Intentionality in Task Design Research: Examining the design process of an online learning tool about mathematics in society

by

Nkechi Ibeh

A thesis submitted to the School of Graduate and Postdoctoral Studies in partial fulfillment of the requirements for the degree of

Master of Arts in Education

Faculty of Education

University of Ontario Institute of Technology (Ontario Tech University)

Oshawa, Ontario, Canada
August 2022

Thesis Examination Information

Submitted by: **Nkechi Ibeh**

Master of Arts in Education

Thesis title:
Intentionality in Task Design Research: Examining the design process of an online learning tool about mathematics in society

An oral defense of this thesis took place on Wednesday, August 10th, 2022 in front of the following examining committee:

Examining Committee:

Chair of Examining Committee: Dr. Diana Petrarca

Research Supervisors: Dr. Ami Mamolo and Dr. Robyn Ruttenberg-Rozen

Examining Committee Member: Dr. Ann LeSage

Thesis Examiner: Dr. Joyce Mgombelo, Brock University

The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

This thesis explores the design intentions and considerations made in the creation of an online learning tool for adults. Research in task design includes two components: design as intention and design as implementation. My research contributes to conversations about design as intention by analyzing my mathematical intentions and how they were, or were not, realized in the development of an online task about genetically modified organisms (GMOs). I draw on three theoretical frames to inform my analyses. **Frame 1** – Mathematics in societal issues, situated in research highlighting the impact of innumeracy and how numbers may misinform society. **Frame 2** – Mathematical representations, situated in research that highlights the importance of curiosity and visualization for addressing societal issues. **Frame 3** – Adult learning, situated in research about fostering mathematical understanding and pedagogy for adults in online learning environments. My research contributes new knowledge regarding the complexities of task design as intention and introduces a new model, Model for Framing and Analyzing Intentionality in Task Design (MFAI).

Key words

Task Design research; design as intention; numeracy in societal issues; visualisation; curiosity

AUTHOR'S DECLARATION

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

I authorize the University of Ontario Institute of Technology (Ontario Tech University) to lend this thesis to other institutions or individuals for the purpose of scholarly research. I further authorize University of Ontario Institute of Technology (Ontario Tech University) to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research. I understand that my thesis will be made electronically available to the public.

Nkechi Ibeh

ACKNOWLEDGEMENTS

This thesis has been quite a journey! It was long and was sometimes rugged, but I made it to the end with the help of these amazing people.

First, I would like to express my deepest gratitude to my supervisor, Dr. Ami Mamolo. This endeavor would not have been possible without your knowledge and care. Your support, hard work, and dedication helped me to persevere during this journey. Thank you for lending your wisdom and expertise to shaping my future career trajectory. To my assistant supervisor, Dr. Robyn Ruttenberg-Rozen, words cannot express my gratitude for your willingness to teach, correct, and guide me graciously through this experience. Both yours and Ami's encouraging and positive words kept me going especially as challenges arose. Your guidance and support were crucial for the formation and direction of my thesis.

I would like to extend my sincere thanks to Dr. Ann Lesage for her corrections and suggestions to my work. Thank you for joining my thesis committee. Your advice and knowledge were impactful. The feedback you provided me contributed to making the thesis the best it could be.

I would like to extend my sincere greetings to Dr. Mgombelo (Brock University) for serving as the external examiner. Thank you for the time and expertise you are willing to bring to my thesis experience.

Last but not the least, I would like to thank my adult children (Emeka, Neke, and Daezy) for their unwavering support, advice, and suggestions during my academic journey. Thank you Neke for your willingness to read every paper of mine. The constructive discussions and insights my children had with me based on their rich academic backgrounds and career perspectives positively impacted me. I am very proud to see them hold me up and support me the same way I held them up. Your love and encouragement kept me motivated throughout this long journey of mine.

Thank you!

STATEMENT OF CONTRIBUTION

I hereby certify that I am the sole author of this work and that no part of this work has been published or submitted for publication. I have used standard referencing practices as outlined in the *Publication Manual of the American Psychological Association*, *7Th Edition* (American Psychological Association, 2020) to acknowledge ideas, research techniques, or other intellectual materials that belong to others. Furthermore, I hereby certify that I am the sole source of the creative works and/or inventive knowledge described in this thesis.

Table of Contents

List of Tables

Chapter 4

List of Figures

Chapter 3

Chapter 4

Chapter 1 - Introduction

This thesis explores the design intentions and considerations made in the creation of an online learning tool for adults. The focus of the tool is on developing mathematical understanding that could help learners make sense of complicated societal issues. This is a timely topic because of the growing impact innumeracy has on adults' awareness and understanding of important societal problems. My research contributes to a new understanding about the design process of a digital tool.

1.1 The Motivation behind my Research

One of my work's theoretical foundations comes from Dewey’s (1938) philosophy of the interconnectedness between experience and education. Dewey says all experiences are educative or miseducative in some way. Some experiences can lead to deep learning and some experiences can be disconnected from each other. I needed an interpretive lens that would give me insight into societal experiences of innumeracy and their consequences (Keleman & Rumens, 2008). This lens would help me understand how to develop a digital learning tool that would address the societal issues that stem from innumeracy. Such a lens allowed me to interconnect my intended learning goals with experiences that could foster and combat innumeracy in societal contexts.

My experiences as a mathematics educator for adult learners and my belief that mathematical understanding, and especially numeracy, is important for many aspects of everyday life inspired my research. In what follows, I share my exploration on the importance of numeracy and the path to my research questions and, ultimately, this thesis.

1.1.1 On the importance of numeracy

Differing definitions of numeracy exist (e.g., Cockcroft, 1982; Gal, 1995; Paulos, 1988), with many providing a holistic view of numeracy. Cockcroft (1982), an early champion of numeracy, provides one such holistic view. He stated that a *numerate* person should be: (i) 'at-home' with numbers and able to apply mathematics skills to the needs of everyday life, and (ii) able to appreciate and grasp the information presented mathematically through graphs, charts, tables or percentages. Similarly, Gal (1995) declares that the term *numeracy* describes the combination of skills, knowledge, beliefs, dispositions, habits of mind, and general communicative and problem-solving skills that people need to effectively handle real-world situations as well as interpretive tasks with embedded mathematical or quantifiable elements. Paulos (1988) defines numeracy through his explanation of 'innumeracy.' Innumeracy, according to Paulos, is the inability to deal comfortably with the fundamental notions of number and chance. Numeracy, then, would be the ability to deal comfortably with the fundamental notions of number and chance. While these early studies are important to understanding the term numeracy, for my study, I focus on a definition that takes into account both understanding, as in Gal (1995), and application. I use a definition from Alberta Education (2015), who defines numeracy as the ability, confidence, and willingness to engage with quantitative information to make informed decisions in all aspects of daily living and real-life situations (p.4). In other words, adults need to draw on their numeracy skills to make sense of issues that arise in their personal lives, at their workplace, and in society. I rely on this definition because it is comprehensive as it takes into account motivation, cognitive processes, affect, and application.

