions in data science education (Garfield & Gal, 1999).

Furthermore, there is a growing recognition of the benefits of actively involving learners in data collection and communication practices. Engaging students in these activities not only

fosters a sense of ownership and empowerment but also enhances learning outcomes, particularly when dealing with complex scientific concepts. For instance, Doering and Veletsianos (2008) implemented geospatial technologies with middle schoolers, allowing them to actively collect and analyze data. In a similar study, Harris et al. (2012) worked with high school students in an ecology class, where students collected water pollution data through scientific inquiry and analyzed it. Both studies showcased significant improvements in students' engagement with data and enhanced their data literacy skills. The use of visual representations, in particular, played a crucial role in sparking student interest in these scientific concepts.

These advancements in data science education, along with actively including learners in data-related activities, complement the need for presenting statistical and data analysis competencies within real-world contexts. By doing so, not only are technical skills improved, but critical thinking, problem-solving, and decision-making skills are also nurtured in students. This holistic approach prepares students to effectively navigate and make informed decisions in our data-driven society.

### **Promoting K-12 Data Literacy through Data Visualizations**

From William Playfair's charts in the 18th century to today's modern graphs, the representation of data has undergone significant advancements. The purpose of today's contemporary data visualizations extends beyond the mere presentation of data; they strive to convey data stories in a contemporary and aesthetically pleasing manner (Segel & Heer, 2010; Tufte, 2001). Tufte (2001) argues that data visualization is a universal language that requires the integration of statistics, data, and design principles to effectively communicate a message. This

observation implies that data visualization plays a pivotal role in fostering data literacy, enabling individuals to comprehend and communicate through the universal language of data.

Expanding on the power of visual representations, an engaged approach to data science education can maximize its benefits for students. The incorporation of Geographic Information System (GIS) mapping tools exemplifies this approach, as it introduces students to statistics and data practices while promoting civic engagement through the inclusion of relevant data (Enyedy & Mukhopadhyay, 2007; Jiang & Kahn, 2019; Kahn, 2020; Radinsky et al., 2014). By using visuals and narratives in data science education, comprehension and engagement are further enhanced, as hidden patterns and trends within datasets are uncovered and the stories behind the data are revealed (Finzer, 2013; Kosara & Mackinlay, 2013; Segel & Heer, 2010). Moreover, incorporating such tools and integrating personally relevant context taps into students' curiosity and creates authentic learning experiences that align with their interests. For instance, Radinsky et al. (2014) and Jiang and Kahn (2019) conducted studies that exemplify the power of visual representations in data science education. In these studies, students were immersed in the exploration of socio-scientific issues by utilizing GIS tools to analyze and visualize family migration data, enabling them to construct compelling data stories that connected to their own family's migration history. This hands-on approach not only deepened their understanding of complex concepts but also fostered a personal and meaningful engagement with the subject matter. By integrating relevant data from students' lives, the learning process becomes more authentic, fostering deeper connections and enhancing overall learning experiences.

The increasing availability of free databases, advanced data tools, and software has opened up new possibilities for enhancing students' comprehensive understanding of real-world issues and facilitating engaging and immersive learning experiences (Rudd, 2014; Taylor & Hall,

2013). However, it is essential to recognize that making data and data tools more accessible does not guarantee effective learning and understanding. This is because data is often collected by experts for professional or scientific purposes, which may not fully capture students' everyday interactions with data (D'Ignazio, 2017; D'Ignazio & Klein, 2020). Moreover, when incorporating complex scientific concepts like climate change into data science education, the predominant focus has been on statistics and technology-based learning experiences, which can present challenges for students with limited technical backgrounds to fully engage with and benefit from (D'Ignazio & Bhargava, 2015). In order to address such challenges in data science education and enhance comprehension and engagement, an integrated approach that incorporates visuals, narratives, and interdisciplinary contexts has emerged as a valuable strategy (Finzer, 2013; Kosara & Mackinlay, 2013; Segel & Heer, 2010). By combining the power of visualizations and narratives with multidisciplinary knowledge can develop a deeper understanding of data and its implications in real-world contexts (Bybee, 2011; Eilam, 2022).

To further emphasize the importance of this multidimensional approach, the integration of interdisciplinary contexts into data visualizations and narratives offers numerous benefits and enriches the learning outcomes for students. This approach allows students to explore data through different disciplinary lenses, providing them with a broader perspective and enabling them to make connections between various domains and their implications in real-life scenarios (Philip et al., 2016; Wilkerson & Laina, 2018; Lee & Wilkerson, 2018).

For instance, Philip et al. (2016) conducted a study in a high school computer science classroom where they incorporated data visualizations to explore students' racial data literacy through classroom discussions about given data visualizations. This approach raised awareness of racial literacy and social justice issues among the students. In another study by Wilkerson and

Laina (2018), students utilized and repurposed public datasets to create data stories addressing socio-scientific community problems like the increasing number of rodent sightings. This process enabled students to establish links between data, understand its contextual factors and the inherent uncertainties. Furthermore, Lee and Wilkerson (2018) investigated the impact of data visualization tools, including TinkerPlots, Scratch, and Dataflow, on students' socio-scientific learning experiences. The incorporation of these tools appeared to particularly support the understanding of complex scientific issues. Collectively, these studies demonstrated that data visualizations and data visualization tools introduced multiple dimensions to the learning process, enabling students to gain new perspectives and insights when interpreting and making sense of data.

Data visualizations also play a crucial role in K-12 education, providing valuable information that helps students understand current issues, anticipate risks, and contribute to societal well-being (D'Ignazio & Bhargava, 2018). In the context of complex concepts like climate change, data visualizations offer insights and facilitate a deeper understanding of the intricate relationships involved (Barwell, 2013; Finzer, 2013). Given the multidimensional nature of climate change, incorporating it into STEM education and social sciences allows students to develop a comprehensive understanding of its complexities and equips them with the necessary skills to navigate our data-driven world (Bybee, 2011; Eilam, 2022).

For example, Forbes et al. (2020) developed a high school climate science curriculum that utilized a web-based climate modeling tool (EzGCM). While the students gained an understanding of the scientific process and data analysis, they also encountered challenges with the tool itself. Similarly, Sanei et al. (2023) worked with diverse high school students and incorporated climate data using the D3.js programming language, enabling students to create

dynamic data stories about climate change. Although the students developed an understanding of climate facts, they faced instructional challenges related to the programming language interface. These studies collectively demonstrate that, with appropriate instructional guidance and tool introduction, students can shift their focus from the challenges associated with the tools to engaging with the actual data and generating meaningful data stories. It highlights the importance of providing support and scaffolding to students as they navigate these tools to fully benefit from data visualizations in their learning experiences.

Speaking of the challenges students faced when working with data tools, innovative and inclusive approaches such as integrating arts, design, and drawing into learning have shown positive impacts on learning outcomes and students' attitudes toward complex scientific concepts (Ainsworth et al., 2011; Bell, 2014; Matuk et al., 2021; van der Veen, 2012). These approaches become particularly valuable when addressing topics like climate change, as drawing can enhance students' understanding of its complexity and improve their data literacy skills. By incorporating visual elements, giving flexibility, and encouraging students to create their own visualizations can facilitate comprehension and provide a platform for students to present and reason about both the data science and these scientific concepts.

Drawing serves as a powerful tool for students to foster creativity, express thoughts, identify misconceptions, and establish connections within and between learning concepts (Matuk et al., 2021; Thudt et al., 2017; van der Veen, 2012). It enables the expression of thoughts, the identification of existing misconceptions, and the establishment of connections through the utilization of visual elements (Ainsworth, 2011; Köse, 2008; Rennie & Jarvis, 1995). The visual encodings used in designing visualizations, such as symbols, size, color, and the placement of elements, play a crucial role in conveying meaning (Cairo, 2019, p. 25). Consequently, diverse

representations and varied data stories can emerge from the same dataset. However, it is important to address the challenges that students face with data tools and ensure an inclusive approach, as data stories lose meaning when there exists an imbalance in power and skills between those who create the data and those who represent it (D'Ignazio, 2017; D'Ignazio & Klein, 2020).

Recognizing the inequalities in teaching data science through digital tools and the importance of creativity and flexibility in increasing student engagement and communication with data, Bhargava et al. (2016) conducted a study at an alternative high school. In this study, students collected data, collaborated in designing data sculptures and data murals, and discovered the playful aspects of working with data. Similarly, Stornaiuolo (2019) implemented a project in a makerspace with high school youth, where students authored their data stories and designed t-shirts featuring the data visualizations, they created using their personal data. Matuk et al. (2021) further extended this approach by conducting a similar study online with middle schoolers, who designed data sculptures using pre-existing data. These studies collectively demonstrated that integrating arts and creativity, including drawing, into data science education enhances students' comfort with working with data, develops their data literacy skills, and provides diverse perspectives on the learning subject.

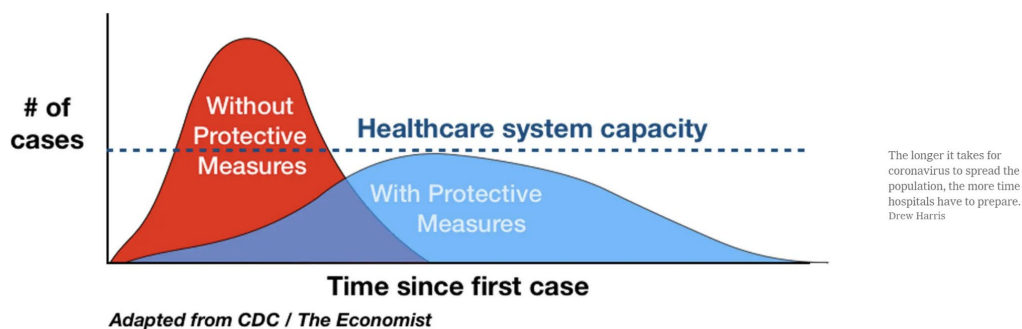
Building upon the understanding of drawing as a powerful tool and drawing inspiration from these studies, the following section will introduce the theoretical framework employed in this study: *creative data literacy*. This framework, along with its complementary frameworks of *data feminism* and *data humanism*, offers valuable insights into promoting data science education, particularly when addressing complex scientific concepts like climate change.

## Theoretical framework

The global outbreak in March 2020 brought to light the critical role of data visualization in informing and guiding public health responses. Visualizations such as the "flatten the curve" line chart effectively conveyed the potential impact of preventive measures on controlling the pandemic (see Figure 2.1). However, while data visualizations have increasingly become essential tools for communicating complex information, there remains a significant gap in effectively teaching data visualization skills. Many existing approaches rely on traditional graphing techniques, which often fall short in empowering learners to become fluent in data literacy and storytelling (D'Ignazio & Bhargava, 2018). Moreover, these approaches tend to prioritize technological and statistical-mathematical knowledge, neglecting the integration of these skills into the broader context of data storytelling and visualizations (Bhargava et al., 2015; Calzada Prado & Marzal, 2013; Sander, 2020). Thus, there is a surging need to develop new and comprehensive approaches that bridge this gap, enabling learners at all levels to effectively communicate insights from data and harness its potential for informed decision-making.

**Figure 2.2**

*How to flatten the curve of coronavirus (Harris, 2020)*



To bridge this gap, I propose an integrated framework that combines *creative data literacy* with the complementary principles of *data feminism* and *data humanism*, with the aim of empowering high school students to become fluent in data. This approach goes beyond traditional data visualization techniques by emphasizing the subjectivity and imperfections of data, fostering a nuanced understanding that anything can be data (Lupi, 2021) and that data can be used for social good. By recognizing the multifaceted nature of data, students can develop the skills and mindset necessary to engage with data as both a source of statistical insights and a means of creating meaningful narratives and memories (D’Ignazio & Sutton, 2015; D’Ignazio & Klein, 2020). Ultimately, this integrated framework seeks to cultivate students’ active involvement in data storytelling and enhance their effectiveness as data communicators.

### ***Creative Data Literacy***

Recognizing the need for a more learner-centric approach, D’Ignazio (2017) introduced the term “creative data literacy.” This concept focuses on developing innovative methods to engage non-technical learners and facilitate the development of their data literacy skills. Within this framework, new teaching strategies have emerged, incorporating elements of art and subjectivity to represent data and weave compelling data stories (D’Ignazio & Bhargava, 2018; Segel & Heer, 2010; Thudt et al., 2017). By embracing creative and constructivist approaches, educators can foster a more inclusive and engaging learning environment that appeals to learners from diverse backgrounds and nurtures their data literacy skills. Creative data literacy goes beyond the traditional focus on statistical literacy and digital data tools, catering to learners, in the case of this study, high school youth, from diverse backgrounds and fostering their abilities to critically engage with data in meaningful and creative ways.

In this framework, the integration of arts and creativity with data science education aims to address the limitations of traditional data literacy approaches that primarily emphasize procedural knowledge and technical skills. By incorporating art and subjectivity, creative data literacy encourages learners to explore alternative ways of representing data, going beyond standard graphs and charts. It recognizes that data can be represented in diverse and imaginative forms that resonate with individuals' lived experiences and perspectives.

Furthermore, within the framework of creative data literacy, new teaching strategies have emerged that incorporate artistic practices and principles. These strategies draw from fields such as information visualization, data storytelling, and data art to engage learners in hands-on, experiential activities that involve creating visual representations and crafting narratives from data (D'Ignazio & Bhargava, 2018; Segel & Heer, 2010; Thudt et al., 2017). By embracing creative and constructivist approaches, educators can create a more inclusive and engaging learning environment that empowers learners to develop critical thinking skills, engage in data-driven storytelling, and make meaning from complex datasets.

**Data Feminism.** In our data-driven society, power imbalances exist within the world of data, as privileged groups tend to dominate this field (Pinney, 2020). Those who collect and own data hold the power to utilize, make decisions based on, and act upon it, thereby influencing the lives of others. The information shared with the public can either guide or mislead them, highlighting the significance of proper education and awareness among the public as data producers and consumers (Cairo, 2020; D'Ignazio & Klein, 2020).

Additionally, the concept of data feminism, as proposed by D'Ignazio and Klein (2020), aligns with the challenges posed by power imbalances in the field of data. Data feminism

challenges the dominant narratives and assumptions in data science, emphasizing the importance of diverse perspectives, context, and social justice in working with data. It highlights the need to consider the social implications and consequences of data representations and to ensure that the creation and interpretation of data are inclusive, equitable, and empowering.

This issue of power imbalances and the potential for discrimination and exclusion in data practices is particularly evident in the ongoing climate crisis, where manipulation of data facts and dissemination of misinformation can impact public opinion and lead to less awareness or action to mitigate its severe consequences. Unfortunately, publicly shared data is often collected by experts for scientific or professional purposes and may not be accessible or useful to the public in their daily data practices. Furthermore, such data may not adequately represent the entire community and may exclude certain groups. However, in today's global society, understanding public datasets is crucial for comprehending cultural, democratic, social, and political structures and for meaningful participation (Philip et al., 2013; Lee et al., 2021).

To address the inequality gap in data science practices, D'Ignazio and Klein (2020), renowned figures in the field of data science education, propose adopting a feminist perspective outlining seven principles to raise awareness of and address the inevitable inequality that arises in data science practices:

1. Examine power: Those involved in data production should also have the agency to utilize and interpret the data.
2. Challenge power: Strive to make data unbiased and inclusive, accounting for disadvantaged groups.

3. Elevate emotion and embodiment: Recognize that the representation of data can evoke various emotions and is susceptible to exploitation.
4. Rethink binaries and hierarchies: Reconsider the use of binary systems and hierarchical structures that may exclude certain groups.
5. Embrace pluralism: Ensure that data is a representative reflection of the diverse population.
6. Consider context: Thoughtfully organize the context and content of data and data visualizations, as they can be manipulated to suit the agendas of privileged groups.
7. Make labor visible: Take steps to prevent gender discrimination within data science practices.

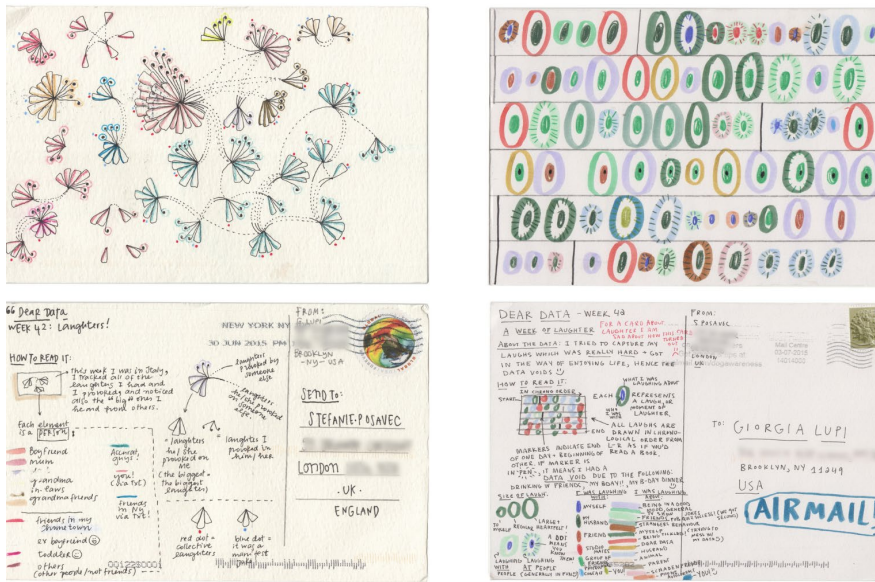
Incorporating these principles into data science can make data more accessible and help prevent potential misinformation, particularly for non-experts.

**Data Humanism.** Giorgia Lupi, a prominent data artist, introduces the concept of “Data Humanism” to foster an understanding of data among non-experts, emphasizing its imperfections and subjective nature, and highlighting its relevance to various aspects of our daily lives (Lupi, 2021). According to Lupi, data serves as an abstracted representation of reality, providing a lens or filter through which we can perceive and make sense of the world. She advocates the idea of data humanism and collaborated with Stefanie Posavec, another data artist, on the Dear Data project in 2014. Over the course of a year, they selected weekly themes, collected data related to those themes, visualized the data on postcards, and exchanged them by mail. The project explored topics such as “a week of laughters,” “a week of clocks,” and “a week of goodbyes” (see Figure 2.2). Through this endeavor, they showcased the “quantified self” approach, utilizing personal data to represent even the small nuances of daily life that often go unnoticed. Adopting

a more humanistic approach to data is essential not only for comprehending and interpreting data visualizations but also for raising critical questions about the data itself, including its collection process, the individuals involved, and its future analysis, storage, and utilization (Bhargava, 2014; boyd & Crawford, 2012; D’Ignazio & Bhargava, 2020).

**Figure 2.3**

*A week of laughters (Lupi & Posavec, 2016)*



“How can we use data for social good?” is a fundamental question that aligns with the principles of data feminism and data humanism. These perspectives emphasize the inclusion of the general public in data science practices and the exploration of data beyond its statistical insights. Several initiatives demonstrate the potential of data for social good. In the Boston Coastline: Future Past project (see Figure 2.3, 2015), Catherine D’Ignazio and artist Andi Sutton engaged volunteers to mark past and future coastlines along the Boston coastline. As participants walked over the predicted/future coastline, they held messages about pressing world issues, such as climate change, symbolizing the intersection of data and social concerns. Similarly, the Data

Murals project implemented at an alternative high school by Bhargava et al. (2015) combined arts and data practices. Participants worked in groups, using the data collected by the project staff, to uncover data stories and design hand-drawn data visualizations. This project not only increased and sustained participants' interest in data literacy but also demonstrated that data science can be performed without relying solely on digital tools, making data for social good initiatives accessible to those without technological resources. These examples highlight the potential for data to serve as a catalyst for social change and empower individuals to actively engage with data in meaningful ways.

## Figure 2.4

*Boston Coastline: Future Past (D'Ignazio & Sutton, 2015).*

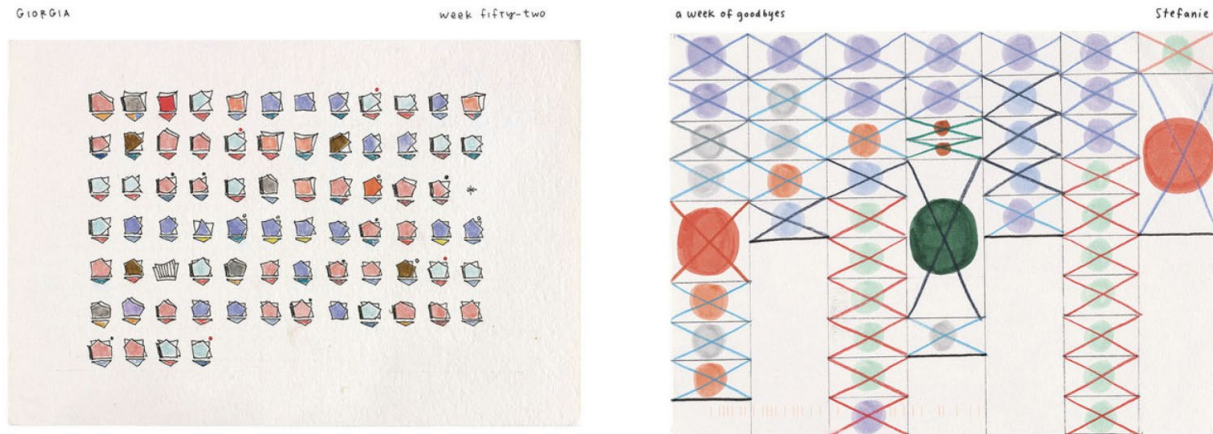


Drawing upon the perspectives presented in the literature, this research endeavors to address the research questions outlined in Chapter 1. By engaging with these inquiries, the aim is to empower high school students in this study with the necessary knowledge and resources to harness the potential of data, thereby fostering a society characterized by equity and informed decision-making.