1.2 Research Questions & Thesis Organization

My intention for this thesis is to explore the design intentions and considerations made in the creation of an online learning tool for adults and to share the design of an online inquiry-based learning tool that aims to tackle innumeracy's manifestations and effects. I investigate two research questions:

1. How can interactive visual displays of data be designed in a task that intends to provoke curiosity and critical thinking about misleading real-world mathematics?
2. How can online mathematical tasks be designed to support adult learning about mathematics in societal issues?

This thesis represents my journey of learning. Each chapter represents a different part of that journey. In my final chapter, I connect the features of my journey and share my findings of what I learned.

Chapter 2 discusses the history and evolution of task design research in mathematics education, and I situate my research in this area. In this chapter, I introduce my theoretical framework, Task Design by Intention (Kieran, 2019). This domain-specific framework informed my design intentions for the learning tool and will be used in later chapters to analyze my data. To support my later analysis, I introduce three conceptual frames in this chapter and situate each frame in a review of the literature.

Frame 1 – Mathematics in societal issues, situated in research highlighting the impact of innumeracy and ways to use numbers to mislead or misinform society

Frame 2 – Mathematical representations situated in research that highlights the importance of curiosity and visualization for addressing different societal issues

Frame 3 – Adult learning situated in research about fostering mathematical understanding and pedagogy for adults in online learning environments

In Chapter 3, I developed a Model for Framing and Analyzing Intentionality in task design (MFAI) in the form of a tetrahedron to represent how the three frames described in Chapter 2 interact with my design intentions. I use this model (MFAI) as a heuristic for showing the complexity of my study as a *design as intention* (Kieran, 2015). In this chapter, I introduce my group makeup, the task as a group project and discuss the intentions, and approach in designing the digital learning tool. Chapter 3 describes the specific tool we developed, with a specific focus on two of the investigations of the task. In task design research, the "data" is the task itself – that is, I take as data features included in the design of the digital learning tool, which I then analyze in Chapter 4.

Chapter 4 addresses my research questions and uses the three frames and the MFAI to give a critical analysis of the features of the learning tool. The focus of my analysis is on how intentions for the task translated into specific features of the online tool. This thesis is from a first-person perspective. My analysis includes how my own intentions resulted in parts of the task. I purposefully remove myself from the group to understand the deep connection between intention and design output. Additionally, the time and space constraints of conducting a master's thesis did not allow me to explore the intersection of group member's intentions and output. At the same time, however, there were important aspects of my experience as a member of a group designing a task that impacted my analysis. I include this reflection in the concluding chapter.

In the final chapter, chapter 5, I discuss and reflect on my experience as a task designer. Using this reflective writing, I discovered new directions for future research, which I discuss along with my research contributions and limitations.

Chapter 2 - Review of the Literature

This chapter provides the conceptual foundation for this task design research. The literature reviewed in this section informed my intentions for the learning goals, context, mathematical content, and digital tools included in this task design. In this way, the literature framed my study both in terms of deciding on my design intentions for the learning tool as well as in analyzing how I was able to realize my design intentions in the tool. I first discuss the history of task design research in mathematics education and situate my study as design-by-intention research (Kieran, 2019). I then review the literature that informed my task design intentions, and frame them around three themes: (i) the uses and misuses of mathematics in society, (ii) issues in fostering mathematical understanding, and (iii) pedagogy for adults in online learning. To help explain how the literature framed my study, I focus my discussion on:

1. Mathematics in Societal Issues: I review literature that explores how mathematics, and mathematical modeling, can get used and misused in society to mislead or deceive adults. This literature informed my intentions on how to address mathematical misinformation about a societal issue in the learning tool.
2. Mathematical Representations and Understanding: I review literature that explores aspects of mathematical understanding that would be relevant for adults, and how visual representations can help foster critical thinking. This literature informed my intentions for what mathematical representations and questions to include in the learning tool.
3. Adult Learning in Online Contexts: I review literature that explores ways that online environments and tools can help meet the learning needs of adult learners. This literature informed my intentions for how I wanted the learning tool to be captivating for adults.

Before discussing the three frames, I explore the history and evolution of task design research in mathematics education with the purpose of underlining the significance of task design in mathematics education for this thesis.

2.1 History and Evolution of Task Design Research in Mathematics Education

Mathematical tasks are complex. Researchers have described mathematical tasks as "the fabric of student learning" (Sierpinska, 2004, p.25), learning activities that serve as opportunities for students to engage in mathematical thinking and sense-making (Stein et al., 1996), and strategies that train students to process information in specific ways (Doyle, 1983). Mathematical tasks are important in research, pedagogy, and learning because they center on revealing students' conceptions and misconceptions rather than testing their knowledge (Stein & Lane, 1996).

Task design in the field of mathematics education has a long history (Krainer, 1993, p. 65). It arose as an important issue in the mathematics education research community in the mid-1970s when researchers began theorizing about task design (Wittmann, 1995; Artigue, 2009). By the 2000s, conjecturing about design in mathematics education research emerged and evolved quickly (Kelly et al., 2008). In 2004, Anna Sierpinska, further contributed to the topic of design in mathematics in a ground-breaking way. She set the stage for research in task design in mathematics education. She argued that the design, analysis, and empirical testing of mathematical tasks were among the most important responsibilities of mathematics education (Sierpinska, 2004). Just before Sierpinska, Cobb et al. (2003) advised for increased attention to the importance of task design research. They argued that design theory focuses on "why designs work" and "how they may be adapted to new circumstances" (Cobb et al., 2003, p.9).

In addition, Paul Cobb (2003) recommended that:

> General philosophical orientations to educational matters—such as constructivism—are important to educational practice, but they often fail to provide detailed guidance in organizing instruction. The critical question that we must ask is whether the theory informs prospective design and, if so, in precisely what way? Rather than grand theories of learning that may be difficult to project into particular circumstances, design experiments tend to emphasize an intermediate theoretical scope (p. 10–11).

In agreement with Cobb (2003) and Sierpinska (2004), Kieran (2019) categorized task design research in three different levels, or "frames":

> …grand, intermediate, and domain-specific frames. Grand theoretical frames focus on learning in general. Intermediate-level frames are more specific and direct in relation to the design of curricular areas across mathematical spaces and domains. Domain-specific frames call for reasoning related to mathematical content (processes or particular tools) (Kieran 2019, p 271).

Kieran (2019) also distinguishes between two branches of task design research, *design as intention* and *design as implementation.* My research is a study in design as intention.

2.1.1 Situating My Task Design Research

Kieran (2019) highlights that Ruthven et al. (2009) define *design as implementation* as the process by which a designed sequence is integrated into the classroom environment and subsequently is progressively refined, while *design as intention* emphasizes the original design and the clarity and coherence of the intentions it expresses (Kieran, 2019, p. 329). It is important to note that design as intention bases its foundation on well-developed theoretical frames for precision and consistency. This distinction helps to situate my study in task design research as a *design as intention* using a domain-specific theory. It is an intersection of theory, application, and practice in math education research.