## CHAPTER 3 – METHODOLOGY

**Figure 3.1**

*A week of goodbyes from The Dear Data Project (Lupi & Posavec, 2016)*



The purpose of this qualitative study (Creswell, 2013) is to explore how high school students from diverse backgrounds, including both technical and non-technical individuals, engage with data and develop creative data literacy skills by utilizing personal data and expressing their understanding through data drawings (Bhargava et al., 2016; D’Ignazio, 2017; Matuk et al., 2021). This investigation aims to address the research questions introduced in Chapter 1, which delve into the various aspects of high school students’ engagement with data, their creative processes, and the acquisition of data literacy skills. Table 3.1 provides an overview of the research objectives, research questions, and data sources, facilitating a clear understanding of the study’s scope and direction.

**Table 3.1***Objectives, Research Questions, and Data Sources*

<b>Objective</b>	<b>Research Questions</b>	<b>Data Sources</b>
For an in-depth understanding of students' approach to data and data practices when crafting and using personal data and creating data stories	1. What are the practices that describe high school students' process of crafting personal data for telling stories about climate change?	Main Zoom and student screen recordings, field notes, student artifacts, self-reflection notes, pre-and post-surveys, semi-structured interviews, self-reflection notes
For an in-depth understanding of students' creative data literacy practices when telling data stories using personal data	2. What kind of creative data literacies do high school students demonstrate in the practices of crafting personal data for telling stories about climate change?	Main Zoom and student screen recordings, field notes, student artifacts, semi-structured interviews, and self-reflection notes

The study was motivated by the project Data VIZion, a free, 5-day summer program that introduced youth to programming and storytelling through data visualizations centered around climate change (Yalcinkaya et al., 2022). In this study, a less technology-dependent approach was employed to establish the fundamentals of the data mindset (D'Ignazio & Bhargava, 2018) and cultivate an understanding that data are imperfect and that all aspects of life can be considered as data (Lupi, 2021). Students actively collected and engaged with their personal data, allowing them to investigate their own contributions to climate change and explore the

impacts of climate change. These activities facilitated the development of creative data literacy skills.

In this chapter, the pilot study, Data VIZion, is discussed as an initial effort to enhance youth's data literacy through programming and visualizing CO2 emissions data to create data stories about climate change. It was observed that students with limited or no programming background faced challenges in creating data visualizations. Taking this into consideration, the study activities in this research are established by emphasizing hand-drawn data visualizations instead of relying on digital tools. This approach aims to foster students' creativity (Lupi & Posavec, 2016; Matuk et al., 2021), facilitate personal connections with data to evoke emotions (Lupton, 2017; Thudt et al., 2017), give them flexibility and freedom when visualizing data, promote comprehension and reasoning of data (D'Ignazio & Bhargava, 2018), and overcome potential limitations associated with digital tools (Ainsworth et al., 2011).

Subsequently, the chapter provides an overview of the study design, student selection, and the specific study activities employed. Finally, the chapter concludes with an outline of the data collection and analysis methods.

### **Pilot Study**

The pilot study was conducted as a free, 5-day summer program aimed at introducing high school youth to computing and data storytelling to enhance their computational data literacy practices. The workshop activities focused on remixing and coding to create interactive data visualizations and to tell data stories related to climate change. The entire workshop was conducted online and synchronously using Zoom, a video conferencing tool, during the summer of 2021. A total of five students, comprising 2 males and 3 females, from different high schools

across two states in the southeastern US participated in the project, representing diverse racial and ethnic backgrounds including White, Asian, African American, and Latinx.

The summer program activities began by introducing students to data visualizations and data stories commonly found in public media. Following this, the ObservableHQ coding platform, a web-based tool that utilizes the D3.js programming language, was introduced as a means to facilitate their exploration. Instructor-gathered datasets, including CO2 emissions data from the Database of Road Transportation Emissions for 2000, 2010, and 2017, as well as ESRI's US census data encompassing variables such as median household income, population density, diversity index, the population counts below poverty level, with bachelor's degree, taking public transportation, taking other types of transportation, average commute time were provided. With these resources, students were encouraged to develop hypotheses regarding CO2 emissions and to explore the coding platform and datasets. Their objective was to create final data visualizations of CO2 emissions and construct narratives that shed light on the human impact on climate change.

The insights gained from the pilot study shed light on students' engagement with data storytelling through coding. The findings highlighted that students were able to establish connections between their personal experiences and climate data, leading to the generation of hypotheses. However, they encountered difficulties in representing data, mainly due to the requirement of reading and comprehending code, data, and the integration of data variables within the code. This indicated a potential gap in the initial activities, where basic data reading practices were missing, which could have yielded different outcomes for the pilot study.

Considering the challenges students faced in the pilot study, the study design for this research is established by prioritizing non-digital tools and emphasizing students' data crafting and representation practices from a creative standpoint, with a focus on the climate change theme.

### **Current Study Design**

This design study (Cobb et al., 2003), Data Viz Art, was implemented as a classroom intervention aimed at facilitating students' interactions with data, particularly their personal data, and fostering creative data literacy skills. The program emphasized a non-technology-centered approach to data visualization, allowing students the freedom to choose whether to use digital tools or not. By providing this flexibility, students were able to explore beyond conventional data visualization methods, establish their own rules, and unleash their creativity (Bhargava et al., 2016; Lupi, 2021; Matuk et al., 2021; Posavec, 2021) while designing their climate change data stories.

The study was conducted in collaboration with a STEM teacher from an Early College Innovation High School in the southeast US and involved a total of nine students from a mixed-grade classroom during the spring of 2023. The workshop comprised four sessions held online, via Zoom, with two sessions per week for two weeks. Each session had a duration of 1.5 hours, aligning with the students' regular class period. The data collection process included approximately 6 hours of Zoom recordings and 16 hours of student screen recordings, in addition to the collection of student artifacts, self-reflection notes, and individual interviews.

The design of this study was informed by a combination of factors, including existing literature on data science education, my own experiences as a data visualization artist and instructional designer, relevant workshops, and the pilot study Data VIZion lesson plans. These

diverse influences provided valuable inspiration in shaping the research design. However, it is important to note that the original design of the study is my own, incorporating elements from these sources to create a unique and tailored approach. By drawing upon my expertise and the insights gained from these inspirations, the study aims to explore the benefits of involving high school students in data visualization practices using their personal data. The integration of creative data literacy, data feminism, and data humanism frameworks further enhances the comprehensiveness of the research design. Overall, the study combines both external inspiration and original contributions to empower high school students, address gaps in data literacy, and foster a more inclusive understanding of data visualization.

The workshop incorporated four fundamental components: the establishment of drawing rule systems, learning about data and data visualization/drawing, crafting personal data (Lupi & Posavec, 2016), and visualizing personal data (Thudt et al., 2017). These components formed the foundation for analyzing the data collected during the project implementation, which facilitated the generation of thematic insights related to creative data literacy practices and skills. Additionally, the components were interconnected and mutually supportive, providing scaffolding for students' learning experiences.

During the initial activity, students acquired the skills to establish drawing rules. Subsequently, they applied these rules in the following activities to visualize and draw the provided and personal data. As the workshop unfolded, students progressively developed data stories that incorporated their personal experiences with climate change. These data stories served as the culmination of their creative data literacy practices and skills. By the end of the program, students had created a series of data stories that reflected their personal insights and engagement with climate change. Table 3.2 shows an overview of session activities.

**Table 3.2**

*Data Viz Art workshop activities*

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**Session 1** Pre-survey

Foraging for data stories in the public media

Introducing Gestalts' visual perception (Wertheimer, 1944) and Bertin's (1981) design principles

Setting up drawing rules exercise (Lupi & Posavec; 2016)

Crafting and drawing personal data on students' "weekly schedule"

Introducing the workshop theme "climate change"

Self-reflection notes

**Session 2** Foraging for climate facts and data visualizations in the public media

Introducing how to read a dataset (Wolff et al., 2016)

Data drawing activity (Food waste dataset)

Introducing the theme of *decomposition in nature* (Cotrufo et al., 2010)

Crafting personal data (everyday items)

Drawing activity (decomposition of everyday items, in class or at home, optional)

Self-reflection notes

**Session 3** Introducing the theme of *carbon footprint* (Wiedmann & Minx, 2008)

Foraging for data stories about carbon emissions in the public media

Introducing data is not perfect

Crafting data from the individual calculations of carbon footprint to repurpose

Drawing activity (individual carbon footprint data)

Self-reflection notes

**Table 3.2** (continued)

<b>Session 4</b>	Introducing the theme of <i>sustainability</i> (Morelli, 2011)
	Sharing and discussing Yale Climate Opinion maps
	What can be used as data (crafting sustainable actions data)
	Drawing activity (sustainable actions)
	Self-reflection notes
	Post-survey

### ***Session Activities***

**Session One.** The first session focused on introducing students to the process of setting up their own drawing rules and crafting personal data. To begin, students completed a pre-survey and installed the screen recording software, Screencastify, which allowed them to capture their on-screen activities. The session then proceeded with an exploration of data visualizations from various public media sources such as the New York Times, Information is Beautiful, and the Tableau Public Gallery. Students were also introduced to renowned data artists, including Giorgia Lupi, Stefanie Posavec, and Federica Fragapane, as well as myself, the instructor of the program.

Following this, students were tasked with selecting a data visualization and sharing it with the rest of the group. They engaged in discussions centered around the questions “What do you notice? and Why does it matter to you?” This exercise aimed to encourage students, as emphasized by other researchers (Hudiburgh & Garbinsky, 2020; Segel & Heer, 2010; Wolfe, 2015), to reflect on the narratives and stories behind the data, enabling them to gain deeper insights.

The next part of the session focused on introducing students to two important resources: Table 3.3, which presents visual design principles from Bertin (1981), and Table 3.4, which outlines the principles of visual perception according to Gestalt theory (Wertheimer, 1944).

Table 3.3, based on Bertin's work, provides a comprehensive set of design principles that students can apply when creating their data visualizations. These principles encompass aspects such as color, shape, size, and arrangement, guiding students in making deliberate design choices that enhance the coherence and legibility of their data stories (Bennett et al., 2007). By referring to this table, students gain a deeper understanding of how these design principles work and can incorporate them into their own data drawings.

Similarly, Table 3.4 presents the fundamental principles of visual perception according to Gestalt theory. These principles explore how humans perceive and organize visual information, including concepts such as proximity, similarity, closure, and continuity. By understanding these principles, students can leverage the innate perceptual tendencies of viewers to create data visualizations that are more intuitive and easier to interpret (Ware, 2012). This knowledge helps students make informed decisions about the arrangement and grouping of visual elements in their data drawings, ensuring that the intended message is effectively conveyed.

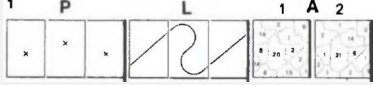


By exploring and applying the principles outlined in Table 3.3 and Table 3.4, students gained a deeper understanding of the concepts and techniques that contribute to effective data visualization. These principles provided a foundation for students to make intentional design choices and create visually compelling data drawings. By internalizing these principles, students were able to communicate their insights and narratives in a visually engaging and accessible manner.

Next, students were introduced to the collaborative whiteboard tool, Miro Board, which was utilized to share resources and materials throughout the workshop. Following these introductions, students engaged in a warm-up exercise called “Draw 100 non-straight lines in a circle for 5 minutes,” designed to stimulate their creativity and prepare them for the upcoming drawing activity.





In the following drawing activity, students were instructed to create a list of their weekly activities/schedules and visually represent this data. The aim of this exercise was to introduce the practical aspect of data crafting and storytelling, providing students with an opportunity to actively engage in the process and experiment with various methods of expressing their personal data. The session concluded with students reflecting on their experiences and documenting them in self-reflection notes.

**Table 3.3**

*Bertin’s seven principles of visual perception (Bertin, 1981)*

Bertin’s visual variables	Description	Sample application in drawing
Two dimensions of the plane	All graphic representations and maps are based on x and y planes and the location of the objects change position on these planes	
Size	The change in length, area, or repetition portrays the proportions of objects	
Value	The superiority of the objects in quantity and order changes from darker to lighter or vice versa	


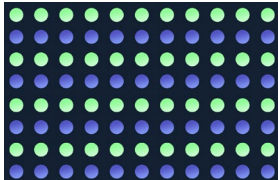
**Table 3.3** (continued)

Texture	The texture of the objects portrays the change in the distribution of values	
Color	The change in the hue of the objects portrays different values and associations	
Orientation	The alignment of the objects portrays variation and different associations	
Shape	Different shapes portray different attributes	

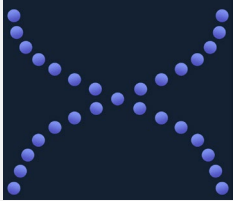
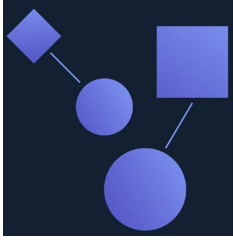
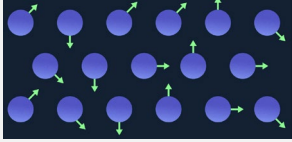
*Note.* Images from Graphics and Graphic Information Processing (Bertin, 1981).

**Table 3.4**

*Gestalt principles of visual perception (Wertheimer, 1944; Ali & Peebles, 2012)*

Gestalt principle	Description	Sample application in drawing
Proximity	Objects that are near each other are perceived as a group	
Similarity	Objects with similar features are perceived as a group	

**Table 3.4** (continued)

Continuity	Objects that form continuous shapes or are perceived as a group	
Connectedness	Objects that are connected visually are perceived as a group	
Common fate	Objects that move or aligned together in the same direction are perceived as a group	

*Note.* Images from the Superside website (Smietana, 2022).

**Session Two.** The second session aimed at introducing how to read a dataset collected by others and data can be subjective (Thudt et al., 2017) through the theme of *waste* and *decomposition in nature*. Cotrufo et al. (2010) define decomposition as “*the process through which dead organic material is broken down into particles of progressively smaller size until the structure can no longer be recognized, and organic molecules are mineralized to their prime constituents: H<sub>2</sub>O<sub>2</sub> CO<sub>2</sub>, and mineral components.*”

The session began with the task of researching factual information about climate change from the provided websites (e.g., [Flourish](#), [Light Pollution](#), [Plastic Air](#)) and any additional sources students wished to explore. Students then shared these facts by responding to the

question, “Why does it matter?” For instance, they might mention that “*24,000 tons of ice melting every second (The Melting Ice Caps, nd) is equivalent to the size of 10 Olympic swimming pools, and at this rate, certain lands may be submerged in the near future.*” Another example could be “*Wasting food contributes to 6% of the world’s total greenhouse gas emissions (Ritchie, 2020), and it matters to me because there are countries experiencing food insecurity and people suffering from starvation.*” The purpose of this activity was to encourage students to consider and discuss the impacts of climate change from various perspectives when sharing these factual statements.

Then, students delved into an instructor-gathered dataset focusing on annual food waste in the US. Exploring this dataset served as a guide for students to develop their skills in reading and interpreting datasets, understanding variables, and identifying outliers and trends within the data. During the drawing activity, students engaged in collaborative discussions with their peers, seeking inspiration and assistance when analyzing the data and seeking visual inspiration.

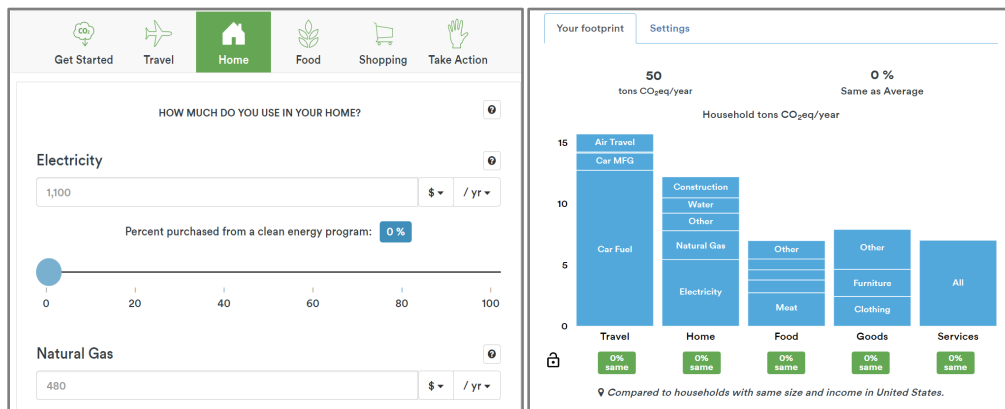
For the second session, two drawing activities were planned. However, due to time constraints, some students had the option to complete the second activity outside of class. For the second drawing activity, students compiled a list of everyday items or items of their choice and utilized this dataset to create their data drawings depicting the decomposition process of these items. Throughout the data collection phase, students collaborated and supported each other. The purpose of this activity was to raise awareness about the environmental impact of everyday items, a theme that was later explored in student interviews. The session concluded with students reflecting on their experiences and documenting their thoughts in self-reflection notes.

**Session Three.** The third session focused on introducing the theme of *carbon footprint* and emphasizing the idea that data is not perfect (Lupi, 2021). Carbon footprint is defined by Wiedmann and Minx (2008) as “*a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities.*”

The session commenced with students searching for data stories about carbon emissions in the public media and on websites of their choice. They then proceeded to the Forterra website, a non-profit environmental organization, to calculate their individual carbon footprints (see Figure 3.2). The calculation involved considering specific human activities such as travel, household energy usage, shopping, and food consumption. By inputting their information, the website generated a bar graph with subsections representing students’ carbon emission levels from various activities and resources. Subsequently, students were tasked with utilizing the information from the bar graph as their dataset and repurposing it by visualizing their carbon footprints.

**Figure 3.2**

*Forterra website carbon footprint calculation overview.*



The purpose of this activity was to encourage students to explore their personal data using a traditional graph format and then repurpose (Wilkerson & Laina, 2018) and visualize it in unconventional ways. Central to their data drawings was the question of “Why does it matter to me and my community?” as the aim of visualizing data is to convey a message (Bhargava et al., 2016; Li, 2020; Segel & Heer, 2010). Due to the nature of this activity, additional web searches were required, such as obtaining the right amounts of electricity bills or annual/monthly gas usage per mile. Moreover, for many students, this was their first experience repurposing data, resulting in a considerable amount of time dedicated to completing the task. The session concluded with students engaging in self-reflection and documenting their thoughts.

**Session Four.** The fourth session aimed to convey the message that anything can be converted into data, and data visualizations reflect the designer’s interpretation of the data (Manovich, 2002; Thudt et al., 2017), using the theme of sustainability. Morelli (2011) emphasizes the connection between human actions and the environment, defining sustainability as “*meeting human needs without compromising the health of the ecosystem.*”

The session began with a discussion of the maps available on the [Yale Climate Opinion](#) website, which displays survey results reflecting the opinions of US citizens about climate change facts. Students shared maps that they found interesting, and then they were instructed to create a dataset that includes the actions they have been taking or considering combating climate change. Unlike other activities, data gathering in this task did not take much time as these students have been learning about sustainability throughout the workshop. However, finding visual inspiration required some time, although students were able to complete the drawing task within the class period. After completing this task, students took the post-survey and filled out

self-reflection notes. Before concluding the session, we discussed plans for individual interviews scheduled for the following week.

After consulting with Mrs. R., the teacher involved in the project, we mutually agreed to hold two meetings per week over a span of two weeks. These meetings took place on Tuesdays and Thursdays, coinciding with the students' regular class period, which lasted approximately 1.5 hours. This scheduling arrangement was chosen to accommodate the students' busy school days effectively. We opted to conduct the project implementation using Zoom, ensuring accessibility for every student. Throughout the meetings, both the students and the teacher were present in the same physical classroom, each equipped with their respective laptops, while I led each session remotely through Zoom. This arrangement facilitated the smooth implementation of the project as the teacher was able to easily guide the activities in person.

### ***Participants***

During the Fall of 2022 and Spring of 2023, a targeted distribution of flyers was carried out within my professional network, reaching out to educators, librarians, and education specialists. These individuals, in turn, shared the flyers with teachers and parents, resulting in a collaborative opportunity with a STEM teacher from an Early College Innovation High School in the southeastern region of the United States. This particular high school is classified as a Title 1<sup>3</sup> school and aligns with the principles of early college innovation education, which emphasize hands-on learning, creativity, and innovation. These schools often provide specialized programs or tracks focusing on areas such as technology, entrepreneurship, STEM (Science, Technology, Engineering, and Mathematics), or the arts. In this context, Mrs. R., a dedicated STEM teacher at

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<sup>3</sup> A Title 1 school is a school that receives federal funding to support students from low-income families in meeting academic standards and reducing the achievement gap (U.S. Department of Education, n.d.).

this high school, expressed keen interest in integrating the workshop into their classroom. Given that the students at this high school have a particular emphasis on science and technology topics, including climate, sustainable development goals, biotechnology, and engineering, the workshop aligns well with their educational focus.

Once the workshop plan was discussed, the teacher provided me with her students’ email addresses. This allowed me to grant them access to the screen recording software and share Zoom links for our meetings. A total of nine students initially participated in the workshop, but one student did not provide consent, resulting in data collection from eight students for this study.

The students represented diverse ethnic backgrounds, including White, African American, and multi-race individuals (see Table 3.5). They also came from diverse socioeconomic backgrounds, as they hailed from various parts of the county. Many of the students were underprivileged, often working part-time or on weekends. Additionally, all students were enrolled in pre-college courses starting in the 9th grade.