Further, Kieran (2019) notes that different design considerations and theories come into play when designing different genres of tasks. She identifies four task genres whose respective learning goals are focused on:

> (i) the development of mathematical knowledge (such as concepts, procedures, representations), (ii) the development of the processes of mathematical reasoning (such as conjecturing, generalizing, proving, as well as fostering creativity, argumentation, and critical thinking), (iii) the development of modelling and problem-solving activity, (iv) the assessment of mathematical knowledge, processes, and problem-solving (p.271).

In my research, I extend Kieran's work to a new fifth genre of tasks, one whose learning goals are focused on highlighting ways that numeracy skills are used and misused in society and helping adults develop positive experiences, identities, and attitudes for understanding real-world issues using mathematics. My approach is inspired by research that suggests that adults' mathematical knowledge and societal knowledge can co-develop by engaging with tasks that help learners "see" the mathematics that underlies societal issues and structures (Mamolo, 2018).

As mentioned, Kieran (2019) conceptualized task design research with three levels of theory that can inform the research objectives: grand theories, intermediate frames, and domain-specific frames. The domain-specific frames that informed my design intentions for the learning tool are:

Frame 1– Mathematics in societal issues

Frame 2 – Mathematical representations

Frame 3 – Adult Learning

In the following section, I review the literature related to each of these frames.

2.2 Mathematics in Societal Issues

In this section, I review literature that explores how mathematics and mathematical modeling are used and misused in society to mislead or deceive adults. This literature informed my intentions on how I might address mathematical misinformation about a societal issue in the learning tool.

2.2.1 Modeling Society through Mathematics

Modelling in Mathematics can be seen as a means as well as a goal in mathematics education. Mathematical modelling evolved in the 1960s, but as Niss et al. (2007) stated, "the maturation phase" was not reached until the 1990s. Niss (1989) argues that application and modelling should be part of mathematics curriculum. She identifies positive impact of modeling on fostering creativity and problem-solving attitudes and skills, as well as on preparing students to apply ideas across other subjects or areas, and to establish a richer picture of mathematics and its role in the world. In particular, Niss (1989) highlights the importance of modelling for generating and developing critical understanding of the use (and misuse) of mathematics in the world (p.23-24). Her propositions have helped to illuminate the essence of modelling in mathematics education. Similar to the above arguments, goals of mathematical modelling could also be projected from different perspectives.

From a mathematical perspective, mathematical modelling can facilitate the teaching of mathematical concepts and procedures (Lamb & Visnovska, 2015), provide avenues for applying mathematical content (Dede, 2019; Didis et al., 2016: Widjaja, 2013), and serve to promote mathematics as a human activity that deals with issues of different nature (Rodríguez-Gallegos, 2015). From an informed citizenry perspective, mathematical modelling enhances "the sustainability of health, education, and environmental well-being, and the reduction of poverty and disadvantage" (Niss et al., 2007, p. 18) while allowing us to dissect and analyze social problems (Luna et al., 2015; Niss et al., 2007; Rosa & Orey, 2015; Villarreal et al., 2015; Yoshimura, 2015).

Mathematical modeling is a process that uses mathematics to describe, represent, analyze, and make predictions about real-world problems or occurrences (Greefrath & Siller, 2017; Henn, 2007; Niss et al., 2007; Sala et al, 2017; Stillman, 2007). According to Greer & Verschaffel (2007), there are three levels of mathematical modelling: implicit (modelling without being aware of it), explicit (modelling with awareness and attention to the modelling process), and critical modelling (critical examination of the roles of modelling within mathematics/science and within society).

A mathematical model is a physical representation of reality using mathematical concepts. In other words, a mathematical model is a representation of reality and it numerically describes the world and its issues. O'Neil (2016) describes a model as a human construct which consists of information input, an information processor, and the output of expected results. In general, models have a purpose to represent trends, data, and statistics; in this way, real world phenomena can be translated into a conceptual framework. However, there are circumstances where models are misused.

Models could be misused through using them to misrepresent the algorithm or statistics. Schield (2021) explains that the nature of statistics (which involve assumptions and choices) makes it easy for policymakers to sometimes lie with statistics; thus, resulting in misleading or false models. Mathematical models that are used in our daily lives by employers, insurance companies, admissions, incarcerations, employment, and campaigning could be opaque, unfair, and massively scalable (O'Neil, 2016, p.196). Similarly, Grote & Keeling (2022) show how health inequalities are perpetuated while using models. These attributes contradict the well-intended purpose of models. Mathematical models are motives, values, agendas, and opinions of people embedded in models through algorithms, statistics, and data (O'Neil, 2016 & Schield, 2021).

In general, the data we gather is directly relevant to the outcomes we want to predict. As such, our models are subjective. The construction of models must, in some way, be hypothesis-driven. In my perspective, the purposes of models are to facilitate understanding, aid in decision-making, explain, control, and predict events based on past observations. While models may be intended for good purposes, modellers through unconscious biases might prefer profitability to accuracy (Baracos & Selbst, 2016; Feldman et al., 2015; Legg et al.; O'Neil, 2016). For example, scientists or policymakers might create visually appealing models instead of accurate models in order to sell their ideas to consumers (Johannssen et al., 2020; Legg et al., 2021). Also, flawed statistical reasoning could further contribute to poor modelling (Gorard, 2010; Johannssen et al., 2020). Models with flawed statistical reasoning could perpetuate and exacerbate the existing inequalities and injustices in society (Baracos & Selbst, 2016; Feldman et al., 2015). Models can have this effect when the subjectivity is forgotten, twisted, or intentionally hidden (O'Neil, 2016, p. 29).

Models provide a representation of reality and how we portray reality is of critical importance to our understanding of it. Grote & Keeling (2022), Johannssen et al. (2020), Schield (2021), and Seife (2011), to mention a few, show examples of how we use mathematical concepts specifically a line, a curve, or a pattern, to describe reality. Seife (2011) refers to some of them as "faulty representations of reality" (p.61).

Following this section's discussion of modeling society through mathematics, in the next section I will discuss how mathematics in societal issues can be misrepresented through the faulty representation of reality.

2.2.2 Misleading through Mathematics

Our society has become more data-driven (Lina et al., 2019; Miller & Goodchild, 2015; Pentland, 2013; Power, 2015; Seife, 2011). Mathematics, numbers, and data, to name a few, are used (or abused) to make decisions, present arguments, and influence the course of civilization (Borocas & Selbst, 2016; Fioramonti, 2014; Kroll, 2015). Despite these applications, "a number is always impure: it is an admixture of truth, error, and uncertainty" (Seife, 2011, p.10). Nonetheless, humans seem to have an innate belief in the infallibility of numbers (Fioramonti, 2014; Paulos, 2001).

We are impressed when we see numbers attached to something. Numbers, figures, and graphs have an aura of perfection (Seife, 2011). We care about numbers, and this might create a false sense of confidence. Our misunderstanding or misplaced faith in numbers and measurements can lead us to make decisions on pretenses (Fioramonti, 2014). According to Seife, if we want people to believe something, just stick a number on it, and it becomes believable (p.7). Such flawed practices with numbers could lead to algorithmic bias which also leads to discrimination (Borocas & Selbst, 2016; Fioramonti, 2014; Kroll, 2015). Due to all these issues with the perception of infallibility of numbers, researchers should take numbers seriously and take care with their interpretation of numbers (Gorard, 2014). One resource that helps researchers and laymen make sense of the difficulties of numbers is Weapons of Math Destruction by O'Neil (2016).

O'Neil (2016) summarizes Weapons of Math Destruction (WMD) as algorithms based on mathematical principles that implement a scoring system that evaluates people in various ways (p.31). Sometimes, as stated earlier, algorithms are used to separate people by class and race. A WMD is widely used to determine life-affecting circumstances like the amount of credit a person can access, job assessments, and criminal or social justice cases (Borocas & Selbst, 2016;

Fioramonti, 2014; Kroll, 2015). These algorithms may be seen as inherently fair because they have a mathematical and statistical basis. However, hidden opinions and assumptions are embedded in the selection of code concealed as impenetrable black boxes (Ananny & Crawford, 2018; Bathaee, 2017; Burell, 2016; Pasquale, 2015). O'Neil (2016, p. 29) depicts how the lack of transparency and inappropriate use of WMD can disadvantage the already disadvantaged and perpetuate inequalities. For example, judges use algorithms to make sentencing decisions based on recidivism rates. Companies use imprecise metrics and proxies, such as personality tests to dictate hiring processes (O’Neil, 2016, p.106). The poor are more likely to lose out because labour management software creates a "poisonous feedback loop" that makes it more difficult for the people with a lower social economic status to advance in their careers (O'Neil, 2016, p. 112). Companies could also (mis)assess financial status. For example, e-scores or methods for collecting and interpreting credit worthiness do not include actual credit scores (O'Neil, 2016, p. 143). They rely on a variety of proxies instead of relevant data and are largely unregulated. Credits scores are based on classes rather than on individuals, making it more difficult for low SES individuals and people of colour to escape poverty (O'Neil, 2016, p.149). Society’s failure to understand the algorithm’s impact, opacity and scale render the process dangerous and unfair (Burrell, 2016).

Humanizing mathematics beginning in elementary school will help educate and equip us with valuable skills needed to understand the world (Fatima, 2015). Humanizing mathematics is when mathematics is taught with emotions, contexts, vulnerability, and curiosity. Currently, math in school mostly focuses on performance (Foster, 2021) and tends to be dehumanised, depersonalized, and decontextualized (Tarmizi et al., 2010, p.533), but we need to encourage curiosity and vulnerability in math education. Teaching mathematics in schools through a social justice lens is crucial (Gutstein & Peterson, 2005; Tanase & Lucey, 2015) and will help us use math as an antidote to these weapons of math destruction. This brings me to issues of how to teach mathematics, and what mathematics content or topics to teach. In the next section, I look at what the literature says about mathematical understanding and representations that can help adults build the knowledge they need to develop numeracy.

2.3 Mathematical Representations and Understanding

In this section, I review literature that explores aspects of mathematical understanding that would be relevant for adults and how visual representations can help foster critical thinking. This literature informed my intentions for what mathematical representations and questions to include in the learning tool.

As Forman and Steen (1995) noted, there is a need for adults to develop “concrete mathematics built on advanced applications of elementary mathematics rather than on elementary applications of advanced mathematics” (p.80). Therefore, adults’ use of mathematics requires more concrete and perceptive skills. The technical skills and problem-solving needs that typify adults’ uses of mathematics connect with what is termed *functional mathematics.*

2.3.1 Functional Mathematics: Effectively Engaging in Real-Life Quantitative Situations

Functional mathematics is about mastering the mathematical skills required for working in the digital economy, such as spreadsheets, data analysis, and statistical quality control (Gal et al., 2020). Some of the curriculum expectations are not entirely part of secondary school mathematics, such as the practical and contextual mathematical knowledge that plays a critical role in adults' understanding of society. Notions of society, mathematics, and education are in a state of continual evolution, influenced by and in turn influencing the social and cultural, economic and political, and technological developments of our time - as has been the case throughout history (Radford, 2003; Restivo, 1992; Sailing-Olesen, 2010). According to Forman & Steen (1999), functional mathematics should address many otherwise often neglected needs, including the technical and problem-solving needs of the modern demands of active citizenship. That is to say that teachers need to bring in elements of mathematics to all subjects and instill in students the ability to think quantitatively.

Galligan and Taylor (2008) address two distinct categories of functional mathematics: (1) adults learning mathematics in the workplace and community, and (2) adults engaging in further studies such as university or vocational studies (p.99). In my research, I am interested in the first category of functional mathematics. I used adult learning pedagogies to foster adult learning for the community and the workplace. Galligan and Taylor concluded that numeracy is becoming more hidden in complex tasks as mathematics becomes less relevant in the workforce. For example, automation occurs when the work of mathematics is set in instruments or tools and the historical development of instrumentation could result in subunits of the workplace community being protected from mathematics by a division of labour (FitzSimons, 2013. p. 14). Thus, the workplace numeracy is more than just the basic arithmetic skills or procedural competence learned in school. Madison and Steen (2003) found that:

> Work-related mathematics is rich in data, interspersed with conjecture, dependent on technology, and tied to useful applications. Work contexts often require multi-step solutions to open-ended problems, a high degree of accuracy, and proper regard for required tolerances. None of these features are found in typical classroom exercises (p. 55).

Adults need to be numerate in order to avoid being misled or misinformed. Geiger et al. (2015) stated that "an important aspect of becoming numerate is developing the capability to take a more critical view of the world—from personal, social, and political perspectives" (p. 535).

2.3.2 Mathematical Representations: Data Visualization

Throughout history, visualization has served as an important problem-solving tool (Arcavi, 2003; Piggot & Woodham, 2011; Sung, 2017). Visualization is the visual representation of data to reinforce human cognition, and Lee described it as “the ability and skill to read and interpret visually represented data in and to extract information from data visualizations.” (Lee et al. 2017, p. 552). All facets of society, including education, use significant amounts of information in visual form. Statistical knowledge helps us select the appropriate methods to collect data, employ the correct analyses, and effectively present the results. An effective presentation is conducted through the visualization of the collected data. Visualization is a human problem-solving tool that is promoted in different learning areas and instruction (Ontario Ministry of Education, 2014). It is a form of spatial reasoning which is needed in various disciplines and professions.

When we convert problems into visual form, the solution is easier to derive (Arcavi, 2003; Landy & Goldstone, 2007; McLoughlin & Krakaowski, 2001; Rieber, 1995; Zaskis et al., 1996). Landy and Goldstone (2007), McLoughlin and Krakaowski (2001), and Rieber (1995) demonstrated how human beings forget to use their inherent capabilities just because schools emphasize verbal skills rather than visual skills and put more emphasis on abstract reasoning than concrete reasoning. As a result, this causes us to overlook use of simple visualization as a cognitive strategy in solving problems.

We use visualization in mathematics knowingly and unconsciously. We often associate visualizing in mathematics with drawing pictures or diagrams to begin problems. However, according to Piggot & Woodham (2011) visualization has a broader role in problem-solving, specifically supporting the development of ideas and facilitating communication of results and understanding. In these senses, it is not just about pictures and diagrams anymore. It is also about critical thinking of visuals. Visualization can help to step into a problem, model, and plan ahead (Piggot & Woodham, 2011). According to Rubel et al. (2021) “the authoring of a data visualization fundamentally relies on mathematics to produce a structure that highlights and defines quantities, relates variables, and justifies inferences” (p.250).