**Table 3.5**

*Student demographics (M=Male, F=Female, AA=African American, W=White, MR=Multi Race)*

<b>Student</b>	<b>Gender</b>	<b>Race</b>	<b>Grade</b>
Amy	F	W	10
Dylan	M	MR	11

**Table 3.5.** (continued)

Kaylee	F	AA	10
Levi	M	AA	10
Lily	F	W	11
Maya	F	W	9
Tyler	M	MR	10
Umay	F	AA	9

***Researcher’s Role***

As the researcher in this study, I played a central and multifaceted role throughout the research process. From study design to student recruitment, data collection, analysis, and interpretation of the findings, I was responsible for overseeing the various aspects of the research. In close collaboration with the STEM teacher and students, I ensured that ethical procedures were followed, and all necessary consent forms were obtained. As the study’s instructor, I provided comprehensive resources and instructions to the students, guiding them through the data visualization process. Through my active engagement in the session activities, I gained valuable insights into the challenges and opportunities that the students encountered on their data visualization journey.

**Data Collection**

Qualitative research scholars emphasize the importance of having an adjustable data collection process in their studies. For a thorough and valid investigation, data should be

gathered from multiple sources, including interviews, observations, audio-visual materials, archival records, documentation, and artifacts (Creswell, 2013; Stake, 2010). By utilizing multiple data sources, researchers gain a comprehensive understanding of the study, uncovering the nuances and differences within the subjects' processes and patterns throughout the implementation. This approach allows for a thorough examination of the data, providing valuable insights into the study's findings and enhancing the overall reliability of the research.

Considering the purpose of this study and the research questions, data were collected through various sources including video recordings of Zoom sessions and students' screens, pre-and post-surveys, student artifacts, self-reflection notes, field notes, and semi-structured individual student interviews. These data collection methods provide a comprehensive and rich understanding of the program outcomes and students' experiences.

Before initiating the study and collecting data, the research obtained ethical approval from the International Review Board (IRB) to ensure compliance with the guidelines (Creswell, 2013). The approved protocols for student recruitment were followed, and the study was conducted in strict adherence to the established ethical guidelines.

**Pre- and Post-Surveys.** In qualitative studies, surveys are commonly used to explore the diversity within a group, understand the meaning of phenomena to students, and capture their prior experiences related to the phenomena (Jansen, 2010). Open-ended questions are particularly valuable as they provide insights into the underlying reasons behind students' responses (Creswell, 2013). Hence, at the beginning of the workshop, a pre-survey (see Appendix A) was conducted. The pre-survey consisted of three Likert-scale questions (rated from 1= strongly disagree to 5= strongly agree) and four open-ended questions. Similarly, on the final day of the workshop, a post-survey (see Appendix B) was administered. The post-survey

comprised three Likert-scale questions and eight open-ended questions. The surveys aimed at capturing students' prior experiences, their experiences in the Data Viz Art program, and their thoughts on working with data, data visualizations, and data drawing in the future.

**Main Zoom and Student Screen Recordings.** Teaching online presents challenges in capturing all student actions and processes. In such cases, the use of video recording tools proves beneficial as it provides richer data compared to written observations. Video recordings not only reduce distractions but also allow the researcher to focus on students and their activities. Furthermore, video recordings can be revisited for thorough interpretation when needed (Erickson, 2011; Miller Scarnato, 2017). In this study, in addition to the main Zoom recordings (approximately 6 hours), students' screen recordings (approximately 16 hours in total) were collected to enable the observation of student interactions, movements, and actions on their screens that may not be captured in the Zoom recordings alone. By using video recordings, the study aimed to uncover students' interactions with each other, the instructor, and the data, providing valuable insights into the learning process.

**Student Artifacts.** Artifacts, as man-made materials, reflected personal values, beliefs, world views, and experiences (Saldaña & Omasta, 2018). In the current study, students' data drawings and personal datasets that carried traces of how they approached and interpreted the learning content and data, were collected. These artifacts also served as a reflection of students' creativity, as defined by Brandt (2021), "producing, sharing, or preserving something imagined and unforeseen." In other words, they represented one's interpretation in novel ways and made invisible things/patterns visible. Students then took pictures of their data drawings and emailed them to me, with assistance from the teacher. Although creativity was a major component of this study, the purpose was not to assess the level of students' creativity but rather to observe and

investigate their unique approaches through their data stories. At the end of the workshop, 34 student artifacts were collected from the students.

**Self-reflection Notes.** Self-reflection plays a pivotal role in learning and academic performance (Cavilla, 2017). The idea of reflecting on one's own learning is to think back about the steps taken, evaluate their effectiveness, and make any necessary changes to develop new strategies and internalize the learning content (Le Cornu, 2009; Vygotsky, 1978). In the current study, students self-reflected on their data crafting and drawing processes by answering pre-structured questions (see Appendix C). This allowed them to identify their own strategies, challenges, and approaches to working with data and gain insights into their learning experiences. At the end the end of the workshop, 28 self-reflection notes were gathered from the students.

**Semi-structured Student Interviews.** Semi-structured interviews are commonly used in qualitative studies for their ability to elicit in-depth and detailed responses from students, providing the researcher with opportunities to explore new areas of investigation (Saldaña & Omasta, 2018). In this study, an interview protocol (see Appendix D) was developed to capture students' overall experiences, delve into the specific details of their data crafting and story creation processes, explore their data stories, and identify the aspects they found most enjoyable and challenging. The interviews were carefully coordinated with the teacher during session four to ensure a systematic approach. As intended, the interviews, lasting approximately 30 minutes, were conducted with a total of eight students.

**Field Notes.** Field notes serve as a valuable tool employed by qualitative researchers to capture detailed descriptions and provide additional contextual information for a more

comprehensive analysis (Creswell, 2013). In this study, to ensure objectivity in interpreting the data, minimize biases, and enhance the overall trustworthiness of the findings, my advisor Dr. Shiyang Jiang helped with recording field notes throughout the program. We held weekly meetings to discuss our observations and reflections while our memories were still fresh. The field notes played a crucial role in developing thick descriptions of the contextual factors surrounding the study (Creswell, 2013).

### **Data Analysis**

As Stake (2010) noted, the process of data analysis does not have a fixed starting point. He emphasized that data analysis involves deconstructing the data, examining its components, and reconstructing it to ultimately address the research questions that guide the entire study. In collaboration with my advisor, we conducted weekly meetings to discuss the findings in relation to the research questions (Saldaña & Omasta, 2018). The following section provides an overview of how each data source was analyzed.

**Pre- and Post-Surveys.** Using qualitative surveys, I sought to delve into students' prior experiences and knowledge through the pre-survey, as well as capture any shifts in their attitudes and experiences over time through the post-survey (Jain, 2021). The goal was indeed to understand whether students benefitted from the Data Viz Art program. It is important to note that the survey data in this study were not analyzed quantitatively; instead, they served to provide context regarding the students' backgrounds and learning experiences. The pre-survey findings indicated that students had limited knowledge about data and data visualizations, as well as little to no experience with data collection and drawing. However, the post-survey findings demonstrated that students had developed a better understanding of data, data visualization, and its potential for social impact.

**Main Zoom and Student Screen Recordings.** To ensure reliability in the analysis process (Creswell, 2013), the video recordings were thoroughly examined and discussed with my advisor during our weekly meetings. To gain a deeper understanding of students' actions related to data gathering and drawing, the interaction analysis method (Derry et al., 2010; Jordan & Henderson, 1995) was employed, focusing on students' multimodal interactions with each other, the instructor, and the datasets. The analysis was conducted in four steps:

1. *Compilation of screen recordings content:* Both the Zoom recordings and student screen recordings were carefully reviewed and analyzed. Using InqScribe, a video analysis and transcription software, time-stamped episodes were created. The focus was on capturing moments of interaction between students, the instructor, and the teacher. Significant points in the screen recordings were closely examined to observe students' on-screen activities, such as their search for visual inspiration, data collection from the web, sharing of their drawings with the group, inclusion of variables in their work, and the challenges they encountered and how they resolved them.
2. *Reviewing selected episodes and engaging in microanalysis:* Selected episodes were re-watched to allow for richer interpretations. The focus was on students' interactions with each other, the instructor, their personal data crafting processes, conversations between students (when available), sequence of turn talks, and their variable choices. These episodes were discussed and reviewed with the advisor during the weekly meetings to ensure a comprehensive analysis.
3. *Individual student case memo development:* Individual memos were developed for each student to unveil their patterns and processes. These memos provided

insights into the challenges encountered during data crafting and storytelling, how students approached data collection and storytelling, how they defined their own drawing rules and depicted them, and any unique methods they demonstrated in drawing data.

4. *Microanalysis of creative data literacy processes to identify challenges and learning opportunities:* A microanalysis was conducted on selected episodes in conjunction with student artifacts, interviews, and self-reflection notes. This approach enriched the findings and closely examined the creative data literacy practices and skills demonstrated by students. Critical moments where challenges and learning opportunities occurred (Jordan & Henderson, 1995) were given particular attention during the analysis process.

#### **Student Artifacts, Semi-structured Interviews, Self-reflection Notes, and Field**

**Notes.** Throughout the study, I employed Otter.ai, a transcription software, to accurately document the student interviews. This tool facilitated the transcription process and ensured the precise capture of their responses. To uncover patterns and processes in the creation of student artifacts, I conducted open coding of the interviews, self-reflection notes, and field notes, following established methodologies (Creswell, 2013; Miles et al., 2014). Although the student artifacts were not evaluated in terms of their creative value, they served as valuable supplementary materials for understanding the students' step-by-step processes. The semi-structured interviews provided an opportunity for the students to explain their artistic choices and methods. Regular meetings with my advisor were held to ensure consensus on data interpretation, following a collaborative approach (Lincoln & Guba, 1985). This collaborative

effort allowed for a comprehensive examination of the data, leading to the identification of patterns and the application of a thematic analysis method.

After the analysis of each data source, I engaged in thoroughly reviewing the analysis for each student case, developing a comprehensive understanding of each case, and identifying key patterns related to the two research questions (i.e., creative data literacy practices and skills) within them. Specifically, I developed a nuanced profile for each case and used an open coding approach to identify and label key patterns within each case. Then I looked for similarities, differences, and patterns across the cases. Through this cross-case analysis, several common patterns emerged, encompassing various aspects of creative data literacy. These patterns included challenges faced by the students, sources of visual inspiration, the construction of data stories, the creation of data drawings and legends, decision-making processes, data collection techniques, and data exploration methods. The identification of these patterns shed light on six distinct creative data literacy practices and three overarching themes of creative data literacy skills. The theme development process involved refining the themes by revisiting the original data and ensuring that they accurately capture the essence of each case and the comparisons made. Furthermore, I carefully considered the depth and breadth of the themes and their relevance to the research question, interpreted the themes in light of the research objectives and theoretical frameworks, and shared the themes with students and other researchers to gather feedback and ensure that the themes resonate with their experiences and interpretations.

### ***Trustworthiness***

In qualitative research, it is acknowledged that findings are subject to interpretation, and influenced by the researcher's values, beliefs, and biases. Therefore, it is essential to establish criteria that can persuade others and ensure the study's credibility and contribution to the field

(Creswell, 2013; Saldaña & Omasta, 2018; Stake, 2010). To ensure trustworthiness in this study, I adhered to standards of credibility, dependability, confirmability, and transferability (Creswell, 2013; Lincoln & Guba, 1985; Miles et al., 2014; Saldaña & Omasta, 2018).

**Credibility.** Credibility in qualitative research entails ensuring that the study methods and findings hold meaning for others (Saldaña & Omasta, 2018) and that the findings are reliable (Tracy & Hinrichs, 2017). To achieve credibility in the current study, multiple data sources were utilized, including video recordings, surveys, student artifacts, field notes, semi-structured interviews, and self-reflection notes, allowing for data triangulation (Creswell, 2013). Furthermore, regular meetings were held with my advisor to discuss the analysis process and findings, employing various methods to enhance the credibility of the study's findings. In addition, member checks were conducted through emails and interviews to confirm the accuracy and interpretation of the data.

**Dependability.** Dependability refers to consistency and obtaining similar results when the study is replicated under the same conditions (Lincoln & Guba, 1985; Miles, 2014). To ensure dependability in the current study, a thorough description of the study design and methods is presented, allowing for transparency and potential replication of the study.

**Confirmability.** Confirmability refers to the neutrality and unbiased nature of the study, ensuring that the findings are not influenced by the researcher's prejudices, assumptions, beliefs, and positionality (Creswell, 2013; Lincoln & Guba, 1985; Miles et al., 2014). As a data artist with a particular interest in representing data using free-form and untraditional methods, there is a potential for my attitudes to impact the analysis and interpretation of the findings. To mitigate this, I have established regular meetings with my advisor throughout the study.

**Transferability.** Transferability refers to the extent to which the findings of the study can be applied or generalized to different contexts or populations (Saldaña & Omasta, 2018). It is important to note that claiming generalizability to a wider population can be misleading due to the specific nature of the study. To enhance transferability, I provided detailed and rich descriptions of the whole class studied, including a comprehensive analysis, clear definitions of the variables, and context (Lincoln & Guba, 1985). This will allow readers to assess the relevance and applicability of the findings to their own contexts.

### **Limitations**

The present study had to contend with several limitations stemming from its scope and the constraints imposed by limited class periods. One of the primary limitations was the relatively small number of students involved in the study. With a larger sample size, the study would have been able to generate more robust and generalizable findings. Furthermore, the originally planned session durations had to be adjusted to accommodate the students' timelines and schedules within the school period, which imposed a limitation on the depth and extent of the activities that could be conducted.

Another notable limitation arose from the study's reliance on Zoom for data collection. While the main Zoom recordings and students' screen recordings provided valuable data, certain aspects of classroom activities, such as the process of drawing and in-person interactions, may have been observed more effectively in a physical setting. The limitations imposed by the online environment restricted the ability to fully capture the nuances and dynamics of the students' engagement with the data visualization exercises.

It is important to acknowledge these limitations as they may have influenced the study's outcomes and the interpretation of the findings. Despite these constraints, the study still offers

valuable insights into the benefits and challenges of involving high school students in data visualization practices.

## CHAPTER 4 – FINDINGS

**Figure 4.1**

*A week of doors from The Dear Data Project (Lupi & Posavec, 2016)*



In this study, I identified six creative data literacy practices, including gathering and collecting data, understanding and interpreting a dataset and its variables, selecting variables based on specific criteria and providing reasoning, searching for and finding inspiration for data drawing, creating legible data drawing, and storytelling and making inferences using personal data (Table 4.1). Furthermore, the study identified three overarching creative data literacy skills demonstrated by the students, namely the innovative representation of both numerical and categorical data, effective communication of complex information in engaging ways for the audience, and exploration of personal data for decision-making and social good (Table 4.2). The upcoming section will provide an in-depth exploration of each practice, accompanied by detailed examples that highlight students' progression from data exploration to the creation of compelling data stories. Building upon this, the subsequent section will shift its focus towards the development of creative data literacy skills. Through a comprehensive examination of students'

processes and their interaction with data, this section will showcase how the integration of a familiar activity, drawing, impacted students’ engagement and comprehension of data.

**Table 4.1**

*Overview of Themes in Creative Data Literacy Practices*

<b>Theme</b>	<b>Description</b>	<b>Instance</b>
Gathering and collecting data	Representation of students’ active data crafting evidence, either as a separate list or attached to the data drawing	During Session Two, students listed their everyday items and researched the decomposition time of each. This provided a comprehensive dataset for further analysis.
Understanding and interpreting a dataset and its variables	Representation of students’ engagement with data through the process of comprehending data points, interpreting data trends, and identifying different types of variables	During Session two, students actively engaged with the annual food waste dataset in the US and successfully identified an outlier, which represented the highest percentage value in the dataset.
Selecting variables based on specific criteria and providing reasoning	Representation of students’ defining criteria for selecting variables and their explanations behind their choices	During Session Three, Tyler took the initiative to carefully select the data points that he considered to be the most accurate within his entire dataset.
Searching for and finding inspiration for data drawing	Representation of students’ active visual inspiration search through peer interaction and web searches	During Session Three, Dylan conducted an image search to find car images for his carbon footprint drawing.
Creating a legible data drawing	Representation of students’ drawings with clear “how to read” instructions for the audience, either embedded in the drawing or as a separate legend	During Session Four, Umay designed her data drawing with a color-coded legend.
Storytelling and making inferences using personal data	Representation of students’ making inferences based on their data drawings	During Session Three, as she examined her drawing - Maya discovered that she was emitting more carbon dioxide compared to an average citizen.

**Table 4.2**

*Overview of Themes in Creative Data Literacy Skills*

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Innovative representation of both numerical and categorical data	Representation of students' diverse approaches in drawing and visualizing data points, encompassing both numerical and categorical representations	During Session Two, Umay utilized a movie scene from Toy Story as a visual metaphor, depicting items moving on a conveyor belt towards a fiery decomposition process.
Effective communication of complex information in engaging ways for the audience	Representation of students' creative transformation of complex data into novel and comprehensible data drawings.	During Session Three, Levi visually depicted his carbon emissions amount by using a slice of cake adorned with sprinkles, symbolizing the precise quantity of carbon emitted.
Exploration of personal data for decision-making and social good	Representation of students' self-discovery through personal data and reconsidering their habits and routines from a climate change perspective	During the interview, when discussing his carbon footprint and sustainable actions data, Dylan expressed that he felt he was not making significant contributions to combatting climate change.

**Creative Data Literacy Practices Students Demonstrated**

Creative data literacy practices stand at the intersection of an understanding of data science, art, and design that captures audiences both aesthetically and conceptually (D'Ignazio & Klein, 2020). Practitioners apply data literacy skills while incorporating their unique and creative design approaches to data science, allowing the creation of effective and visually appealing data representations. This helps to reach a diverse audience, including those without technical or professional backgrounds, making the data more accessible and understandable. Creative data literacy practices also enable the implementation of data humanism, which involves incorporating artistic aspects and personalized elements into data representations (D'Ignazio &

Bhargava, 2018; Lupi, 2021). This approach can create more engaging and relatable data visualizations that resonate with the audience.

In the context of this study, I classified the *creative data literacy practices* students demonstrated into the following six categories: 1) gathering and collecting data, 2) understanding and interpreting a datasets and its variables, 3) selecting variables based on specific criteria and providing reasoning, 4) searching for and finding inspiration for data drawing, 5) creating a legible data drawing, and 6) storytelling and making inferences using personal data. These practices aimed to unveil how students approach datasets, understand their components, select variables effectively, create visual representations of data, and effectively convey their data stories. It is worth noting that these practices were not always carried out in a specific order; rather, their application and sequence were influenced by the activity flow and components. For example, when using a pre-existing dataset, students often began by understanding and interpreting a dataset and its variables, while they typically initiated data collection when in other cases. In the next section, I will elaborate on each practice with detailed examples to illustrate how students progressed from data exploration to telling their own data stories.

### ***Gathering and Collecting Data***

As boyd and Crawford (2012) stated, *gathering and collecting data* is a crucial step in data science, as it allows the data owner to develop a deeper understanding of the subject matter and gain valuable insights that can be used for decision-making and other purposes. Furthermore, it is essential to recognize that the data collection and analysis process is inherently influenced by the data owner's perspective, emphasizing their role in shaping and guiding the entire process. This practice also serves as the initial step in data visualization and storytelling, encompassing various data forms beyond numeric data such as daily habits, everyday items, future plans (Thudt

et al., 2017). In this study, the gathering and collecting data practice aimed to introduce students to different data forms and guide them in creating personal climate change data visualizations. Prior to hands-on activities, students watched an informative video by a data artist, Giorgia Lupi (2021), to explore the concept of data and its significance in revealing hidden aspects of everyday life. Examples from the Dear Data project (Lupi & Posavec, 2016) and other designers, including myself, were presented to inspire students with personal data visualizations.

The first drawing activity, involving creating visual representations of students' weekly schedules, was a challenging experience for all as it was their first attempt at crafting data drawings. Although it was not related to climate change in the first place, it served to familiarize students with data drawing and build a solid foundation for meaningful visualizations.

As the workshop progressed, students grew more adept at gathering and collecting data. During the decomposition in nature activity on day two, they collected data on everyday items like cell phones, batteries, cans, and disposable face masks, as well as items from their immediate surroundings and personal belongings like Levi<sup>4</sup> did (see Figure 4.2, right). Some students also included a mix of everyday items and intriguing objects in their lists. For instance, Umay conducted thorough online research and included items like cremated ash after coming across them during her search (see Figure 4.2, left).

This practice remained challenging for some students like Amy. She struggled to think of possible data variables and mentioned that she initially had only five items in her dataset and encountered difficulties in identifying additional variables to incorporate. Consulting with their peers (see Figure 4.3, left), reviewing their lists, and utilizing the workshop resources also provided valuable assistance for students, including Amy. After discussing with her peer, she

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<sup>4</sup> All names are pseudonyms.