Data visualization can help us make sense of the volumes of captured data we have access to in today's world. A vital video that addresses how numbers mislead society is a TED Talk by Hans Rosling, an expert in the field of mathematics visualisation. The TED Talk is entitled, "The Best Stats You've Ever Seen." In this TED Talk, Hans Rosling (2006) emphasized that data collection is critical, but the interpretation is more imperative. The interpretation process includes reading and translating the visualization results into insights and stories that make a difference in the real-world application (Lee et al., 2017). Rosling (2006) posited that "the problem was not ignorance; it was preconceived ideas." Throughout his TED Talk, he presented data educatively so that the viewer became aware of their biases. Data is never neutral; neither is its interpretation, he was able to show us the changing world through the visualization of data. Examples of such issues are fertility rates, child mortality, family planning, income distribution, and the power of social change. He asserted problems are not caused by ignorance but through preconceived ideas. Similarly, Rubel et al. (2021) argued that,

> Reading data visualizations with the orientation of considering how data visualizations mathematize reality through interrelated processes of formatting, framing, and narrating, reveals how data visualizations rely on mathematics, play a significant role in shaping local and global decision-making, but are not neutral representations (p.263).

Hans Rosling is telling us that visualization is an agent of change, a powerful tool that needs to be understood not just in terms of mathematics or perception but also in terms of its impact on the views and opinions of people. According to Andy Kirk (2014), visualization might not be as accurate as statistics but it will enable us to discover exciting structures and new themes. While data collection is critical, interpretation is more imperative. We can educate ourselves and find solutions to our prejudiced views and preconceived ideas. In other words, incorporating a bit of creative visualization can change people's views about data analysis and help the world move a step closer to making some of the changes it needs. Visualizations serve as a discovery tool for individuals and as a medium to spur discussion and ignite curiosity among users.

2.4 Adult Learning in Online Contexts – Self-directed Inquiry Mediated Through Digital Technology

In this section, I review literature that explores ways that online environments and tools can help meet the learning needs of adult learners. This literature informed my intentions for how I wanted the learning tool to be captivating for adults.

2.4.1 Special Considerations for Adult Learners

Usually, teaching adults is not like teaching children and therefore, special considerations should be given when designing tools for adult learners (Bryant, 2014; Rogers & Horrocks, 2010, p.80). Sometimes, what we learn in childhood forms the foundation of what we know as adults, and our life experiences could add to that, thus creating a substantial reservoir of information.

Adult learning, known as andragogy, is a facilitated type of learning (Knowles, 1980). When designing learning tools for adults, specifically online learning tools, one must consider how to motivate adult learners (Park & Choi, 2009). In addition, Bryant (2014) reminds us that it is important to include materials that connect and apply to the experiences of the adult learners in our design of the learning experience. According to Anderson & McCormick (2005), online learning tools can place a greater emphasis on self-directiveness and subject matter content. From an andragogical perspective, adult learning should be self-directed, transformative, experiential, and contextualized (Knowles, 1980).

Researchers of andragogy (e.g., Kelly, 2013) have identified special considerations for adult learners, namely; having a need to know why they should learn something, having a deep need to be self-directed, having a greater volume and different quality of experience, learning with a task centred (problem-centred) orientation, and learning and being motivated to learn by both extrinsic and intrinsic motivators. Furthermore, Beck & Hughes (2014) discuss the need for these special considerations when designing for online learning environments. Some of these unique factors should be included in: the design of educational programs, choices of technological and instructional methods/materials, and attention to the disadvantaged ways that adults may think about their technological skills. For the online learning experience to be efficient, the information should be presented through various visualization tools (Klerkx et al., 2014). Therefore, the quality and platform for this data visualization could become critical to the student's success.

2.4.2 Curiosity: Harnessing Curiosity Using Online Math Learning Tools

Curiosity is defined as a desire for acquiring new knowledge and new sensory experience that motivates exploratory behavior (Litman & Spielberger, 2003; Lowenstein, 1994; McDougall, 1921; Spielberger & Star, 1994). Schmitt & Lahroodi (2008) stated "that we take curiosity to be instrumental to and even essential for education, inquiry, and knowledge is confirmed by the fact that teachers often prefer instruction techniques that excite curiosity…stimulating curiosity is central to education and learning" (p.48). Studies have shown that curiosity may increase learning by motivating people to think more about the material being presented and the more they learn, the more curious they become (Minigan, 2015; Pluck & Johnson, 2011).

Curiosity is more productive than bombarding people with learning facts (Harford, 2017). We cannot form our worldviews by relying on the media and statistics or figures presented by others because as Gorard (2014) and O'Neil (2016) point out, this could lead to discrimination or social injustice. Curiosity can move us to ask questions that would lead to facts, as uncomfortable as these facts may be.

Curiosity with the absence of fear could lead us to facts, allow us see issues from various perspectives, and eventually lead to fair decision-making that improves the lives of others. Thus, curiosity leads to facts that help to fight devastating global ignorance (Stewart-Rozema, 2019) and social curiosity could allow us to develop great hope about the world in general (Menning, 2019). Benefits of curiosity in society include fewer decision-making errors, reduced group conflict, and more efficient open communication (Harvard Business Review, 2019).

Curiosity can be embedded in online learning environments because of its special affordances. Online learning is learning that is supported and delivered through the internet (Clarke, 2004). Engaging adult learners in an online environment takes special considerations that include opportunities to see and question ideas and preconceived notions in a new light (Karge et al., 2011). Through technology, the online educator can enhance the course/topic content and encourage student-centred learning (Hamid et al., 2015). For adult learners, this also involves examining the unique factors that shape their online learning experience (Beck & Hughes, 2014). According to Ke & Xie (2009), examples of such unique factors are social interaction and collaboration with peers, connecting new knowledge to past experiences, a climate of self-reflection, and self-regulated learning. The online learning environment can also create an opportunity to use interactive and collaborative models of learning (McDonald & Reushle, 2000). The various types of models of learning can provide a rich, interactive environment; students can engage more fully with course content using different media while interacting with others to make learning more productive (McDonald & Reushle, 2002).

In this chapter, I provided a theoretical overview of the history of mathematical task design as an area of research in mathematics education. Students' experiences and learning trajectories within mathematics could be directly influenced by the mathematical tasks with which they engage (Johnson et al., 2017). For this reason, it is important that these tasks incorporate and reflect students' perspectives. As mathematics is increasingly used as a tool for characterizing and solving social issues, thoughtful task design can incite curiosity and contribute to fostering mathematical literacy amongst adult students. In the next chapter, I describe a digital learning tool that was designed for the purpose of teaching students how to navigate and dissect a polarizing societal issue through a mathematical lens.

Chapter 3 - Designing an Online Math Learning Tool for Adults

In this chapter, I provide the context and background of the task designers. I also provide an overview of the online learning tool on Genetically Modified Organisms developed as part of this project. Lastly, I introduce my model for task design by intention – a Model for Framing and Analysing Intentionality in Task Design (MFAI).

I co-developed the tool with two peers as part of a Master of Education course assignment. The intention or learning goal of the assignment was to develop a learning tool to educate a specific audience on a societal issue for which incomplete or inaccurate mathematical numeracy and literacy could lead to inappropriate and socially detrimental conclusions. Our group chose to explore Genetically Modified Organisms (GMOs) as our context. We focused on GMOs as we believed that the public did not sufficiently understand GMOs, and consequently, the misunderstanding creates unanswered questions. Most of the uncertainty surrounding GMOs is rooted in misinformation and manipulation perpetuated by stakeholders who misuse data (Drum, 2016). Some companies, stakeholders, and scientists are able to spread misinformation through graphs, infographics, data visualization, due to our society's deficiency of numerical skills (Legg et al., 2021; Gal et al., 2020). For these reasons, we decided to focus part of our learning tool on data and number sense and include examples of misleading graphs and infographics on GMOs.

In the next sections, I introduce my group makeup, intentions, and approach in designing a GMO tool. I describe the issues and context of the digital tool, overview of the online learning tool, the learning style that was used in the design, and finally, the activities used in the learning tool. I will also introduce a model that I designed as a heuristic for the representation of the complexity of this online learning tool.

3.1 Context and Background

In this section, I briefly introduce my group members, the setting of our collaboration, and our intended approach for designing our online mathematical learning tool. I also discuss how we used technology to collaborate, design, and develop our tool. I have elected not to be specific in sharing descriptions of the other members of the group. I have done this to retain the anonymity of the other members.

3.1.1 My group makeup, intentions, and approach in designing a GMO tool

The design team included three female graduate students who are all instructors at some level in STEM areas. My first co-developer is an educator who is passionate about learning, sharing ideas and collaborating on various design and research projects. She has a B.Sc. in a pure science. My second co-developer is an educator whose pedagogical belief is that everyone is poised to learn when they feel supported socially, emotionally, and intellectually. Her first degree is in an applied science. Then there is me; my bachelor's and master's degrees are in Chemical Engineering. I have been a dedicated and devoted instructor in mathematics, and have taught all ages in school settings and in workplace settings, for more than 25 years in Bulgaria and Canada. I am interested in working with students from all academic levels and ages, especially adults in STEM subjects, specifically mathematics. My goal is to nurture a love for learning and passion for curiosity. I desire to use education as a channel for building equity, diversity, and inclusion amongst different people.

As educators, we wanted learners who engage with our task to acquire skills through challenging problems that will open the door to new insights into mathematics and its applications. Thus, my group members and I felt that it would be appropriate to create a digital learning tool (in our case, a website) that would enable adults to educate themselves mathematically on GMOs.

This digital learning tool provides learner-centred activities that apply Problem Based Learning (PBL) strategies and role-playing, data deconstruction, real-world simulations, and reflective practice to embolden emerging adults to cultivate informed opinions about the potential impact of GMOs and GM foods. The potential impact of GMOs is a topic of high importance worldwide due to the high level of misinformation that is spread by policymakers, biochemists, company CEOs, politicians, farmers, and marketers (Brookes & Barfoot, 2018).

3.1.2 Our Collaborative Approach to the Task Design

We emphasized collaborative approaches (Paulus, 2007) in our design and used various communicative technologies to facilitate our negotiation of learning aims, structures, and tools. We used digital collaborative tools like Mindomo, Google Docs and WhatsApp to communicate. We used WhatsApp as an effective messaging method since it is user-friendly, accessible, and end-to-end encrypted. Mindomo is software for mind mapping, concept mapping, and outlining. Its automated updates, minimal editing problems, versatility, and brainstorming are impressive. Mindomo helped us to improve our understanding, learning, and decision-making. It aided our visualization of the many science connections developed during our discussions. At the same time, Google Docs allowed seamless collaboration, creation and management of assignments, and organization of documents.

We took a team approach, which served the task design process well as interdisciplinary, team-designed tasks and curriculum are a high priority for learning (Ganter & Barker, 2004). However, interdisciplinary work can be challenging as each team member had different ideas about the task's scope and purposes. (Flowers et al., 2000)

Our design approach was to first research key concepts of GMOs and how they could be explored through a mathematical lens. Navigating the information regarding GMOs and narrowing the scope of our conversations and learning goals was a challenging. It required several meetings and discussions before we agreed to separate the learning tool into three sections, each geared towards a different aspect of GMOs. While we each had different visions for what content related to GMOs was most important, we shared similar values regarding the learning experiences and what we wanted our intended learners to gain. We ultimately decided to emphasize opportunities to engage in mathematical thinking (i.e., exemplifying, correcting, comparing, conjecturing, justifying) to explore the GMO's controversy and provide learners with an opportunity to apply mathematical reasoning to explain and reconcile this complex global issue.

3.2 The GMO Online Digital Learning Tool

The tool was designed with Problem-Based Learning (PBL) activities, as this was a requirement of the course assignment. PBL is a category of experiential learning that involves students in critical thinking to examine problems that lack a well-defined answer (Ali, 2019). Because our digital tool was created for adults in order to be self-directed, transformative, experiential, and contextualized (Herod, 2012), PBL was appropriate. In PBL, students are required to solve the problems themselves, rather than reviewing how others have solved the situation or problem, as in a case study; this is learning by doing (Goldring et al., 1996).

PBL is a type of learning that begins with an "ill-structured" (open-ended) problem (Campbell, 2014). PBL tasks provide authentic applications of content and skills, build 21st century success skills, emphasize student independence and inquiry, and are more multifaceted than traditional lessons or assignments (Larmer, 2014). PBL is based on constructivist-based learning, and it is a teaching pedagogy that is very student-centred. For this digital tool, our group learned about our chosen topic through the experience of solving an open-ended problem of the impact of numeracy on our decision-making. We constructed our learning, and the process empowered me as a learner to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem (Savery, 2006).

3.2.1. Societal Issue

Genetically Modified Organisms (GMOs) are organisms that have had their DNA altered or modified in some way through genetic engineering (Lallanilla, 2019), which is the artificial manipulation of an organism's genetic material using biotechnology. These organisms have widespread applications in basic research, medicine, industry, and agriculture. Examples of GMOs include animal models of human diseases, insulin-producing bacteria, and crops with improved nutritional value or pest resistance. Trigo & Cap (2003) highlight the economic benefits from GMO crops and subsequent positive impacts on the Argentinian agricultural industry and farmers. Regardless of position, stakeholders need access to credible information, however data about GMOs is often misleading.

Stakeholders (e.g., politicians, researchers, medical professionals, farmers, corporations, the public) involved in the GMO debate have diverse perspectives (e.g., scientific, religious, ethical, cultural) and concerns (e.g., medical, economic, environmental, political) regarding the management and global distribution of GMOs. Scientifically, Adenle et al. (2012) presented the potential positive impacts of GMO biofortified crops for impoverished and chronically-malnourished developing countries' citizens. There are political and ethical concerns regarding GMOs, research on GMOs, and statements from pro-GMO organizations asserting consensus on GMOs' safety (Hilbeck et al., 2015). Houdenine et al. (2014) identified social, ethical, and environmental concerns with transgenic animals, including regulations for creating transgenic pets (e.g., GloFish), cloning practices, food safety and feed products, and the threat of GM humans or scientists who are “playing God.”