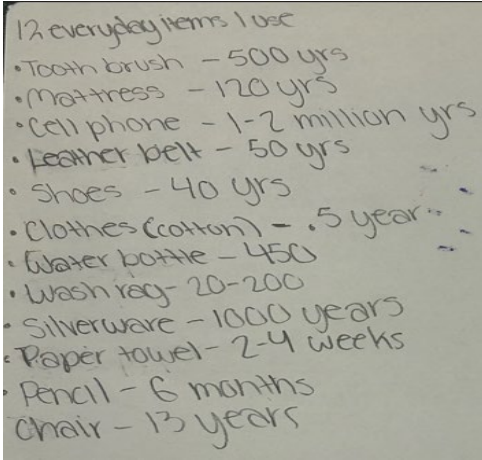
added more items to her list including hair accessories and jewelry (see Figure 4.3, right). She said,

And then the data... I was trying to figure out how, like, what I use and what to put for the data. Because I was, I only had like, five, and then my friends did give me some, like, they told me what they put. And then I was like, “Oh my gosh, you're so right! I use some of these.” (Student interview)

**Figure 4.2**

*Umay's decomposition dataset (on the left) and Levi's decomposition dataset (on the right).*

Item	How long it takes to decompose
iPhone	One - Two Million Years
Cremated Ashes	One Million Years
DVD-R Discs	One Hundred - Two Hundred Years
Light Bulbs	One Thousand Years
One Hundred Dollar Bill (U.S)	Twenty-Three Years
Sneakers	Thirty - Forty Years
Disposable Face Masks	Four Hundred And Fifty Years
Detergent Bottles	Four Hundred And Fifty Years
Lego Brick	One Hundred - Thirteen Hundred Years
Oil	One - Thirty Years
Toothbrush	One Thousand Years
Ziploc Bags	One Thousand Years

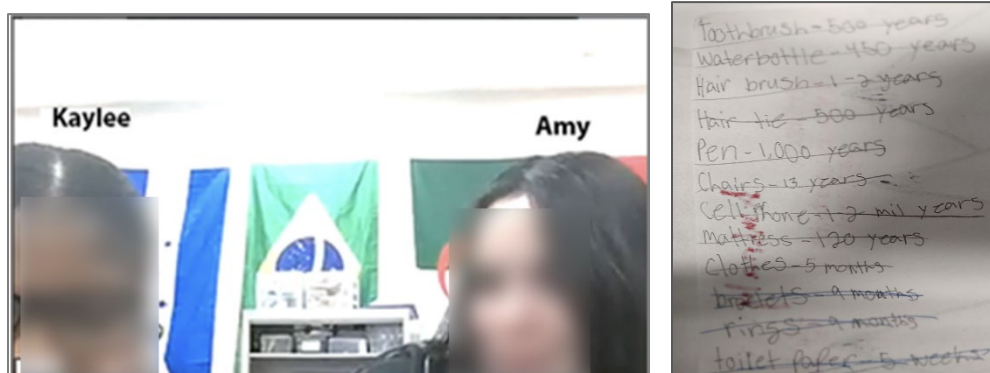


12 everyday items I use

- Tooth brush - 500 yrs
- Mattress - 120 yrs
- Cell phone - 1-2 million yrs
- Leather belt - 50 yrs
- Shoes - 40 yrs
- Clothes (cotton) - .5 year
- Water bottle - 450
- Wash rag - 20-200
- Silverware - 1000 years
- Paper towel - 2-4 weeks
- Pencil - 6 months
- Chair - 13 years

**Figure 4.3**

*Kaylee and Amy are discussing decomposition in nature dataset (on the left), Amy's everyday items dataset (on the right).*



In another activity, students utilized the Forterra website, a non-profit environmentalist organization, to calculate and collect their household carbon emissions data. The website offers sections (see Figure 3.2) for gathering information on specific actions and their corresponding emissions. It generates a bar graph with subsections to provide insights into individual actions. The website also includes a comparison percentage (individual vs. average citizen) to motivate users in their environmental efforts.

Students began by entering essential data, such as zip code and household size, in the initial tab. They then input relevant information in subsequent tabs, aiming to extract data from an original graph and construct a new dataset applicable in different contexts. The activity assessed their understanding of the carbon footprint linked to daily actions and items, as well as their climate impact. Some questions, particularly those related to service expenditures, caused confusion among students. In Excerpt 4.1<sup>5</sup>, I intervened to clarify and encouraged them to consider services that might influence the climate.

Even though the cable itself may not have significant harmful effects on climate compared to other factors, this brief discussion prompted students to reflect on their daily habits and actions. For instance, Tyler searched for the electricity usage of his gaming PC (see Figure 4.4) and included it in his data entry, making his dataset more personalized and meaningful. Though not depicted in the bar graph, Tyler's research increased his awareness of the environmental impact of his PC and gaming habits.

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<sup>5</sup> Transcript conventions: .. indicates pause longer than a second, ... indicates incomplete talk, CAPITALS indicate emphasis, [*Observer notes*] indicates significant gesture and intonation.

## Excerpt 4.1

[Main Zoom recording. Amy is speaking in the group discussion during the carbon footprint activity. February 7, 2023]

1 Instructor: Does any of you know what the services can be, except for the Internet?

2 Dylan: [*looks hesitant*] Umm.. cable? That is what I can think of.

3 Mrs. R.: You mean like TV?

4 Dylan: Yes.

5 Mrs. R.: I have cable because I am old [*laughs*].

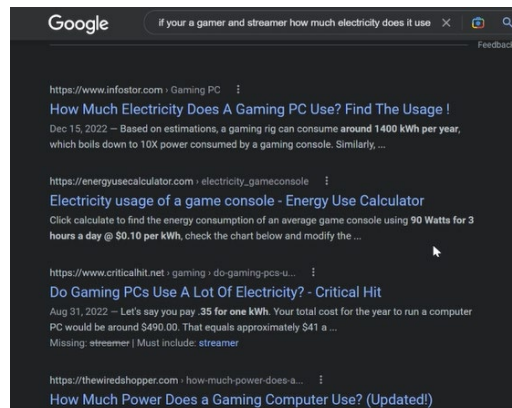
6 Amy: [*looks serious*] I dislike cable. It costs a lot of money.

7 Dylan: [*laughs*] You pay a lot for that.



## Figure 4.4

*Tyler is searching for gaming PC electricity use.*

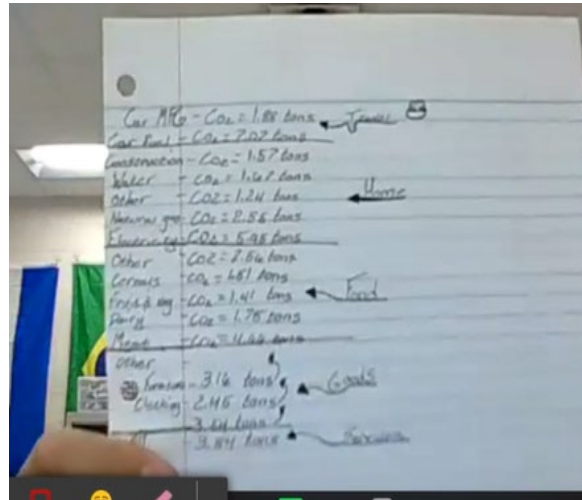


After entering the data, students were tasked with transforming the bar graph into a dataset using its sections and subsections. Initially, some students found this task challenging, requesting examples for better understanding. With a quick demonstration, students proceeded to develop their own datasets. Dylan, an eleventh grader, took the initiative and shared his dataset

with the class as an example (see Figure 4.5). His comprehensive list of items and their subsections from the bar graph served as a reference for his classmates.

### Figure 4.5

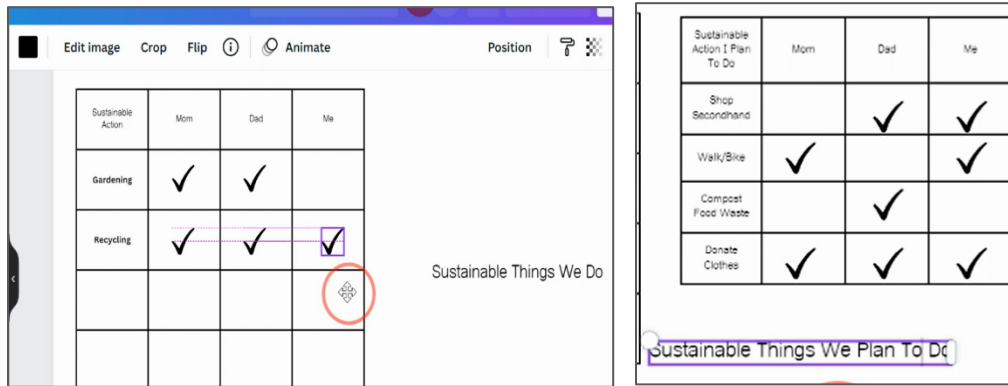
*Dylan is sharing his carbon footprint dataset with the class.*



In the final activity, students created datasets of their environmental and sustainable actions related to climate change. This activity aimed to demonstrate that data can be generated from various sources, even without numerical information. Students quickly brainstormed and documented their ideas, showcasing their awareness of individual efforts to combat climate change. For instance, Umay utilized Canva to create two tables (see Figure 4.6) listing current and future actions for herself, her mother, and her father. Her dataset included sustainable actions like gardening, recycling, and using public transportation. Umay completed her dataset without numerical input, using checkmarks to indicate a commitment to each action.

**Figure 4.6**

*Umay is gathering and collecting sustainable actions data on Canva.*



As seen in these examples, the *gathering and collecting data* practice involved in the workshop served as a scaffold to prepare students for subsequent practices, expand their data knowledge, and inform them about climate facts from a personal perspective.

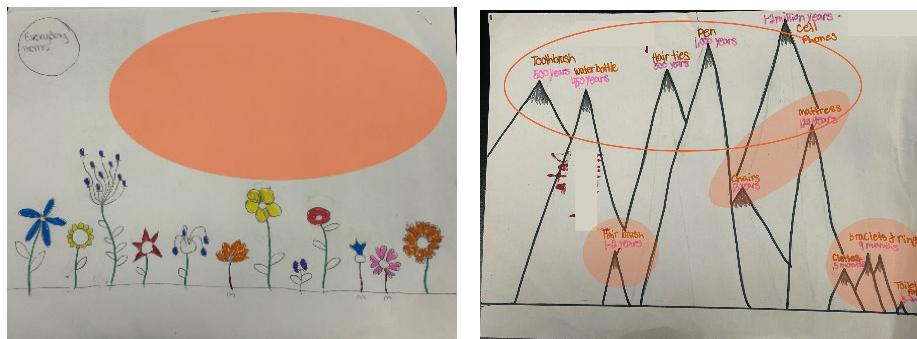
### ***Understanding and Interpreting a Dataset and Its Variables***

*Understanding and interpreting a dataset and its variables* practices are generally associated with statistical data analysis. However, in today's data-immersed world, actively engaging citizens and promoting a data mindset in a creative and non-technical manner has become a critical objective, as emphasized by D'Ignazio and Bhargava (2018). This is also regarded as one of the fundamental principles of data literacy. In this study context, the practice of understanding and interpreting a dataset and its variables involved guiding students to read the dataset, comprehend its variables, and understand and interpret the representation of each data point (e.g., percentages, years, hours), regardless of whether it is personal or pre-provided (e.g., for personal, decomposition in nature; for pre-provided, annual food waste data). For students who participated in the current study, implementing this practice represented a critical initial stage in their decision-making process to optimize the utilization of drawing space, variable

selection, inspiration search, and planning for data visualization. Since the students lacked prior experience in working with and visualizing data, applying this practice was fundamental to building their data literacy skills. For instance, when students were exploring food waste data (see Figure 4.8, left), they were able to identify ‘grapefruit juice’ as an outlier with the highest waste percentage of 47.98%. This unexpected finding sparked a discussion among the teacher and students regarding grapefruit and its juice and motivated them to critically evaluate the data. As the students explored and discussed the data, they began to plan criteria for selecting variables and how they could visualize the data. This demonstrates that these practices were interconnected rather than distinct from one another. Additionally, some students reported that they would adjust their design layout due to an underestimation of the total number of data variables. While some students drew small images resulting in an excessive amount of blank space, others drew large images that needed to be reorganized their images or compressed at the end to fit all the variables within the drawing space.

#### Figure 4.7

*Levi’s excessive blank space (on the left) and Amy’s compressed drawing (on the right). Both are highlighted in orange.*

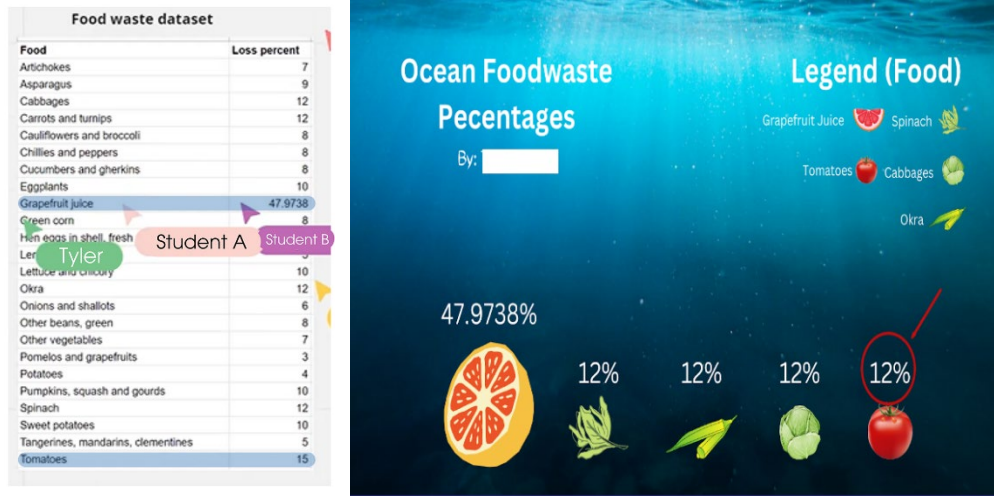


For instance, in the decomposition in nature activity, Levi stated that he would redesign his drawing and adjust the sizes of his shapes because he did not initially pay attention to the total number of data variables (12). He realized this only after completing his drawing which left plenty of empty space on his paper (see Figure 4.7, left). Similarly, in the same activity, Amy stated that her initial figures were tall and large but then she had to erase her drawing several times to fit all her data variables in the available space when she realized that there was not much space left on her paper (see Figure 4.7, right). She attempted to redraw her images but was still unable to achieve the desired image composition.

As mentioned above, one aspect of the practice that guided students was the data variables. Although this practice encouraged sophisticated thinking, students sometimes failed to pay adequate attention to the data variables due to the overwhelming number of numerical values. Tyler, for example, examined the dataset like his peers and selected five variables and their associated numerical values in the annual food waste dataset (see Figure 4.8, left). While he paid close attention to the highest value, grapefruit juice, he misread the percentage of tomatoes and entered 12 instead of 15 (see Figure 4.8, right). Though this may seem insignificant and did not affect the message the data drawing conveyed, mistakes, even on small datasets like Tyler's case can prompt educators and data scientists to rethink how they present information to non-experts, making it important to carefully consider how data is interpreted and communicated.

**Figure 4.8**

*Tyler is exploring the dataset (on the left), Tyler misread the data point (on the right, circled in red).*



The ability to understand and interpret data is crucial for informed inferences. Data serves not only to provide information but also to promote critical thinking and thorough scrutiny to ensure accuracy (D’Ignazio & Klein, 2020). Understanding and interpreting datasets and their variables fosters an inquiry-based approach, encouraging questions about the data and its sources and deepening the analysis. This process offered students an opportunity for exploration and self-discovery. For instance, Tyler gained deeper insight into his personal impact on climate change through novel discoveries, such as examining the electricity usage of his gaming PC during the carbon footprint calculation activity. In the same activity, Maya had self-exploration experiences and she discovered that she emits more carbon dioxide than an average citizen in her neighborhood and stated,

So um, so I thought it was really crazy how like the average US citizen is at 28.2 tons of emissions, and I was all the way at like 53. So I thought that was like really crazy. So I

wanted to make like, like a representation of like, how much that was. (Student interview)

During the decomposition in nature activity, Levi reflected on the severity of climate change and how examining his dataset served as a reminder of it. This experience prompted him to reconsider the everyday items, stating,

The numbers that I got, did kind of shocked me, a match is taking 120 years, a whole lifetime like that. That kind of just surprised me. And then cellphones 1 to 2 million years like that. It kind of opened my eyes about the actions we should be taking. (Student interview)

Initiating the search for inspiration and planning how to visualize data were other essential aspects of understanding and interpreting a dataset and its variables practice. These factors influenced students' processes differently, depending on the dataset. For example, when using a pre-existing dataset, analyzing the variables often stimulated students' immediate search for inspiration, as Umay demonstrated during the annual food waste activity. Conversely, in the case of utilizing a personal dataset, there were instances where the process of data gathering and the search for inspiration were intertwined, as exemplified by Dylan. Dylan expressed that his contemplation of sustainable actions to address climate change prompted him to envision a series of steps, which led him to search for images of stairs to represent these steps (see Figure 4.22).

The examples presented above demonstrate how understanding and interpreting a dataset and its variables influenced students' processes to construct their data stories in diverse ways, ranging from simply interpreting the data to engaging in decision-making and planning strategies, to effectively utilizing drawing tools and visualizing their data. This practice also allowed students to explore invisible layers of their lives regarding climate change.

### *Selecting Variables Based on Specific Criteria and Providing Reasoning*

To create effective data visualizations, data designers often approach a dataset strategically with the goal of representing and conveying a clear message to inform and engage viewers. One common strategy designers implement is the selection of variables based on specific criteria, as Lau and Pan (2015) described, in order to create a comprehensible and convincing visual narrative (Segel & Heer, 2010). On the other hand, when selecting variables, omitting important ones can misinform readers, or including all variables and data points can be overwhelming. Therefore, having a rationale behind the variable selection is crucial for creating compelling data stories. In addition, this practice is intertwined with the previous one, understanding and interpreting a dataset and its variables as one cannot plan the next steps in data visualization if the dataset is unclear. In this study context, the practice of selecting variables based on specific criteria and providing reasoning illustrates students' processes of variable selection and the criteria they identified. Many students found this practice challenging because they were unsure whether they should display all the data variables or choose among them, and how to select the variables that would best represent the dataset. The practice was observed in two distinct forms: one involved selecting variables from a pre-existing dataset, while the other entailed selecting variables for a personally curated dataset.

When working with pre-existing data, students employed various strategies to choose variables. In the food waste activity, Lily organized the data points by grouping them based on initial letters (e.g., As, Cs, Es) and assigned unique symbols to each group, presenting all variables in a single drawing. Lily's selection criteria were her interest in the topic and the variables' impact on the climate crisis. However, some students, like Amy, faced uncertainties in selecting variables. She sought guidance from Levi (Excerpt 4.2) and in Turn 6, Levi provided an

example of defining criteria and applying them when drawing data. This interaction showcases Levi's understanding of variable selection and the supportive collaboration between Amy and Levi.

### Excerpt 4.2

[Amy's screen recording. Levi is helping Amy during the food waste drawing activity. February 2, 2023]

1 Amy: [On the Miro board, pointing to the food waste dataset] Is it this one?

2 Levi: ..Let me see.

3 Amy: Oh, yeah! You can't see.

[Zooms in] This one?

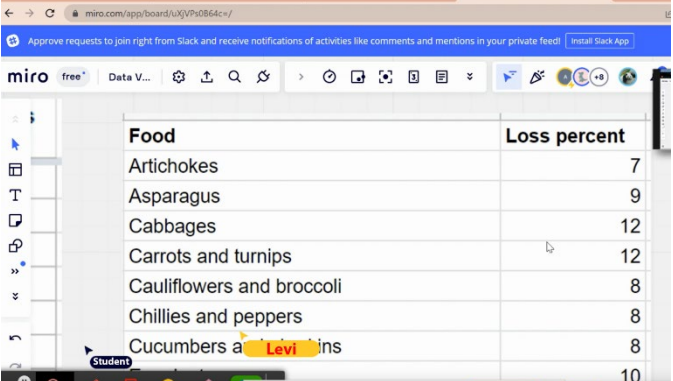
4 Levi: Does that say.. "loss?" Does that

...

5 Amy: Yeah. I am thinking all of that [sounds uncertain].

6 Levi: She [referring to the instructor] says you can group it. So like, say you love these foods [his cursor is on the dataset]...

7 Amy: Uh huh!



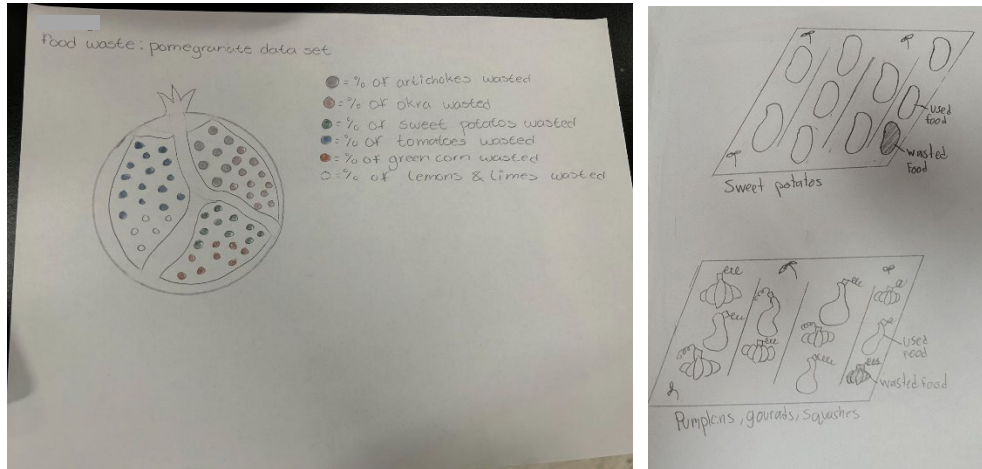
Food	Loss percent
Artichokes	7
Asparagus	9
Cabbages	12
Carrots and turnips	12
Cauliflowers and broccoli	8
Chillies and peppers	8
Cucumbers and lemons	8
	10

Selecting variables was not challenging for some students and exploring the dataset helped with their variable selection criteria. To exemplify, in the same activity, Umay chose to visualize middle values in the dataset (see Figure 4.9, left), but she made her decision after finding visual inspiration, and she stated,

I chose the numbers that were lower in percentage, so I can represent them in the pomegranate because pomegranates are not that big of a fruit. And they only have so many, like fruit seeds inside of them. So, I wanted to make sure I could include each number accurately in the pomegranate. (Student interview)

## Figure 4.9

*Umay's food waste data drawing (on the left), and Maya's food waste data drawing (on the right).*



Similarly, Maya (see Figure 4.9, right) used variables that had the same percentage (10%) in the same activity and said,

So I wanted to... Yeah, I wanted to choose like one was like a percent wasted. That was kind of, like, easy to draw. Because, like, if it was like 13% is kind of hard to divide it. I think each one of these were like 12, like, an exact percentage. So I could draw like 10 or something. Yeah, so yeah, 10. So they're exactly 10%." (Student interview).