Graphs, statistics, and proportions are frequently misrepresented to strengthen key arguments or agendas. Ultimately, objectivity regarding the GMO controversy requires awareness of the strategies typically used to manipulate interpretations of mathematical data.

One of the challenges of presenting information about GMOs is that the topic is scoping and of interest to a broad audience. Maintaining a focus on mathematics was especially challenging particularly when contextualizing math in societal issues. Our challenge in maintaining a focus on mathematics aligns with research on the challenges associated with teaching and designing math tasks for social justice (Bartell, 2013; Mamolo, 2018). Our group wanted to ensure that the learning activities were collaborative and consisted of the six interactive components of a learning process (attention, memory, language, processing and organizing, graphomotor, and high-order thinking) (Thomas & Thorne, 2008). We codeveloped three PBL activities to engage learners in conversations and investigations about GMOs. These activities are depicted in Figure 3.1 and discussed later in the chapter.

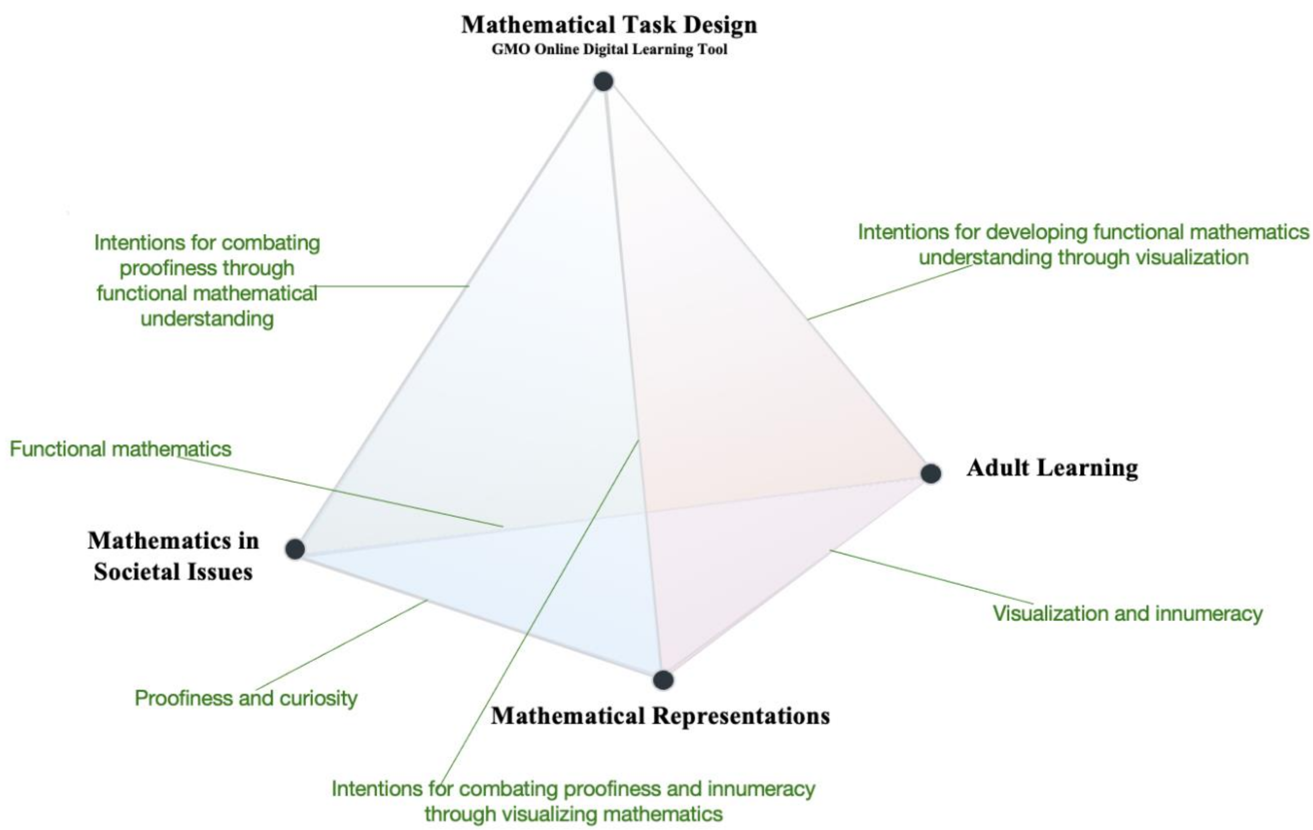
Figure 3.1: Three PBL Activities to Investigate Issues Related to GMOs

We created this digital learning tool within a paradigm of improving numeracy in society. The design and use of tasks are a core part of effective teaching and are an important consideration in some mathematics education design research (Artigue & Perrin-Glorian, 1991; Watson & Ohtani, 2015).

3.3 A Model for Task Design by Intention: Introducing my MFAI

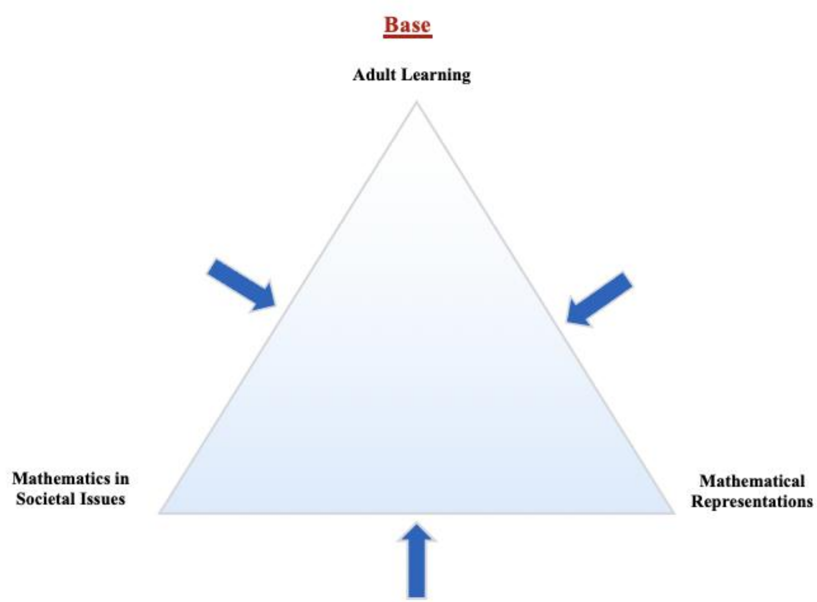
In my research, I created a model (MFAI) (Figure 3.2) as a tool for analysing my intentions and for showing the complexity of my study as a *design as intention*. This MFAI outlines the design connections between the task and my three domain-specific frames. It allows me to look at the faces, edges, and vertices and analyze the relationships that exist amongst them.