Both Maya and Umay explained that selecting variables with similar values was due to design considerations, such as achieving equal division of the drawing space or fitting all variables with similar values in the drawing space. On the other hand, for some students, design considerations were not as important when selecting variables, as was the case with Tyler. He explained that he chose five foods with the highest percentages of food waste, stating, "I decided to take the 5 foods that I found had the most concerning percentages of food waste and use them as a legend for my soon-to-be data story." (Student self-reflection).

Another student, Dylan, took a different approach than Tyler. As did some other students, he decided to include grapefruit juice, which had the highest rate of food waste, along with other foods he was familiar with (see Figure 4.23). Another factor that influenced his variable selection was creating a realistic scene featuring fruits and vegetables growing together in a natural setting.

When working with personally curated data, students took different approaches in selecting variables and data points based on their interests. In the carbon footprint activity, some students included specific data points related to their food consumption habits, while others focused on all main categories or exclusively used the main categories. For example, Umay represented her carbon footprint data by focusing on the main categories and their corresponding subsections, including items like clothes and food. On the other hand, Levi concentrated on the food category and its subsections, influenced by a previous activity on food waste. He stated, “I 1st imagined something that I could alter and change the variables on, all while still relating back to food.” (Student self-reflection)

While Levi’s criterion was established on another activity, food waste, Tyler explained that he looked for the accuracy in his data (see Figure 4.10) whether the data reflected true information. Because it was not possible for him to measure the exact amount of carbon dioxide, he tried to enter his information as precisely as he could and defined his variable selection criterion based on reliability, stating, “The variables I chose were the five most confident amounts of CO<sub>2</sub> emissions that I felt accurately represented me in the form of symbols.” (Student self-reflection)

**Figure 4.10**

*Tyler's carbon footprint dataset.*

CO2 Emission Dataset	
Activity	CO2 Emission
Furniture	2.70 tons CO2
Electricity	2.57 tons CO2
Water	1.35 tons CO2
Clothing	2.55 tons CO2
Car Fuel	11.19 tons CO2

The examples provided suggest that students' selection criteria for variables were predominantly influenced by their data stories, as they all sought to convey a message about the climate crisis and its underlying causes. Even though some students mentioned having initial design ideas, their primary goal was to highlight the factors contributing to climate change. Although pre-existing and personal data sources resulted in varied approaches to variable selection and criteria identification, students reported gaining new perspectives on climate change through these exercises.

### ***Searching for and Finding Inspiration for Data Drawing***

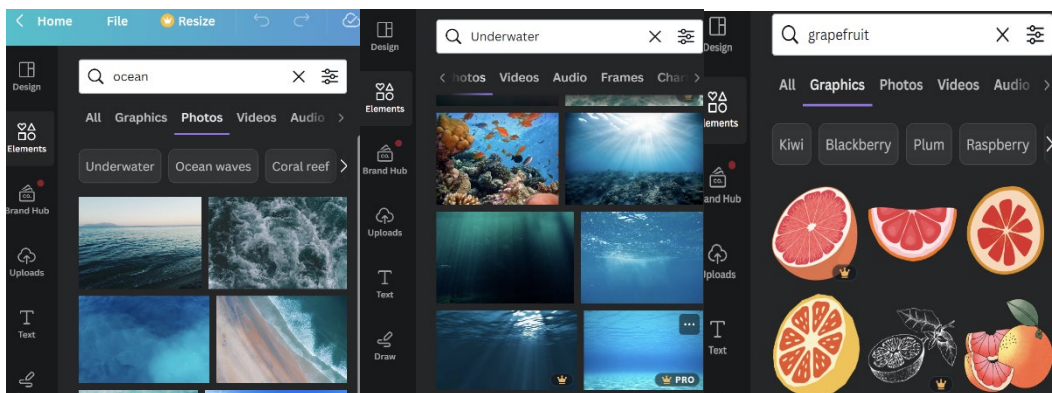
Designers commonly utilize the practice of seeking examples and sources of inspiration during the creation of data visualizations (Bako et al., 2022). As highlighted by Dörk et al. (2020), this approach not only inspires designers but also enables them to gain a fresh perspective by considering the data from the viewpoint of their intended audience. In this learning context, the practice of *searching for and finding inspiration* served as a guide for students to think about effective ways to communicate with their audience. Before letting their data speak, they reviewed learning materials and resources, searched for inspiration in their surroundings, such as the classroom or cafeteria, considered personal interests and previous

projects, and even sought images on the web to develop initial concepts. This step was essential for expressing their ideas and was the final stage before creating their visualizations. Students approached the iterative process with care, often modifying their initial ideas to find the most effective approach.

Tyler stated that due to his tendency to overthink, he had numerous ideas, which made it challenging for him to complete the task within the class period. Regardless, he explored the dataset and its variables, focusing on the top five wasted foods. Inspired by an environmental YouTuber, Tyler aimed to depict the connection between food waste and ocean pollution. Initially considering marine animals, he realized that using actual food images would be more fitting. Leveraging Canva, a digital design tool, he searched for relevant images (see Figure 4.11) and constructed his data visualization, featuring an ocean background and food images symbolizing the waste that ends up in deep seas.

**Figure 4.11**

*Tyler is searching for ocean background and food images on Canva.*



During the same drawing activity, the teacher Mrs. R. realized that Levi was struggling and to encourage and support him, she inquired about his progress (Excerpt 4.3) and the excerpt below demonstrates how this enjoyable conversation both engaged and motivated students.

### Excerpt 4.3

[Main Zoom recording. In-class food waste drawing activity. February 2, 2023]

1 Mrs. R.: [*smiling*] Levi, what do you think? What have you done so far? Let me see.

2 Levi: [*laughs*] Nothing.

3 Mrs. R.: I have a lot of ideas to draw but it is difficult to transfer on paper. Anyone like me? [*laughs*]

4 Mrs. R.: You see? Umay is able to focus [*whole class laughs*]

5 Levi: That's because you have stuff in your mind, I have nothing. [*whole class laughs*]

6 Amy: That's why I was looking... and I was just like, it is the only thing, like came to my mind. [*laughs*]

7 Amy: [*holds her drawing to show Levi*] Look! This is what I did. DON'T JUDGE MY DRAWING! [*laughs*] So, you see the lines, like each part? That's how much percentage loss [*refers to the food waste*]

8 Levi: [*comes closer*] Oh my God! So...

9 Amy: [*keeps holding her drawing*] I haven't finished coloring.

10 Levi: Oh! So you drew each?

11 Amy: Yeah!

12 Mrs. R.: She used actual food.

13 Dylan: That's just one idea [*highlighting alternative ideas can be explored*]



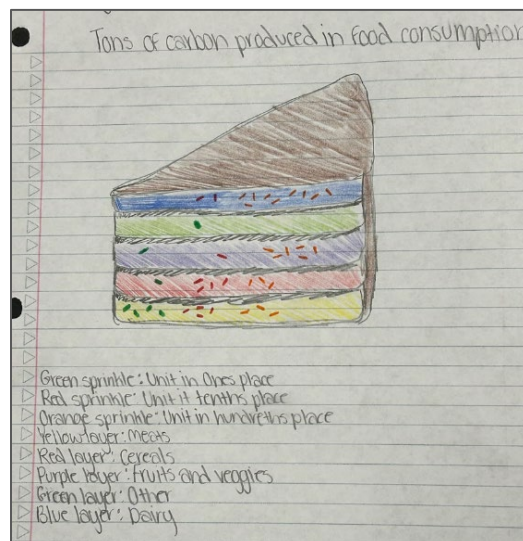
In Turn 3, Mrs. R. reassures Levi that it's normal to have ideas but struggle to put them on paper, to encourage him. In Turn 6, Amy further normalizes this challenge by sharing her own experience of having only one idea for her drawing. Dylan intervenes in Turn 13, emphasizing that there are countless ideas one can explore in their drawings. This class discussion, involving all students, served as motivation for them to seek inspiration and seek feedback from their peers, which in itself was a source of inspiration.

Different scales of variables played a significant role in inspiring students during the drawing activities. For instance, in the carbon footprint activity, Levi focused on his household's food consumption and gathered data on carbon emissions associated with different food types such as meats, cereals, fruits and vegetables, dairy, and others (see Figure 4.12). Each food type had a specific carbon emission value represented in decimal form (e.g., meats emitted 4.43 tons of carbon dioxide per year for Levi's household). Levi's objective was to create a precise visual representation of the carbon emissions for each food type while incorporating the concept of food into his drawing. In his self-reflection, he said:

I 1st imagined something that I could alter and change the variables on, all while still relating back to food. Since my numbers in my dataset were variable I thought how would I be able to show the difference when the scale was so small. This is where I developed my idea to have different color sprinkles represent different number holders, for example the ones place, tenths place and hundredths place. (student self-reflection)

**Figure 4.12**

*Levi's data and legend for the carbon footprint of food.*

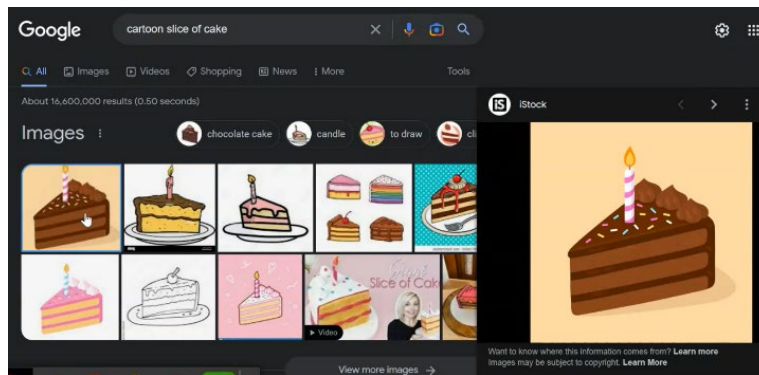


Using the search term ‘cartoon slice of cake’ (see Figure 4.13), he began looking for an image to draw and display different layers as various types of food, and cake decorations as his data variables in numbers (see Figure 4.11). Although he found an image easily, representing the decimals in a meaningful way proved to be the most challenging part of this activity. However, while browsing cake images with sprinkles, he found inspiration in the varied colors of sprinkles that could be used to decorate a cake.

Levi used a slice of cake with five layers to represent carbon emission data. Each layer corresponded to a food type, and the sprinkles on the cake represented decimal numbers. For example, in the meats layer, four green sprinkles represented “4” units, four red sprinkles represented “.4” tenths, and three orange sprinkles represented “.03” hundredths. These numbers added up to a total of 4.43 tons of carbon emissions annually. This creative visualization effectively conveyed Levi’s household’s food carbon emission data story.

### Figure 4.13

*[Levi’s screen recording] Levi is searching for birthday cake images.*



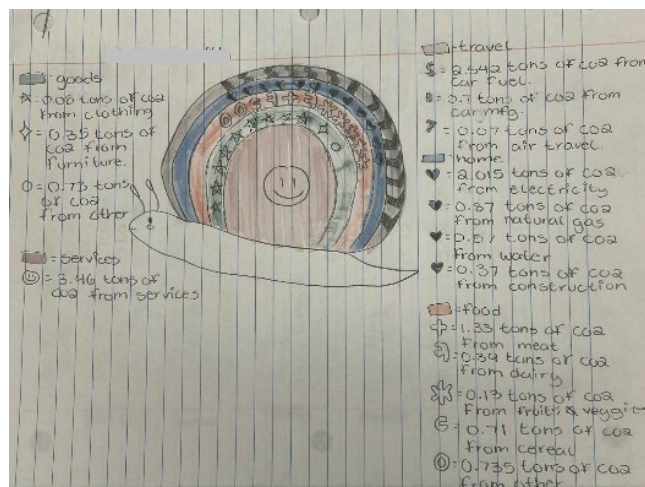
Students’ preliminary knowledge was another source of inspiration as in Umay’s case. She was influenced by her previous Earth science class and drew a snail image stating that it resembles a rock formation with layers (see Figure 4.14). Contemplating the word “carbon” in

conjunction with the theme “climate” also prompted her to consider the Earth and its geological formations. She said, “When people think of carbon, they might think of rock formations or global warming. A snail shell resembles rock formations with its layering, and a snail can represent life on earth that is affected by global warming.” (Student interview).

After combining her ideas and utilizing the resources provided in the workshop, Umay decided to search for snail shell images on the web (see Figure 4.15) and ultimately chose a snail image as her canvas. To represent her data points, she color-coded the main categories, namely “goods, services, travel, home, and food,” and created a different symbol for each subcategory (see Figure 4.14). Umay’s symbol designs were based on the frequency of appearance, rather than the area they occupied on the snail shell. However, some symbols were repeated for design purposes only. For example, she divided her electricity usage numerical value of 8.06 by 4, resulting in 2.015, and drew four symbols to represent this value. Umay explained that she chose this design to achieve a spiral-like effect.

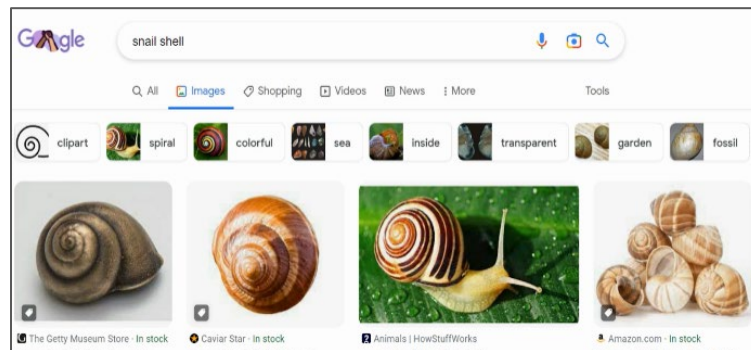
**Figure 4.14**

*Umay’s final drawing for carbon footprint activity.*



**Figure 4.15**

*Umay is searching the web for snail shell images.*



As these examples demonstrate, students found inspiration in various ways. Whether it was by drawing on their prior knowledge, observing their daily lives, utilizing the resources available in the workshop, or being provoked by the topic itself, students were able to create meaningful data stories that effectively conveyed their messages. Even though it was challenging for some students, by finding inspiration from a variety of sources, students were able to connect climate data to other topics and aspects of daily life and gain deeper insights into it.

### ***Creating a Legible Data Drawing***

In previous exercises, students demonstrated their skills in data collection and analysis, as well as interpreting findings and identifying criteria for selecting variables to represent data. Additionally, they explored different sources for inspiration when creating data visualizations. In this study context, the practice of *creating a legible data drawing* facilitated students to develop data visualizations that included a road map, in the form of a legend, to guide their audience in understanding how to read the visualizations. In this final hands-on practice, students demonstrated their proficiency in combining all of these skills to create data drawings using

either paper or digital drawing tools. Through this process, they transformed raw data into visual stories, with each student exhibiting a unique approach to this transformation.

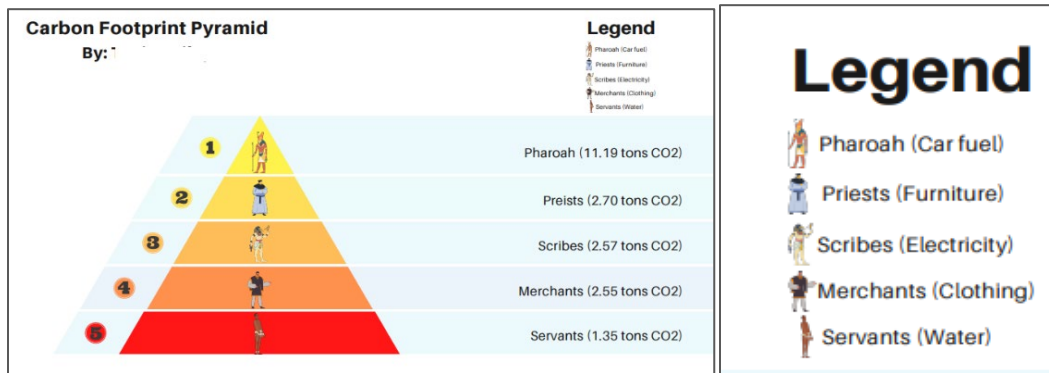
From visual narratives to complete data stories, all students showcased their drawing skills. While the purpose was not to evaluate the level of their skills, it was evident that their approach to climate change and data was closely tied to what they displayed and whether they included a clear legend or glossary for the viewers. Regardless of what the activity was, the practice of including a legend occurred in two ways: providing a separate legend and integrating the legend within the drawing itself.

While students frequently utilize drawings in their classes, the notion of visually representing data points and including a legend for their viewers were new concepts to them. In order to clarify how a legend can be structured, I provided examples within the workshop resources and consistently reminded them to include a legend. Although some students created a simple legend, others included a more detailed one. To exemplify, during the ‘carbon footprint’ activity, Tyler utilized his personal interests and prior knowledge in history class to guide his visual encoding process. He employed a pyramid-like shape with five layers inspired by Maslow's Hierarchy of Needs pyramid, and the shape pyramid was inspired using ancient Egyptian figures (see Figure 4.16, right) to rank his carbon emissions. In his reflection, he noted,

I decided to go with a pyramid, due to the fact that when comparing numbers those values can often go into different places from least to greatest like a pyramid. In other words, when you are dividing power amongst a kingdom in the way of a pyramid you have the most powerful, high-ranking people at the top, and the less powerful, low-ranking people at the bottom. So what I did to draw my data, was to apply the same method. (Student self-reflection)

**Figure 4.16**

*Tyler's carbon footprint drawing (on the left), and Tyler's legend (on the right).*



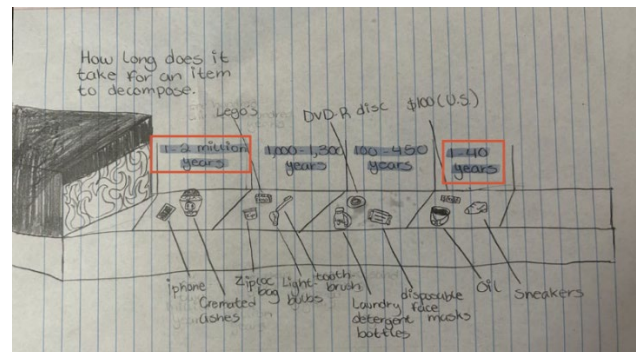
In his design, the pharaoh, representing the most carbon-emitting item, was at the top of the pyramid, while the servant, representing the least carbon-emitting activity, was at the bottom (see Figure 4.16, left). In his legend, Tyler provided information about what each of the ancient Egyptian figures represented. Additionally, he used different colors for each layer of the triangle purely for design purposes. Although Tyler's legend was not detailed as some of his peers, he was able to effectively convey his message. Tyler's approach demonstrated how personal interests and prior knowledge can inform and enhance the visual encoding process. His use of striking images was able to capture the viewers' eye and help to inform them about the carbon emissions of certain items and services.

Unlike Tyler, Umay incorporated her legend within her drawing using labels to guide her audience. During the decomposition in nature activity, Umay drew a garbage disposal conveyor (see Figure 4.17) and placed items on it. The conveyor belt was divided into five sections labeled with decomposition time ranges, from 1-2 million years to 1-40 years. Umay strategically positioned longer-lasting items closer to the decomposer and quicker decomposing items at the far edge. Inspired by a scene from Toy Story, her drawing depicted the accidental collection of toys in a garbage disposal. Though lacking color, Umay effectively conveyed her message with

the title, labeled sections, and tagged items like Ziplock bags and light bulbs. Umay's drawing had the potential to inspire readers to reconsider their own habits and make changes accordingly.

### Figure 4.17

*Umay's decomposition in nature drawing.*



Levi, like some of his peers, represented his sustainable actions data through a drawing without a legend (see Figure 4.18). His drawing featured water drops coming out of a watering pot to nourish a sprouting plant, which he referred to as a sapling. Although he did not provide a legend, he included labels to guide readers. Through his drawing, Levi portrayed sustainability as something that can grow through taking more environmental actions, just like how a plant grows as it is watered, and stated,

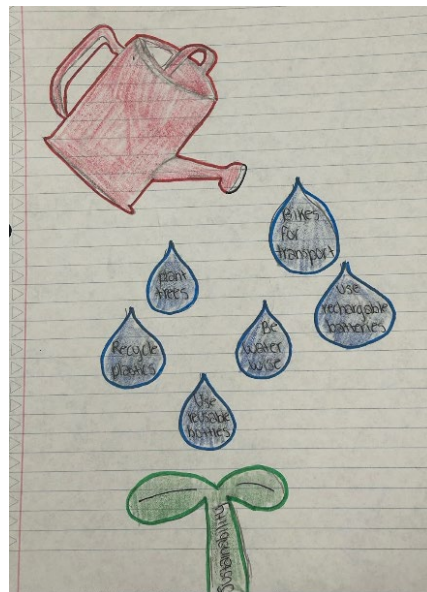
...the watering pot, the red watering pot, that represents like me, myself. And then each other droplets dripping from that pot. Inside each of them, it shows the different actions I will take towards reaching sustainability. And I chose a watering pot in plants, specifically, because the more I water that plant, and the more I do those actions, the more that plant will grow, or the more sustainability will grow. (Student interview)

Levi demonstrated a proactive approach to sustainability by considering himself a “watering pot” for nurturing the growth of sustainable actions. He internalized these actions and

displayed them in a simple and relatable way, which captured the attention of viewers and allowed them to learn from his example. Levi's commitment to sustainability serves as a valuable model for others to follow in taking steps toward a more sustainable future. In fact, during his interview, Levi emphasized his intention to share his drawings with individuals who may be unaware of the effects of climate change. He purposefully chose simple, actionable steps to depict in his drawings, recognizing that these actions can be easily taken by many people.

**Figure 4.18**

*Levi's sustainable actions drawing.*



In the same activity, despite not including numerical data like some of her peers, Kaylee's representation was captivating in its own right. She skillfully depicted leaves embellished with intricate vein patterns. However, initially, she was not sure if her drawing was clear and comprehensible and she asked her peer, sitting next to her, shown in the excerpt below.

#### Excerpt 4.4

[Main Zoom recording. Kaylee asks for feedback and shows her drawing to Amy. February 9, 2023]

1 Kaylee: [*Lowers her tone, showing her drawing to Amy*] If you just came up to this, would you think these are leaves?

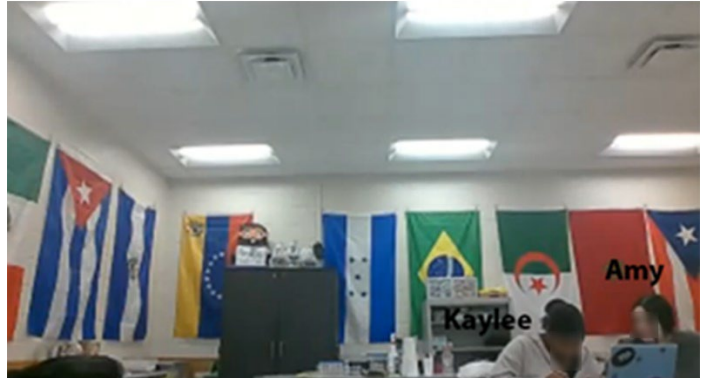
2 Amy: Yeah?

3 Kaylee: [*Hesitant tone*] Really?

4 Amy: What is that one? Like a weird, weird cage? [*laughs*]

5 Kaylee: [*Whispers*] Maybe I need to color them green? [*asks for approval*]

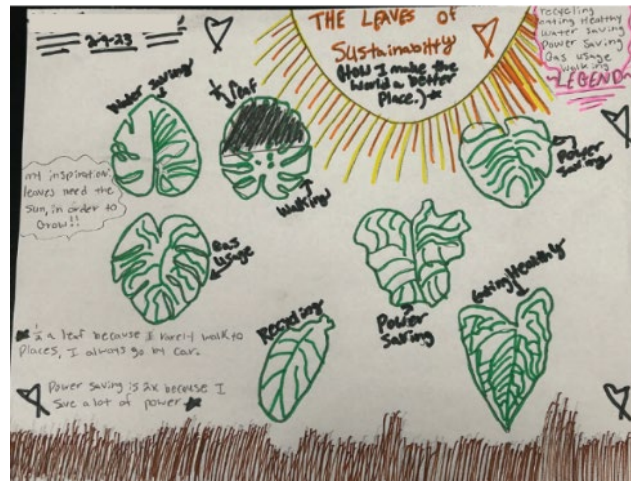
6 Amy: Yeah!



In Excerpt 4.4, Turn 4, Amy's laughter and the analogy of Kaylee's shapes to a strange cage motivated Kaylee to add color and make her data representation more visually appealing. She also added annotations next to some of the leaves, showcasing her commitment to those specific actions (see Figure 4.19). For instance, she drew a leaf to represent "walking" but annotated that she primarily drives instead. To depict this, she decided to draw a half leaf, albeit with some scribbles due to the non-erasable nature of her pencil. Nevertheless, her representation effectively communicated her sustainable actions and areas for improvement.

**Figure 4.19**

*Kaylee's sustainable actions data drawing.*



These examples demonstrate the unique approaches that each student took in drawing data, utilizing various techniques such as color-coding, length, symbols, images, personal interests, and prior knowledge to visualize their data stories. Additionally, the process of internalizing data into one's own identity was observed, as exemplified in Levi's case through his sustainable actions activity. However, despite the differences in their methods, all students successfully conveyed the message of the significance of addressing climate change.

### ***Storytelling and Making Inferences Using Personal Data***

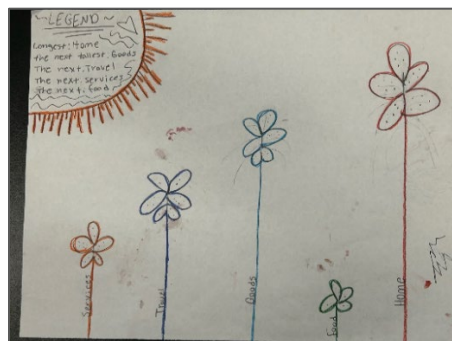
Storytelling has played a fundamental role throughout human history, serving as a powerful tool for education and as noted by Matei and Hunter (2021), a skillfully crafted story has the ability to ignite curiosity within the audience and inspire them to embark on further exploration and inquiry. Therefore, it is integrated into various disciplines, including science, statistics, and the arts. In the domain of data science, researchers advocate for the incorporation of creativity and visual narratives to enhance engagement, similar to the traditional use of

storytelling. This approach stimulates learners to seek more information, derive conclusions, and attain a deeper understanding of the subject matter (D'Ignazio & Bhargava, 2018). In this study context, the concept of *storytelling and making inferences using personal data* pertains to how students interpreted their data narratives and whether they discovered new insights regarding themselves or climate change.

In this study, the data stories students presented uncovered the various dimensions of their daily lives and how they impact climate change, also, prompting them to consider potential precautions and actively engage in mitigating its effects. While some students' data stories may not have visually appeared directly linked to the data or climate change, others creatively employed settings and symbols that were relevant to the environment and the fight against climate change. For instance, in Kaylee's carbon footprint drawing (see Figure 4.20), she used flowers of different lengths to represent carbon emissions. While she did not include specific numerical values, it was evident that, for example, the carbon emitted from foods was less than the carbon from home, including utilities. However, due to the absence of numbers, the exact carbon emission levels were unclear. To provide clearer guidance to her readers, it would be beneficial to include some numerical values alongside her simple legend.

**Figure 4.20**

*Kaylee's carbon footprint drawing.*

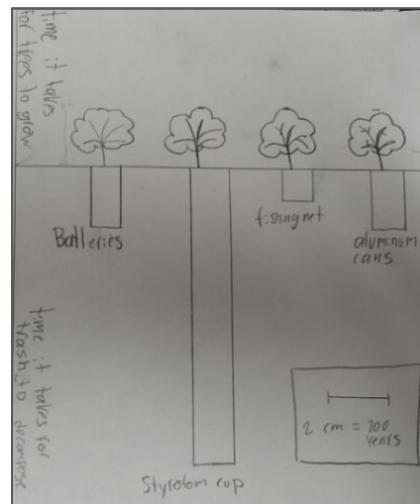


Unlike Kaylee, Tyler's drawing (see Figure 4.16, left) clearly displayed numbers, but his data setting was unrelated to the environment or nature. Instead, he chose to incorporate an Egyptian theme, featuring a pyramid with figures representing ancient Egyptians, such as the pharaoh and priests. Tyler strategically placed the pharaoh at the top of the pyramid to represent his highest carbon emissions, and then hierarchically positioned the remaining figures below. To provide clarity and support to his drawing, Tyler included a numerical order on the left side of the pyramid and assigned specific carbon amounts to each figure on the right side.

Another student, Maya, incorporated a limited number of everyday items in her data story during the decomposition in nature activity. She specifically focused on Styrofoam cups and aluminum cans and compared their decomposition time to the growth time of a tree (see Figure 4.21). Maya visually represented this comparison by placing the trees above and the bars representing the decomposition time below. By highlighting such a contrast, Maya's drawing encourages the audience to reconsider the impact of their everyday items and consider environmentally friendly alternatives. After crafting her data story, she realized that she was not using most of these items except for batteries, and stated, "I don't really use Styrofoam cups, or aluminum cans, or fishing nets. I know there's definitely batteries and some of the stuff that I used. I don't know how I would. I could probably use rechargeable batteries." (Student interview).

**Figure 4.21**

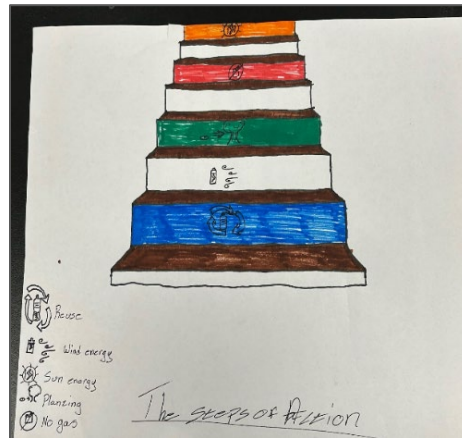
*Maya's decomposition in nature drawing.*



In the sustainable actions activity, students showcased what they have been doing or plan to do in the future to promote sustainability. While reflecting on “what steps you can take,” the idea of stairs emerged. For example, Dylan realized he could have been more sustainable. In his drawing, he depicted stairs in his illustration (see Figure 4.22) and incorporated symbols of sustainable actions on each step to demonstrate progress toward environmental protection, and he reflected, “...that last one I kind of felt personal, cuz when I, when I realized all I do is I’m like okay, dang! I could be taking a lot more accountability for renewable energy and stuff on the planet.” (Student interview).

**Figure 4.22**

*Dylan's sustainable actions drawing.*



As mentioned above, the examples illustrate how students portrayed their personal data in various creative ways, effectively conveying messages, particularly about climate change that could capture viewers' attention and spark their curiosity. The data stories created by students enabled them to make personal discoveries and gain distinctive perspectives and insights into the issue of climate change. This newfound understanding has the potential to lead to further actions and inspire changes in everyday habits, such as reducing the use of disposable materials and opting for reusable alternatives.

In the next section, I will present the creative data literacy skills students demonstrated during the activities.

### **Creative Data Literacy Skills Students Demonstrated**

While data literacy skills are defined as “reading, working with, analyzing, and arguing with data,” (D’Ignazio & Bhargava, 2016), creative data literacy skills incorporate innovative 'design and storytelling' aspects into this definition, humanizing data science and making it more personally relevant (D’Ignazio, 2017; Matuk et al., 2021). These innovative approaches to data storytelling are often associated with art, as individuals represent data using non-traditional

methods such as drawing, audio, and even embodied elements of data (Bhargava et al., 2022; Hannigan et al., 2023; Vacca et al., 2022). In this way, creative data literacy skills go beyond traditional data analysis and visualization methods to better engage and inform diverse audiences.

In this study, I classified the creative data literacy skills demonstrated by the students into three categories: 1) innovative representation of both numerical and categorical data, 2) effective communication of complex information in engaging ways for the audience, and 3) exploration of personal data for decision-making and social good. These skills were observed in all students as evidenced by their artifacts throughout the activities, although the personal approaches varied due to their lack of prior experience with data visualization. While some students demonstrated these skills all at once in certain activities, others developed them gradually. For example, some students preferred to use familiar shapes (such as flowers) when sketching, while others started with a blank slate and sought visual inspiration. In the following section, I will present how students demonstrated these skills utilizing examples from student artifacts.

### ***Innovative Representation of Both Numerical and Categorical Data***

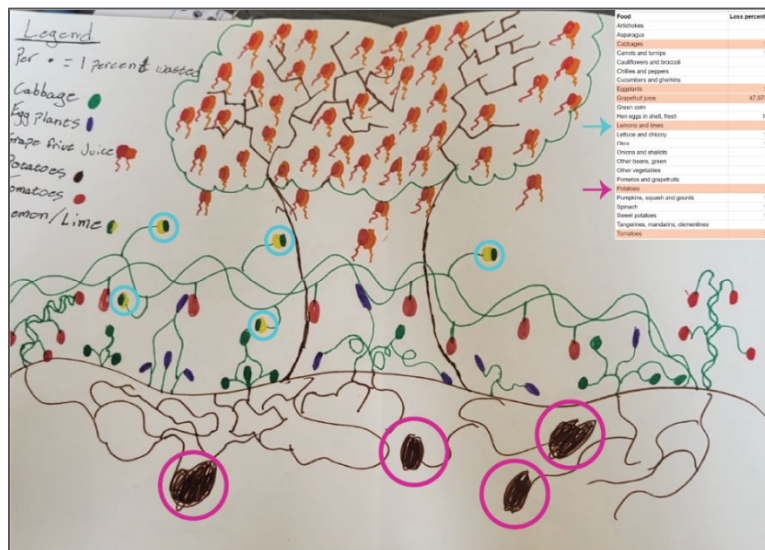
The purpose of the study was to introduce students to creative ways of data representations integrating art and moving beyond traditional data visualization techniques. To provide a better understanding of what these creative approaches entail, students requested examples at the beginning of the study. Along with visual design principles, the Dear Data project (Lupi & Posavec, 2016), and the data visualization designs I created as part of the instruction were among the most utilized resources, as noted by students.

When *representing numerical data*, most students used size and the number of items as their primary methods of differentiation among data points. Additionally, color coding was

utilized to differentiate between types of items, such as fruits and vegetables, when representing more than one aspect of the dataset. During the food waste activity, Dylan chose to represent the precise percentage of waste (numerical data) by drawing the number of items corresponding to the percentage (see Figure 4.23).

**Figure 4.23**

*Dylan's food waste data drawing and the data points he used.*



*Note.* The lemon/lime is highlighted in blue, and the potatoes are highlighted in pink on both the drawing and the dataset. Dylan's variables are also highlighted on the dataset, at the top right.

Dylan's drawing captures a realistic growing environment inspired by his father's garden. He effectively encodes data through symbols and colors that resemble the actual fruits and vegetables. Each symbol represents a percentage of wasted food, carefully placed in their natural habitats. Potatoes lie under the soil, grapefruits hang from the tree, and the rest are displayed above the soil, connected by green stems. While the legend provides instructions on reading the drawing (per ● 1 percent wasted food), the varying circle sizes may cause confusion. Including additional information could clarify the drawing, but overall, it successfully communicates

insights on food waste and the climate crisis by presenting a negative situation in a positive setting.

In the sustainable actions activity, Tyler sketched two different ideas but only completed one of them. Initially, he planned to represent his data through a solar system setting (see Figure 24), inspired by the varying sizes and shapes of stars and planets. He thought that he could display his variables using the solar system. However, he encountered a challenge with managing variables that had the same value on a circular system, which led to him not finalizing this idea. He stated,

I thought if I had everything, every piece of variable had different times where a solar system would have been perfect. But since I have, since I have some of the same things like same times and stuff on them, I didn't go with umm, I didn't go with that. (Student interview)

**Figure 4.24**

*Tyler's initial sketch for sustainable actions drawing.*



**Figure 4.25**

*Tyler's sustainable actions dataset.*

<b>Sustainability Dataset</b>	
<b>Activities</b>	<b>Time Spent</b>
Limited AC usage	3 Years
Local Shopping	3 Years
Using grocery bags as trashbags	2 Years
Turning off of electronics when not in use.	10 Years
Using reusable rags.	10 Years

In Tyler's initial sketch (see Figure 4.24), he placed his first variable which takes "3 years" based on his dataset (see Figure 4.25). However, he may not have had a clear plan on how to represent and differentiate each variable, as well as how to effectively place them on the solar system setting, as his dataset shows that his smallest value was "2 years." Consequently, he decided to switch to a new concept and drew a flower garden setting (see Figure 4.26, left). He noted in his reflection,

I solved this issue by taking a step back and going with something different; in which I chose a flower garden, due to the fact that it can come in all different shapes and sizes no matter what, without having limited options. (Student self-reflection)

**Figure 4.26**

*Tyler’s final drawing for the sustainable actions activity (on the left), and his legend (on the right).*



Tyler’s ‘Sustainability Garden’ drawing adopts a minimalist approach, depicting the Sun, grass, blue sky, flowers, and soil. Each flower represents a sustainable action, tagged with the number of years it has been practiced. The flower sizes reflect the duration, with the tallest flower symbolizing ‘limited AC usage’ for 10 years and the shortest representing ‘reused grocery bags’ for 2 years (see Figure 4.26 right). By utilizing a realistic nature scene, Tyler’s data story inspires reflection on personal actions and encourages combating climate change.

While many students utilized numerical data, there were cases where some students employed categorical data such as Umay’s sustainable actions dataset (see Figure 4.27).

**Figure 4.27**

*Umay's 'sustainable actions' dataset. On the left, she lists their current actions, and on the right, she lists their future actions.*

Sustainable Action	Mom	Dad	Me
Gardening	✓	✓	
Recycling	✓	✓	✓
Eating Organic Foods	✓	✓	✓
Use of public transport			✓

Sustainable Things We Do

Sustainable Action I Plan To Do	Mom	Dad	Me
Shop Secondhand		✓	✓
Walk/Bike	✓		✓
Compost Food Waste		✓	
Donate Clothes	✓	✓	✓

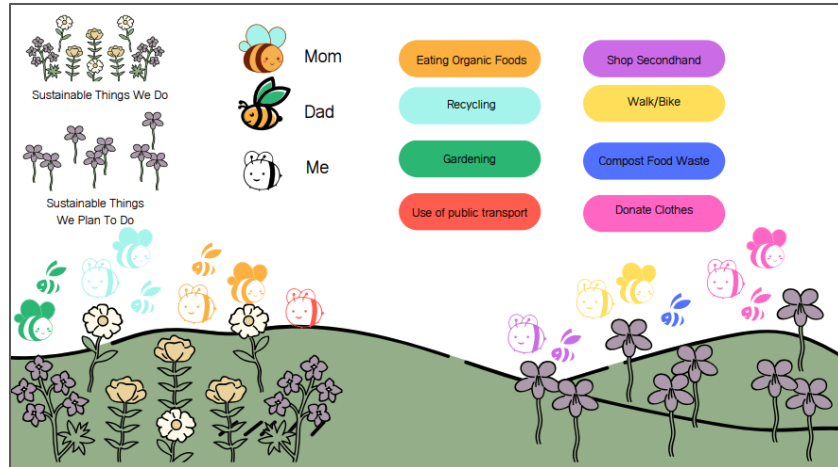
Sustainable Things We Plan To Do

In her drawing, Umay represented herself and her family as bees (see Figure 4.28) and she explained, “I think it’s because it was starting to get warmer outside. And I feel like Bees play a big role in sustainability overall. So I wanted to make use of that in nature.” (Student interview).

Umay creatively depicted sustainability and climate crisis mitigation by incorporating bees, flowers, and a green background. She divided her sustainable actions into current and future fields, color-coding them for clarity. The bees, representing her and her family’s actions, are color-matched to each sustainable action, such as green for gardening. This symbolic representation effectively communicates Umay’s approach to sustainability in a concise and visually appealing manner. Umay drew inspiration from a previous assignment where she used a bee’s nest to represent her hopes and wishes. Using bees and flowers, she depicted categorical variables in a positive nature scene, showcasing her approach to environmental protection and sharing insights through natural elements.

**Figure 4.28**

*Umay's sustainable actions data drawing.*



These examples showcase students' use of numerical and categorical data to create engaging data stories, incorporating actions, emotions, and surrounding events. They communicate their messages through innovative data drawings, reflecting an understanding of data humanism. Furthermore, Tyler's approach exemplifies the students' ability to navigate overlapping variables, demonstrating their resilience in problem-solving. Tyler seamlessly transitioned to alternative ideas to complete their data drawings, showcasing adaptability and resourcefulness. On the other hand, Umay's approach highlights students' creative thinking in representing categorical data. Umay's innovative approach showcases her ability to think outside the box and find creative solutions for visually representing different categories of data. Moreover, their experiences highlight the significance of incorporating the human aspects of data collection, emphasizing the role of individuals in shaping and interpreting data. These diverse approaches reflect creative visualization and critical examination of data, aligning with data feminism.

## *Effective Communication of Complex Information in Engaging Ways for the Audience*

As Wojtkowski and Wojtkowski (2002) emphasized, data visualizations play a vital role in conveying intricate data, surpassing other forms of visual communication, and serving as essential tools to effectively communicate complex datasets, enable readers to comprehend vast amounts of information, and convey complex information effectively. By using unconventional methods to visualize data, they become engaging and comprehensible to a broad range of audiences (D'Ignazio, 2017). In this study, although the students worked with small-scale datasets, their ability to effectively communicate complex information in engaging ways varied greatly based on their imagination and how they incorporated it into their data drawings.

During the decomposition in nature activity, students created datasets by compiling information about the decomposition times of their most-used everyday items. They used web searches to find this information and added their findings to their datasets. However, Umay followed slightly a different approach and she added two items that she found and added during her web search: cremated ash (the ashes of a human body that have been pulverized through the cremation process into a fine powder) and DVD-R disks (see Figure 4.29).

**Figure 4.29**

*Umay's dataset for everyday items.*

Item	How long it takes to decompose
iPhone	One - Two Million Years
Cremated Ashes	One Million Years
DVD-R Discs	One Hundred - Two Hundred Years
Light Bulbs	One Thousand Years
One Hundred Dollar Bill (U.S)	Twenty-Three Years
Sneakers	Thirty - Forty Years
Disposable Face Masks	Four Hundred And Fifty Years
Detergent Bottles	Four Hundred And Fifty Years
Lego Brick	One Hundred - Thirteen Hundred Years
Oil	One - Thirty Years
Toothbrush	One Thousand Years
Ziploc Bags	One Thousand Years

She conveyed her insights by drawing a conveyor belt with various items on it, which appeared to be moving towards a fire (although her drawing was not colored) at the end of the belt (see Figure 4.17). She explained that she was inspired by the conveyor belt scene in the Toy Story movie, adding,

This entire data drawing was based off of a scene from Toy Story where the toys were going into a garbage disposal. So I thought that would be an easy way to represent how long it takes for something to decompose. So the closer it was to the garbage disposal, the longer it took to decompose. And that was also represented by a legend with the numbers in each section. (Student interview)

Umay's realistic approach to depicting data involved a conveyor belt divided into sections based on decomposition time. She tagged each item with years to enhance clarity. However, the positioning of faster decomposing items at the beginning may create confusion about her intended message. Using a familiar device, the conveyor belt, and everyday objects, Umay informs and raises awareness about the impact of everyday choices on climate. While her use of relatable items makes decomposition accessible, the inclusion of cremated ash and DVD-R discs may surprise some as less commonly associated with everyday items.

Another example highlighting students' consideration of their audience when designing data drawings and decision-making with a specific theme can be seen in Umay's food waste data drawing (see Figure 4.9, left). Umay intentionally chose to represent food waste using food visuals to foster stronger connections between the audience and the data, and she stated,

Um, I think just the topic of food overall, was a way that I wanted to represent it. I feel like if people associated food waste with food in general, it would be a better way to get the data across. (Student interview)

In the carbon footprint activity, as mentioned earlier, Levi focused on the food category, which included various items represented as decimal values. To enhance comprehension, Levi creatively represented his carbon footprint of food data using a slice of cake with sprinkles (see Figure 4.12). While the title of his drawing may not immediately explain the connection between food consumption and carbon emissions, the use of sprinkles visually represents the decimal values. For instance, blue represents dairy consumption, and two red sprinkles and nine orange sprinkles represent “0.2” and “0.09” respectively, totaling 0.29 tons of carbon emissions per year. This approach makes the data more accessible and engaging for viewers, encouraging further exploration, and understanding.

These examples show how students creatively visualized complex scientific data, making it engaging and inclusive. Modifying certain aspects can address potential confusion, such as Levi adding a narrative to explain food emissions and Umay enhancing clarity in her depiction of decomposition. These modifications would maintain the students' original data context while still addressing the climate crisis and making data accessible. Their innovative approaches demonstrate dedication to making a positive impact and raising awareness about the global issue of climate change.

### ***Exploration of Personal Data for Decision-making and Social Good***

Using personal data for social impact, an evolving niche in data science, involves meaningfully applying interdisciplinary approaches to extract insights from data and aim at improving well-being and enhance positive outcomes, as Zegura et al. (2018) indicated. This study demonstrates the transformative potential of personal data exploration in fostering climate consciousness and inspiring individual actions. Students creatively utilized their personal data to

create impactful data drawings on climate change, gaining awareness of their own contributions. Interviews revealed that students acquired new insights, prompting them to reevaluate their actions and acknowledge the effects of the climate crisis. For example, Tyler’s reflection on the ‘carbon footprint’ and ‘sustainable actions’ activities led him to recognize that his actions and habits were actually contributing to reducing his carbon emissions. Referring his unplugging unused electronics (see Figure 4.30), he said, “I didn’t even realize I was reducing them, which like most, some people leave their electronics on overnight, I turn them on off, because I don't see the point.” (Student interview).

**Figure 4.30**

*Tyler’s sustainable actions data drawing.*



By comparing his electricity use to his peers, such as Levi, Tyler’s statement can be verified. In fact, by monitoring the students’ screen recordings, it was noted that Tyler’s carbon emissions (see Figure 4.31, left) from electricity usage were around 2.57 tons, while Levi’s was around 7.24 tons (see Figure 4.31, right). Although these values were only approximate, students could still draw inferences about how their daily lives may impact the climate and the steps they can take to reduce its effects.

**Figure 4.31**

*Tyler's carbon emissions amount from electricity usage is on the left, and Levi's is on the right.*



In this example, students demonstrated the principles of both data humanism and data feminism by actively considering the social and practical implications of data. They also exhibited a critical mindset by questioning their personal data to seek additional information and promote more inclusive and equitable practices. Moreover, their act of questioning and comparing personal data suggests their awareness of the limitations inherent in data, such as potential inaccuracies, omissions, or biases.

Exploring his personal data such as how long it takes for his everyday items to decompose, his carbon footprint, and also other workshop resources that show the impacts of climate change, Levi stated,

I'd present it with people who didn't know the effects of climate change or severity of climate change, and the same way I do, I will probably try and share my same viewpoint on that... And I think telling them a data story through data visualizations would probably be the best way. (Student interview)

During the activities, another student, Umay, explored that she was not doing enough to help reduce climate change and stated,

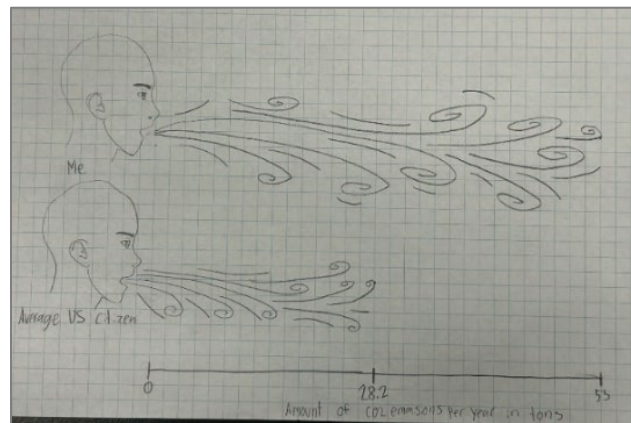
I definitely learned that a lot of the things I do that like, I personally can't change as of now, like with my situation and being a student, that a lot of them do emit a good amount of carbon, and that a lot of things I use are detrimental to the environment and a major factor in climate change. (Student interview)

By exploring her carbon footprint, another student, Maya found out that her carbon dioxide emissions were higher than those of other residents in her neighborhood (see Figure 4.32) and stated,

So um, so I thought it was really crazy how like the average US citizen is at 28.2 tons of emissions, and I was all the way at like 53. So I thought that was like really crazy... I definitely, I definitely found it like really crazy, the sheer amount of carbon, like tons of carbon emissions per year that I produce. (Student interview)

**Figure 4.32**

*Maya's carbon footprint data drawing.*



Maya mentioned that her inspiration came from a data visualization about winds, which she discovered among the workshop resources, and she decided to implement the idea.

Moreover, the activity itself served as a source of inspiration, as it reminded her that humans exhale carbon dioxide. In her drawing, she depicted two human faces exhaling, symbolizing the

average US citizen in her neighborhood and herself. To emphasize the concept, Maya included a scale at the bottom of her drawing to indicate the amount of carbon emissions. While it might not have been immediately evident to viewers, this detail helped clarify the message she wanted to convey. Furthermore, presenting such a comparison can enhance audience awareness and encourage them to seek more information.

These examples highlight how students effectively communicated their comprehension of climate change while infusing their personal experiences into the data, thus humanizing it. Through their drawings and reflections, they conveyed the idea that data extends beyond mere numbers. This approach not only captures the interest of a diverse audience but also generates a social impact and facilitates understanding the significance of the data. Additionally, from a data feminist standpoint, the students' representation of their daily lives serves to reinforce the connection between human activities and climate change. By challenging existing biases and misconceptions that undermine the urgency of the climate crisis, they contribute to fostering environmental protection and awareness.

This research study vividly exemplifies the profound impact of fostering creativity and flexibility in the learning experience on students' development of creative data literacy practices and skills. Remarkably, even without prior experience in working with data and data visualizations, students demonstrated a remarkable understanding of complex scientific concepts. They seamlessly expressed themselves through captivating data stories and exploration of their personal data. This emphasis on creativity not only empowered them to actively engage with data but also enabled them to effectively communicate their insights to others. By embracing and nurturing students' creativity, we unlock their full potential as skilled data users and storytellers.

It is important to highlight that the practices of gathering and collecting data, understanding and interpreting a dataset and its variables, searching for and finding inspiration for data drawing were instructional outcomes of the study. These activities aimed to guide and support students in developing their data literacy skills and creating compelling climate data stories. In addition, the practices of selecting variables based on specific criteria and providing reasoning and creating a legible data drawing were a combination of instructional guidance and student-driven exploration.

As this was the students' first experience working with data and creating data stories, my active involvement was crucial in facilitating the instructional outcomes. I provided guidance, instruction, and support to help students navigate the data visualization process effectively. This active involvement helped shape the learning experiences and fostered a supportive environment for students to engage in the practices and develop their skills.

However, it is important to note that the storytelling and making inferences using personal data was primarily student-driven. Students had the opportunity to explore and express their own narratives and insights based on their personal data, which allowed for greater autonomy and creativity in their learning experiences. Additionally, all creative data literacy skills were also student-driven. As the students progressed and acquired more knowledge during the workshop, they actively demonstrated these skills. These student-driven practices and skills emerged organically as a result of their engagement with the instructional materials and the guidance provided. Overall, a combination of instructional outcomes and student-driven practices contributed to the students' learning experiences in data visualization and data storytelling.

## CHAPTER 5 – DISCUSSION

**Figure 5.1**

*A week of indecision from the Dear Data Project (Lupi & Posavec, 2016)*



In this chapter, I will discuss the significance of the findings in relation to the research literature on data literacy education in K-12 settings and how it was integrated into interdisciplinary learning environments. I will also highlight implications for future research and practice.

This study is built upon the foundation of Creative Data Literacy (D’Ignazio, 2017) and incorporates the perspectives of Data Feminism (D’Ignazio & Klein, 2020) and Data Humanism (Lupi, 2017) to enrich and strengthen the framework. The findings of the study were presented in two main categories: creative data literacy practices and creative data literacy skills. The data analysis encompassed multiple sources, including student artifacts, Zoom recordings, student screen recordings, student interviews, pre- and post-surveys, and student self-reflection notes. Through this comprehensive data collection, the study revealed both commonalities and differences in students’ approaches, offering insights into their patterns and progression

throughout each drawing activity and it shed light on the distinctive techniques employed by students for data collection and drawing processes.

In the context of this study, which centers on students' creation of personal data and climate data drawings, the inclusion of data feminism and data humanism provides meaningful perspectives. Data feminism prompts a critical examination of power dynamics and biases within data practices, emphasizing the significance of inclusivity and social justice. By integrating data feminism, this study recognizes the potential impact of power imbalances and strives to foster equitable data literacy practices while challenging biases. Furthermore, data humanism underscores the importance of ethical considerations and human values in data-driven contexts, aligning with the study's focus on establishing personal connections and encouraging self-expression in climate data drawings. By embracing data humanism, this research prioritizes the well-being and autonomy of students as they engage with data.

The findings of the study highlight the potential of integrating creative data literacy into complex learning concepts, such as STEM subjects, as it enables high school students to develop their unique representations of data that go beyond traditional methods (Bhargava & D'Ignazio, 2017; Matuk et al., 2021). This approach facilitates personal connections between students and the learning subject, as observed in the students' experiences with their data drawings, where they collected and utilized their personal data. This process allowed them to see themselves as data producers and data scientists, fostering a sense of ownership and empowerment in their engagement with data. The findings also revealed that drawing data unlocked creativity and gave more flexibility to students when designing data stories. By incorporating creative data literacy, students not only gained a deeper understanding of the subject matter but also developed valuable skills and perspectives. They engaged in self-exploration through personal climate data

and acquired the ability to add self-expression when visualizing it. As a result, their climate data stories became more personalized and subjective in nature (Thudt et al., 2017).

### **Navigating the Intersection of Personal Data and Creative Data Literacy**

Through the analysis of students' artifacts, video recordings, self-reflection notes, and interviews, six creative data literacy practices emerged, including *gathering and collecting data, understanding and interpreting a dataset and its variables, selecting variables based on specific criteria and providing reasoning, searching for and finding inspiration for data drawing, creating a legible data drawing, and storytelling and making inferences using personal data*. Additionally, three creative data literacy skills were identified, namely *innovative representation of both numerical and categorical data, effective communication of complex information in engaging ways for the audience, and exploration of personal data for decision-making and social good*.

While some of these findings align with existing literature on data collection, interpretation, visualization, and storytelling with data, this study introduces distinctive discoveries that extend beyond the current understanding.

Through a comprehensive synthesis of these emerging themes, three key takeaways have emerged. The first takeaway underscores the significance of establishing a **personal connection to climate data**. During the project implementation, a notable observation was that students who developed a strong personal connection with the data were able to establish meaningful engagements and gain deeper insights. This finding was further supported by the interviews conducted with the students, where they expressed the impact of their personal connection on their engagement and understanding of the data. The ability to establish a personal connection with the data not only enhanced their learning experience but also facilitated a more profound

exploration and interpretation of the information at hand (Jiang & Kahn, 2019; Radinsky et al., 2014; Radinsky et al., 2019; Stornaiuolo, 2020; Wilkerson & Laina, 2018).

The second noteworthy takeaway pertains to the practice of **inspiration hunting**, where students actively pursued and explored creative ideas. This deliberate process involved an active search for inspiration from various sources, allowing students to discover novel and imaginative approaches. By engaging in this practice, students were able to expand their creative horizons and enhance their understanding of data visualization and storytelling techniques. This emphasis on **inspiration hunting** fostered a sense of curiosity and encouraged students to explore different avenues, ultimately enabling them to develop their own unique styles and approaches in working with data (Bako et al., 2022; D'Ignazio & Bhargava, 2015; Matuk et al., 2021) and played a pivotal role in nurturing students' creative data literacy skills and fostering their ability to convey compelling stories through data (D'Ignazio & Bhargava, 2018).

Finally, the third significant takeaway underscores the students' ability to create **innovative and engaging climate data representations**, highlighting their exceptional creative data literacy skills. Through their unique data drawings, the students demonstrated a remarkable capacity for originality and effectiveness in communicating complex information. By employing imaginative and artistic approaches rather than relying on traditional charts or graphs, they showcased their creative thinking and resourcefulness (D'Ignazio, 2017; Stornaiuolo, 2020). This showcases how creative data literacy can transcend traditional visualization methods, allowing students to explore alternative ways of conveying insights and engaging their audience. The students' ability to create such imaginative climate data representations exemplifies the power of creativity in enhancing data communication and fostering a deeper understanding of complex scientific concepts (Gebre, 2022; Matuk et al. 2021; Wilkerson & Laina, 2018).

The comprehensive synthesis of these key takeaways has provided valuable insights into the study context, thereby facilitating a deeper exploration of the research questions. The first takeaway encompasses both research questions, emphasizing the importance of establishing a personal connection to climate data and its impact on meaningful engagements. The second takeaway specifically addresses the first research question, highlighting the practice of inspiration hunting as a means to actively seek and explore creative ideas to depict personal climate data. Lastly, the third takeaway directly pertains to the second research question, showcasing the significance of innovative creative data literacy skills in the creation of engaging climate data representations.

### ***Feeling Personally Connected to Climate Data***

Previous research has demonstrated that shifting the focus of data practices from technical skills and numerical calculations to real-life or personally relevant contexts leads to improvements in both data literacy practices and the understanding of complex learning subjects, such as scientific concepts in K-12 data science education (e.g., Jiang & Kahn, 2019; Matuk et al., 2021; Philip et al., 2016; Radinsky et al., 2014; Rubel et al., 2016; Rudd, 2014). Aligned with prior research, this study observed improvements in students' data literacy skills, such as proficient data interpretation, effective data visualization techniques, and critical analysis of personal data patterns and trends. These improvements were observed through the analysis of student artifacts, screen recordings, and interviews. Notably, students' prior knowledge, experiences, and interests significantly influenced their utilization of personal climate data in creating data stories about climate change. By leveraging their existing knowledge and interests, students were able to engage more meaningfully with the climate data and demonstrate their growing creative data literacy skills within the context of the study.

Moreover, the adoption of learner-centered approaches in data science education shows promise in cultivating high school students' critical thinking, problem-solving, and creativity, distinguishing it from technology-heavy approaches (Bhargava & D'Ignazio, 2015; Bhargava & D'Ignazio, 2017; Harris et al., 2012; Philip et al., 2013; Radinsky et al., 2014). The incorporation of personal data and art into the learning process, especially within scientific concepts, promoted the relevance and motivation for students, while also fostering their tendency to explore the art of storytelling with data, as indicated by previous research (Bhargava et al., 2016; Stornaiuolo, 2020; Thudt et al., 2017). In fact, students ranked the carbon footprint calculation as their top choice in which they felt more personally connected. Sustainable actions followed it. It is noteworthy that these activities involved the use of personal data. One possible explanation for the students' preference for carbon footprint calculation might be that it required entering numerical data, which prompted them to search the web for accurate information. Indeed, Tyler mentioned in his self-reflection that he carefully selected the variables he considered to be the most accurate.

The sustainable actions activity ranked second in terms of personal connection and engagement for the students. While all students listed their own sustainable actions, some took it a step further by personalizing the experience. Umay, for instance, included her household members and their current and future sustainable actions in her data drawing. This personalized approach showcased their collective commitment to addressing climate change and their determination to continue making a difference. Umay's inclusion of her family's actions highlighted the broader impact and long-term perspective that students brought to their data drawings, underscoring the significance of personalizing the data and relating it to their own lives and experiences (Matuk et al., 2021; Wilkerson & Laina, 2018).

Another contribution of using personal data in the sustainable actions activity that increased students' feeling more personally connected was self-exploration through data (Stornaiuolo, 2020). Although not all students crafted numerical data, Tyler, for instance, listed actions he has been doing and for how long, and in his interview, he stated that he was not aware that he was helping with climate change with his simple actions such as unplugging unused electronic devices or reusing shopping bags. This self-exploration through personal climate data increased students' awareness (Gebre, 2022; Wilkerson & Laina, 2018) of their behaviors and habits and may have led them to reconsider their daily lives from a climate change perspective. During the interviews, students expressed their awareness of the actions that can either mitigate or contribute to climate change. However, they also acknowledged their current limitations as students and recognized that their individual impact might be limited at this stage. Nonetheless, they emphasized their willingness to do whatever they can as students to address climate change and it underscores the importance of using personal data and highlights that even small-scale data can have a significant impact when interpreted and analyzed properly. This, in general, demonstrates the value of data literacy in empowering individuals to understand and leverage data effectively (Bhargava et al. 2016; D'Ignazio & Bhargava; 2015).

### ***Inspiration-Hunting: Why Nobody Talks About This?***

One *unique* finding of this study is the practice of searching for and finding inspiration, which was reported by students as the most challenging aspect during the interviews. Despite the existing literature discussing how professional designers find inspiration from other data visualizations, which tends to be software-focused, and literature on how designers sketch and prototype using pen and paper for interface design, both of which target professional designers (Bako et al., 2022; Dörk et al., 2020), there is currently not enough mention in the existing

literature regarding high school students' process of finding inspiration when drawing data. Therefore, this study makes a valuable contribution to literature by shedding light on this overlooked aspect of high school students' creative data literacy, specifically their approach to seeking inspiration.

The process of inspiration-hunting often resulted in the creation of innovative data drawing concepts and settings, exemplified by Tyler's depiction of food waste in the ocean, Dylan's representation of carbon footprint using a gas station and car setting, Umay's portrayal of bees and a garden and Levi's watering pot and sprouting plant to depict sustainable actions, and more. Drawing empowered students to visualize data with flexibility and freedom in unconventional ways, enabling them to push the boundaries of their imagination and break the traditional molds of data representation, which is not commonly seen in traditional formal learning settings (Ainsworth et al., 2011). However, despite this flexibility and freedom, drawing also presented students with significant challenges, as highlighted by all students during the interviews. The process of ideation, where they determined what to draw, consumed a substantial amount of their time and effort. They sought inspiration from various sources, including the workshop materials, available resources (e.g., Google images, Pinterest), their immediate surroundings, past experiences in other projects and classes, personal interests, and interactions with peers. For instance, Tyler encountered challenges in completing his drawings within the class period. He mentioned having numerous ideas for the project but struggled to select one. His teacher, Mrs. R., acknowledged this difficulty in decision-making and noted that Tyler requires clear instructions, detailed guidance, and more time compared to his peers.

During the inspiration-hunting stage, students actively sought visual concepts and design elements to start their data visualizations. Screen recordings revealed that most students initiated

the inspiration search by looking for specific images on the web, evoked by the theme itself, such as food waste and carbon emissions. For example, Dylan associated carbon emissions with cars and gas stations he sees daily on his way to school, and he started searching for car images on the web. Maya drew inspiration from another data visualization about winds as professional designers do (Bako et al., 2022) and represented her carbon emissions as an exhaling human face. Drawing habits also played a significant role in the inspiration-hunting process, as seen in Kaylee's case. Kaylee, who enjoys drawing nature scenes, searched for pictures of flowers, the sky, and landscapes on platforms like Pinterest and incorporated these elements into her drawings. The students' engagement in inspiration-hunting demonstrates their active exploration of visual ideas and their ability to draw connections between the theme and relevant imagery, resulting in unique and creative data stories (Segel & Heer, 2010).

At times, inspiration came from various resources that influenced students' data drawings. Levi, for example, drew inspiration from one of his previous drawings and his peers, incorporating elements to depict his everyday items' decomposition in nature. In his self-reflection notes, he expressed the desire to find inspiration that not only visually appealed to him but also allowed for the smart display of numerical values. Similar sentiments were echoed by Tyler and Umay in their self-reflection notes and interviews, highlighting a common starting idea among students. However, the process of inspiration-hunting was subjective (Bako et al., 2022; Thudt et al., 2017), with some students being data-driven while others were concept-driven. Despite the inherent difficulties, students showcased their creativity and skillfulness by creating unique and distinct data representations. Their drawings ranged from real-life scenes to imaginative elements inspired by their personal interests (Matuk et al., 2021) demonstrating that students not only curated and visualized personal data but also approached data drawing with

remarkable techniques, showcasing their diverse backgrounds, perspectives, and abilities (Bhargava & D'Ignazio, 2015)

### ***Transforming Climate Data into Innovative and Engaging Data Representations***

While there is existing literature on high school students' creation of authentic data visualizations using digital tools or pen and paper, there is limited evidence available on the underlying process of why and how specific representations were chosen and created (e.g., Bhargava et al, 2016; D'Ignazio, 2017; Stornaiuolo, 2020). In the context of this study, the term “innovative” is used to describe approaches to data visualization that go beyond conventional methods, pushing the boundaries of traditional practices. On the other hand, “engaging” refers to the creation of data visualizations that are not only easily understandable but also stimulate curiosity and encourage further exploration of the topic or personal reflection on how the data relates to oneself.

In this study, students showcased exceptional visual encoding abilities by transforming data into novel and engaging data representations through the application of creative data literacy skills. Indeed, visual encoding, a fundamental aspect of data visualization, plays a crucial role as designers establish systems or rules to convey their intended message, assigning specific shapes to represent increasing numbers. This systematic approach establishes a coherent and visually appealing framework for their data stories. By harnessing the power of visual encoding, students effectively communicated complex information and crafted compelling narratives with their data.

Furthermore, the selection of variables or topics of interest and the practice of searching for and finding inspiration was closely connected to the students' creation of data representations. The choices they made regarding variables and their selected methods of data

representation had a significant impact on the context of their data stories and the effectiveness with which they transformed their data into visually appealing drawings to convey their message.

For example, Levi used sprinkles to represent carbon emissions in decimals, Umay used pomegranate kernels to depict food waste in similar percentages, and Maya represented sustainable actions as gift boxes, which she referred to as “Gifts to Mother Nature.” These examples highlight how each student employed a unique approach in transforming their data, whether numerical or categorical, into innovative representations that were visually appealing and, as a result, engaging due to their unconventional nature (Bhargava & D’Ignazio, 2017; Matuk et al., 2021; Segel & Heer, 2010).

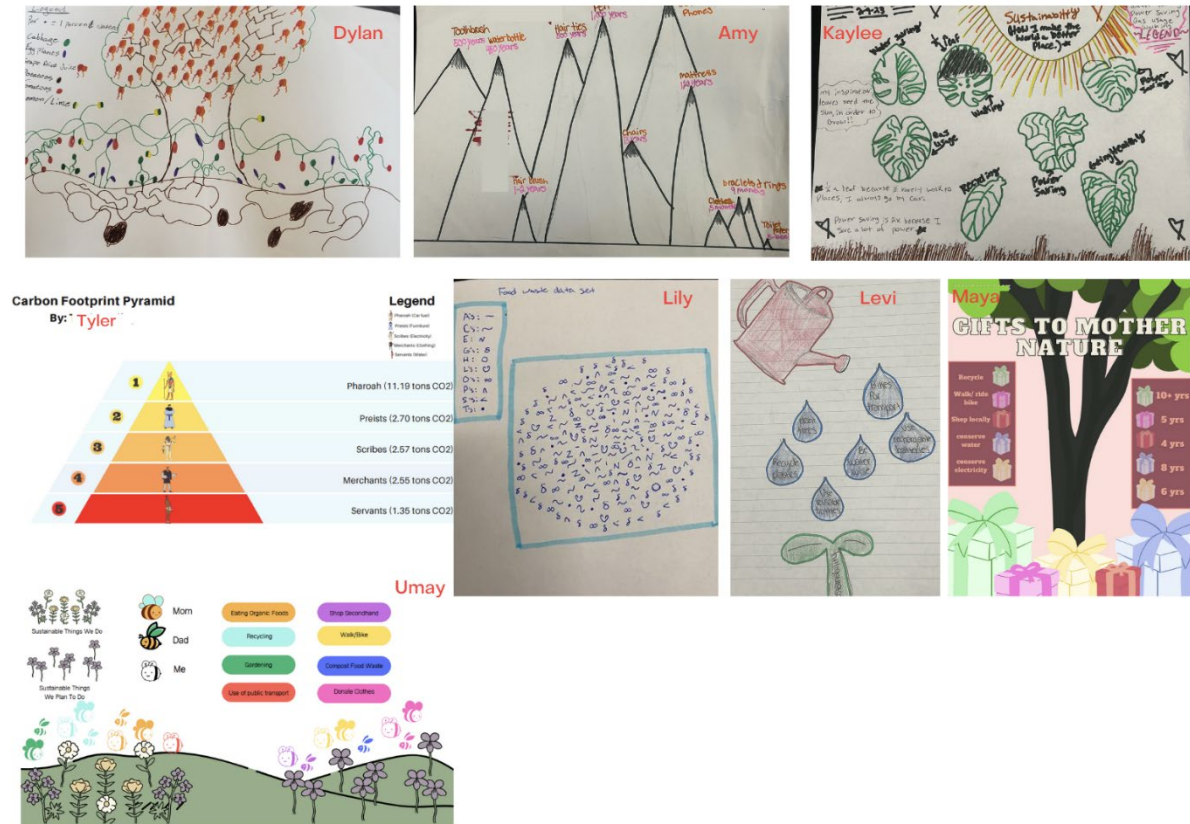
Another notable finding was the observation of students narrating data stories about the causes of climate change, such as food waste and carbon emissions, by employing positive imagery. For instance, Kaylee utilized flowers of varying lengths to depict the decomposition time of her everyday items, and to represent the food waste data, Dylan created a realistic nature setting with fruits and vegetables arranged in their natural growing environments. In both cases, the students transformed negative data into visually appealing drawings that convey a message about climate change while evoking positive emotions, as stated by students during the interviews. By presenting the data in this way, they aimed to encourage their audience to reconsider their behaviors and embrace more climate-friendly practices (Bhargava & D’Ignazio, 2017; Wilkerson & Laina, 2018)

Despite the unconventional and engaging nature of the student drawings, it was observed that not all data stories were easily understandable due to the absence of directions or a legend. For instance, in Kaylee’s drawing representing different levels of carbon emissions from various resources using flowers of different lengths, the absence of numerical values made it challenging

for an outsider to determine the exact amount of carbon emitted. While the data representation was visually appealing, the lack of a legend or numerical annotations hindered clear interpretation. It is possible that students invested a significant amount of time in finding visual inspiration and creating their drawings, which left limited time for including essential explanatory elements. The time constraints within the class period may have posed challenges in fully addressing this aspect of their data stories. In fact, during interviews, students emphasized the importance of adding a legend or potentially revisiting their representations to enhance clarity, therefore enabling them to effectively convey their message and raise awareness about climate change. Figure 5.2 shows a collection of selected data drawings from students.

**Figure 5.2**

Top row, from left to right: Dylan’s food waste drawing, Amy’s decomposition in nature drawing, and Kaylee’s sustainable actions drawing. Middle row, from left to right: Tyler’s carbon footprint drawing, Lily’s food waste drawing, Levi’s sustainable actions drawing, and Maya’s sustainable actions drawing. Bottom row: Umay’s sustainable actions drawing



## Implications

### Implications for Research

This study sheds light on the implementation of creative data literacy in high school students’ data science education and suggests promising areas for further exploration. Notably, the integration of creativity and art allows for self-expression and the infusion of unique perspectives into data representations. Additionally, incorporating personal climate data and art

alongside complex scientific concepts has been shown to enhance student engagement and foster positive learning outcomes. To expand the scale of data, future research should explore the use of software tools for data visualization, moving beyond traditional drawing methods. By embracing digital tools and devices, researchers can investigate the changes and improvements in data literacy, while keeping creativity and students at the forefront of their investigations.

Another important aspect to explore is the application of creative data literacy beyond scientific concepts. This study focused on the use of drawings and visuals to teach a familiar topic like climate change. However, it is essential to extend this approach to other disciplines such as linguistics, social studies, and geography. Investigating how high school students transfer their creative data literacy skills to interdisciplinary fields will provide valuable insights. Moreover, exploring how personal data is utilized in these disciplines has the potential to uncover personal details that may not be typically explored within scientific concepts. Integrating personal data into different disciplines can enhance student engagement by providing meaningful learning experiences (Wilkerson & Laina, 2018) and allowing them to view both their learning and themselves through a data mindset. Additionally, integrating personal data into diverse disciplines serves as a bridge between the statistical perspective of science and other academic fields. This approach enables students to develop a deeper understanding of how data is interconnected with their daily lives and society as a whole. By incorporating personal data in various disciplines, students can see the relevance and applicability of data beyond scientific contexts, fostering a more holistic and comprehensive understanding of the role and impact of data in different aspects of their lives.

Although there is a growing number of studies incorporating creativity and art into data science education, limited research has focused on high school students' processes and patterns

of finding inspiration to visualize data in unconventional ways. Only a few studies have addressed this aspect (e.g., Bhargava & D'Ignazio, 2017; Matuk et al., 2021; Stornaiuolo, 2020), leaving a gap in our understanding. Further research is needed to uncover these processes, as they not only reveal learning patterns and trajectories but also contribute to developing engaging and effective creative data literacy interventions. Investigating the factors that impact students' inspiration search and how they navigate from data to visual inspiration provides valuable insights into their perspectives, challenges, strategies, and biases during data exploration and visualization. Hence, further research is necessary to uncover students' inspiration search processes and patterns in data visualization, as it provides valuable insights into their perspectives and informs the development of effective data literacy interventions. Exploring how students navigate from data to visual inspiration can guide researchers in designing interventions that leverage students' interests and motivations, resulting in increased engagement and improved learning outcomes. Understanding students' creative approaches to data exploration and visualization allows researchers to provide better support and foster meaningful student engagement with data. This line of inquiry holds the potential to shape the design of impactful data literacy interventions that are tailored to students' needs and preferences.

From data exploration to visualization, understanding how students transform data into meaningful and innovative data visualizations is a research area that requires further exploration. This process involves not only data exploration and inspiration search but also the application of specific rules and visual encoding systems such as color, icons, and symbols. By investigating how students navigate and transform data into novel representations, researchers can gain valuable insights into their creative approaches, decision-making processes, and problem-solving strategies. It is important to consider that this process, like other processes, can be influenced by

students' personal interests, prior knowledge, experiences, interactions with instructors, peers, and learning materials, as well as the specific theme or topic being explored. Understanding this process can inform the development of effective instructional strategies and tools that support students' creativity in creating compelling and innovative data visualizations. Moreover, it is worth noting that in the current study, students worked with small-scale data that did not pose significant challenges. However, in today's data-driven era, the volume and scale of data are much larger. Exploring how students can work with larger-scale data and transform and apply their creative data literacy practices and skills is an important avenue for future research. Building upon the current study's approach can serve as a foundation to expand the scope of research and delve into the complexities of working with larger and more diverse datasets.

Finally, it is important to note that the implementations of creative data literacy, as well as data literacy in general, are often confined to the learning environment. There is limited knowledge about the long-term effects of these skills, such as high school students' ability to transfer them to other domains in their social and personal lives. It is necessary to investigate how they apply creative data literacies beyond the classroom, including tracking aspects of their lives, utilizing these skills for social good, and expanding their perspectives on data. Exploring these dimensions is essential for gaining a comprehensive understanding of the impact and potential of creative data literacy beyond educational settings. By examining how creative and artistic approaches to data literacy can be applied, we have the potential to integrate principles of data feminism and humanism perspectives into the field, addressing power imbalances in the world of data and engaging learners from diverse backgrounds. This research direction holds promise for promoting inclusivity, equity, and critical awareness in data literacy practices.

### *Implications for Practice*

Given the increasing importance of data literacy as a fundamental skill, just like reading and writing, this research study has significant implications for the introduction of creative data literacies to K-12 students. It highlights the potential to enhance their ability to communicate with diverse types of data and effectively convey data stories. By integrating creativity and artistic approaches, particularly utilizing personal data, students' creative data literacy skills can be further developed. The study's findings shed light on students' patterns and processes when creating data representations and narratives, offering valuable suggestions for advancing data literacy and data science education. This research provides insights that can guide educators and educational practitioners in fostering meaningful and engaging data literacy practices among students.

One challenge students encountered in the implementation of this study was the time constraints inherent in the class period, which may not provide sufficient time for the students to fully explore and engage with data literacy practices. This observation aligns with existing literature discussing the challenges of time limitations in data science education (Vahey et al., 2012). Although the impact of limited time was not a significant factor in the findings of this particular study, it is crucial to acknowledge that insufficient time can potentially restrict students' creativity, as demonstrated in Tyler's case. Both Tyler and his teacher expressed the need for additional time for Tyler to complete tasks. To address the constraints posed by the limited class period and accommodate students like Tyler, teachers may consider organizing activities in smaller segments and allocating more time for completion. Additionally, tracking students' progress outside of the classroom could be beneficial if they are unable to finish tasks within the designated timeframe. Furthermore, when teaching creative data literacy through the

implementation of drawing and visualization practices, that require creative and flexible thinking, in formal learning settings, educational practitioners may need to carefully plan and allocate sufficient time to allow students to fully engage with and explore these practices. By adapting instructional strategies to account for time limitations and individual student needs, educators can better support students' engagement and learning in data literacy.

Another challenge encountered by students in this study was the process of finding visual inspirations and translating their ideas onto paper. While the students were familiar with drawing, data drawing presented a new concept for them. That is to say, there was a gap between students' current abilities and desired visual outcomes that they wanted to create. It was observed that there were instances where students struggled to complete the task within the class period, such as in the case of Levi during the food waste activity, as they faced difficulty in generating ideas to start drawing their data stories. The teacher, Mrs. R., recognized this issue and provided reassurance by expressing that it is normal to feel stuck at times. This observation highlights the importance of offering sufficient introductory-level hands-on activities that encompass visual design principles, and visual encoding practices and provide inspiration when introducing creative data literacies to novice learners.

Moreover, teachers can provide structured guidance and support in the form of brainstorming sessions, visual references, and demonstrations of different data drawing techniques. By offering step-by-step instructions and examples, educators can help students bridge the gap between their current abilities and the desired visuals they aim to create. Additionally, encouraging peer collaboration and feedback can foster a supportive environment where students can exchange ideas and learn from one another. Through these scaffolding

strategies, teachers can empower students to overcome challenges and develop the necessary skills and confidence to effectively translate their ideas into visually compelling data drawings.

Educators can prompt inspiration search and guide students in implementing creative data literacies by introducing diverse sources and examples. They can showcase a wide range of data visualizations, including those created by other designers, and emphasize that inspiration can come from anywhere. By highlighting the varied sources of inspiration and encouraging students to explore different domains and perspectives, educators can foster a culture of creativity and expand students' creative horizons in data visualization and storytelling. Such an approach will enable students to develop effective data drawing strategies, as data drawing and representation involve incorporating information visualization techniques to effectively communicate data to an audience.

Speaking of the limitations of a single class period, teachers can address this by collaborating with educators from different disciplines. This approach aligns with the notion that 'teaching data literacy in K-12 settings should not only be associated with and integrated into STEM subjects' (Bhargava & D'Ignazio, 2017; Gebre & Polman, 2016; Markham, 2018). By integrating data literacy skills across various disciplines, students can seamlessly apply and further develop their creative data literacies without interruptions. This interdisciplinary approach fosters a continuous learning experience and provides opportunities for students to enhance their data literacy skills in a holistic manner. By incorporating creative data literacy into a wide range of subjects, students can explore the relevance and applicability of data literacy beyond traditional STEM fields, fostering a broader understanding of the role of data in various disciplines and real-world contexts.

For example, in an English language arts class, the teacher can provide plays of Shakespeare as a data source. Students can then generate research questions, such as analyzing the frequency of certain words, examining the usage of old English words, or conducting character analysis. Based on their research questions, students gather and collect relevant data. With the teacher's guidance and prompts, students can search for visual inspiration and create their own data stories, incorporating multidisciplinary knowledge and skills from mathematics and literature. They can choose to display the whole dataset or select variables based on specific criteria, depending on the scale of their data.

Assigning the same data source to the entire class could be another alternative, and students can have the opportunity to explore different perspectives and approaches, developing a deeper understanding of the data and enhancing their data storytelling abilities. This exercise not only integrates creative data literacy into the English language arts curriculum but also enables students to address a broader audience with their data stories.

Collaboration should be built among students as well, as they can encourage and motivate each other, and each student brings a different background and perspective. In this regard, educational practitioners can plan collaborative data visualization practices where students can bring their unique abilities and approaches to the table. This collaborative approach not only enhances their creative data literacy skills but also fosters teamwork, communication, and appreciation for diverse perspectives. Additionally, such collaborative data visualization projects can be leveraged to address real-world problems and create solutions with social impact. By engaging in these collaborative projects, students not only learn from one another and exchange ideas but also develop a deeper understanding of the power of data in bringing positive change and making informed decisions.

Introducing different types of data, such as numerical and categorical, is a crucial aspect of teaching creative data literacies. When students engage in depicting data, they learn to develop visual encoding systems and translate data points into visual attributes like color, shape, and length. Moreover, in today's data-driven world, it is important for students to recognize that data can be derived from various sources and may not always be perfect. Educational practitioners should emphasize these aspects when planning learning activities to foster students' creative data literacies. By doing so, students gain a deeper understanding of how to effectively work with and interpret data, enhancing their ability to harness the power of data in creative and meaningful ways.

Along with suggestions for educational practitioners to implement when integrating creative data literacies into their classrooms, it is essential for educators to familiarize themselves with these practices as well. It is crucial for educators to have knowledge of visual design principles and encoding techniques, engage in creative data literacy activities, understand data visualization strategies, explore creative approaches to working with data, and stay informed about existing trends and tools in the field. By actively improving their own creative data literacy skills alongside their students, educational practitioners can serve as role models and inspire students through their continuous learning and embrace of a growth mindset. This shared learning experience creates a supportive and collaborative environment where educators and students can explore and discover the potential of creative data literacies together.

## **Conclusion**

This study has provided valuable insights into the processes and approaches of students in a mixed-grade high school classroom as they navigate from data exploration to creating data stories using their personal data in the context of climate change. The analysis of the data and

synthesis of the findings have revealed several important factors. Firstly, the presence of a personal connection to the data significantly enhances student motivation and engagement. Secondly, the search for inspiration plays a crucial role in unlocking unique and inventive approaches to data visualization. Lastly, the ability of students to transform data into innovative representations demonstrates their capacity for developing novel and compelling data visualizations.

To address the time constraints of regular class periods, educators are encouraged to foster interdisciplinary collaborations, enabling continuous learning and the application of creative data literacy skills across various disciplines. Integrating these skills into different subject areas empowers students to reinforce their learning outcomes and further develop their creative data literacy skills. Through a deep understanding of these processes and the promotion of interdisciplinary collaborations, educators can create an environment that nurtures students' continuous learning and enables them to apply their creative data literacy skills effectively in diverse contexts.

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## **APPENDICES**

## Appendix A: Pre-survey

Name: \_\_\_\_\_

Date \_\_\_\_\_

Age

\_\_\_\_\_

What grade are you in?

\_\_\_\_\_

Race

\_\_\_\_\_

**1. Rate the following statement: *I feel confident learning new technology:***

---

Strongly Disagree

Disagree

Undecided

Agree

Strongly Agree

Please explain your response:

**2. Rate the following statement: *I am interested in learning about data and data storytelling.***

---

Strongly Disagree

Disagree

Undecided

Agree

Strongly Agree

Please explain your response.

**3. Rate the following statement: *My future career / job will be closely related to STEM (Science, Technology, Engineering, and Math).***

---

Strongly Disagree      Disagree      Undecided      Agree      Strongly Agree

Please explain your response. For example, what do you want to do in the future?

**4. Have you learned about data or data visualization? Please explain your response.**

**5. What does storytelling with data mean to you? Please explain your response.**

**6. What do you expect to learn in this project? Please explain your response.**

**7. Is there anything else you'd like for us to know?**

## Appendix B: Post-survey

Name: \_\_\_\_\_ Date \_\_\_\_\_

### 1. Rate the following statement: *I feel confident learning new technology:*

---

Strongly Disagree      Disagree      Undecided      Agree      Strongly Agree

Please explain your response:

### 2. Rate the following statement: *I am interested in data and data storytelling.*

---

Strongly Disagree      Disagree      Undecided      Agree      Strongly Agree

Please explain your response.

### 3. Rate the following statement: *My future career / job will be closely related to STEM (Science, Technology, Engineering, and Math).*

---

Strongly Disagree      Disagree      Undecided      Agree      Strongly Agree

Please explain your response. For example, what do you want to do in the future?

### 4. What's your understanding of data or data visualization? Please explain your response.

### 5. What does storytelling with data mean to you? Please explain your response.

**6. What did you learn in this project? Please explain your response.**

**7. What did you learn from this workshop that you would use again in the future? Please explain your response.**

**8. Did this project help you to think about possible careers to pursue in the future? Please explain your response.**

**10. Is there anything else you'd like for us to know?**

## Appendix C: Self-reflection Notes

My name is

---

What is my data story?

---

What steps did I take to draw my data?

---

What was my inspiration?

---

What variables did I use and why I chose them?

---

Any moments that I had to change my drawing? If so, what was it and why? How did I solve it?

---

## **Appendix D: Student Interview Protocol**

During our sessions, you learned about data visualization, and its components, and finally, you built data drawings where you told stories about climate change using your own data. I want to mention that you did a great job and I hope you also had some fun during this experience. Now, let's talk about your overall experience. I am going to record this interview, is it okay with you?

Now, let's take a look at the data stories and drawings that you created.

### **Designing and building data drawings/visualizations process:**

1. Can you tell us your data stories?
2. Describe for us step-by-step what your overall process was for creating your data drawing. What did you do first, second, third, and last?
3. Where did the ideas come from for creating your drawings? What was your inspiration for this one? Did your friends influence your design? Did you talk to your friends or get help? How?
4. What kind of challenges did you encounter when creating your data drawings and how did you address them?
  - a) How was it to gather/collect your data?
  - b) How did you find/search for visual inspiration? Was it easy?

### **Learning about storytelling with data:**

Let's recall the datasets we used (students' personal data and the pre-downloaded data)

1. Did you feel personally connected to the data (or story told)? How so?
  - a) What do you think you learned about climate change in this workshop?

- b) Your contribution to climate change or preventing our planet?
- 2. Were there other stories you could have told with the data? Any counter-stories?
- 3. What do you think you learned from creating your data drawings? (About data science and data visualization)
  - a) What data is?
  - b) What data can be used for?
  - c) What do data stories mean?
- 4. Do you think you will tell stories with data in the future? What might they be about?

**General feedback:**

If you had more time to work on your data visualizations, what would you add or change? Why?

- 1. What was your favorite part of the workshop? Why?
- 2. What did you enjoy least about the workshop? Any suggestions on improving it?
- 3. Anything else you'd like me to know?