Figure 3.2: Task Design Model for Framing and Analysing Intentionality in Task Design (MFAI)



There are six edges, three faces, one base, and four vertices in the MFAI structure. The vertices represent the domain-specific frames and the task of this study. The edges represent my design intentions for the task. My analysis lies in the faces. The base serves as the foundational structure for my study. Below, I will explain the components of this MFAI.

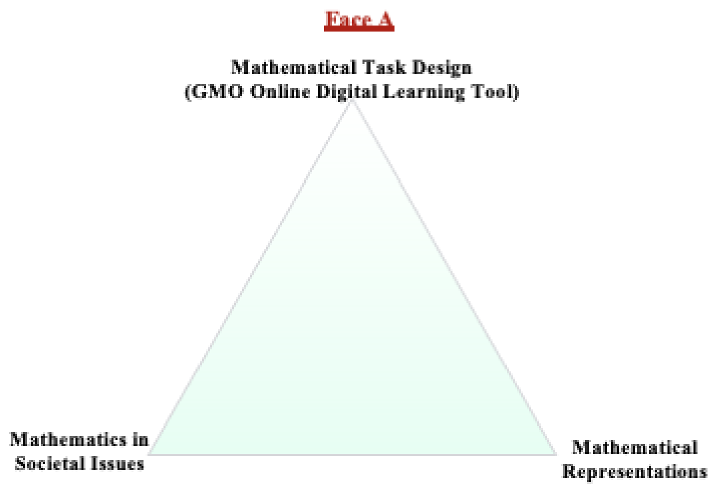
Figure 3.3: The Base of the MFAI: Connecting Domain-Specific Frames



The base of the MFAI (*Mathematics in Societal Issues + Mathematical Representations + Adult Learning*) consolidates the background literature and the domain-specific frameworks described in chapters 1 and 2. This base represents the point of inception for my research. The edges (see the ➡) on the MFAI base show the connections between the framings mentioned above. Although these edges establish the borders of the frames, the frames are not entirely independent of one another. For instance, the link between 'mathematics in societal issues' and 'mathematical representations' is demonstrated in section 2.2.2. In section 2.2.4, the relationship between 'mathematics in societal issues' and 'adult learning' was illustrated by examining functional mathematics and its usefulness in societal issues. Finally, the third edge of the base, which links 'mathematical representations' with 'adult learning' was represented in section 2.2.3, through the exploration of data visualization. The edges leading to the peak of the MFAI (mathematical task design) represent how an individual frame influenced and contributed to my design intentions for the task.

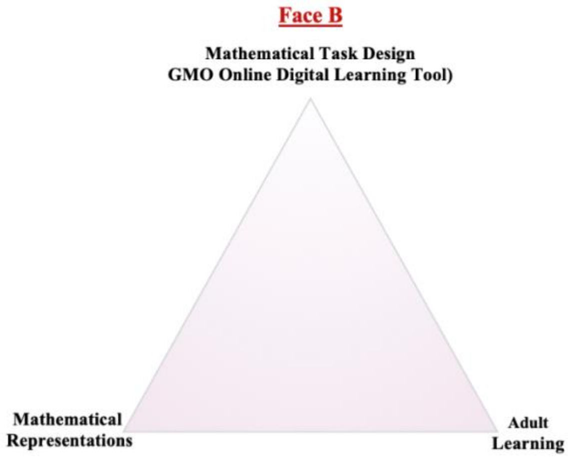
These ideas influenced my intentions for how to design this task.

Figure 3.4: Face A of the MFAI: Framing Mathematical Misinformation about GMOs



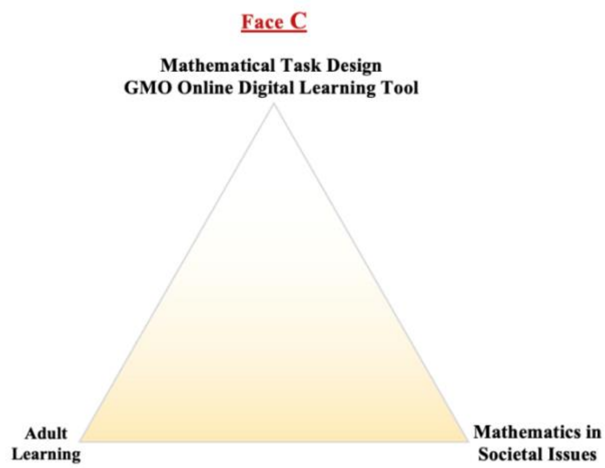
Face A of the MFAI (*Mathematics in Societal Issues + Mathematical Representations + Mathematical Task Design)* addresses my design intentions for the societal issues and mathematical representations included in the digital tool. As mentioned, the main societal issue we addressed in the digital tool is GMO misinformation. In this part of my framing, my design intentions included using ideas about proofiness and visualization to show how mathematical misinformation about GMOs can look and provide opportunities for learners to think critically about what they see. As a deception tactic, proofiness manifests through the use of numbers, graphs, or figures that misdirect and deceive the intended audience (Seife, 2011). At the same time, mathematical visualizations, such as figures and graphs, can serve as a tool for combatting the effect of proofiness in a societal context. Therefore, the design of the digital tool hinges on my intentions to include tasks and activities that highlight the interplay between visual representations of mathematics and proofiness in a real-world societal issue (the debate surrounding GMOs).

Figure 3.5: Face B of the MFAI: Framing Adults' Mathematical Experiences



Face B of the MFAI (*Mathematical Representations + Adult Learning + Mathematical Task Design*) addresses my intentions for using mathematical representations that would be most relevant or helpful to adults learning about GMOs. My intentions were to design a digital learning tool that piqued curiosity and critical thinking about GMOs. Problem-solving and self-directed inquiry are essential features of adult learning experiences (Morris, 2019). They go hand-in-hand with fostering the functional mathematical understanding necessary for society and the workplace (Özcan, 2015). I wanted to use visual representations to provoke curiosity and critical thinking about GMOs and the mathematical relationships that were presented in the graphs I intended to include in the task design.

Figure 3.6: Face C of the MFAI: Framing Sense-Making for Societal Issues



Face C of the MFAI (*Adult Learning +Mathematics in Societal Issues + Mathematical Task Design*) addresses my intentions to foster critical thinking and numeracy skills in adults who are trying to make sense of societal issues that are disguised in mathematical misinformation. GMOs are a societal issue that suffers from mathematical misinformation, but it is not the only issue. I wanted the digital tool to be designed with relevant and applicable strategies to other societal issues. For example, I intend that students would be able to apply their knowledge from this tool to other societal issues such as climate change, racial profiling, and criminal justice.

As mentioned earlier, my domain-specific frames are connected. By presenting them in this way, as vertices of a MFAI with connecting edges and faces, I can elucidate my design intentions through an analysis of how I tried to realize these intentions in my design of an online digital learning tool.

3.4 Overview of the GMO Tool

Each activity created for the digital tool was intended to invite learners to explore controversies related to GMOs through a mathematical lens with latitude for interdisciplinary adaptations (e.g., science, geography, history) and scaffolding to expand the scope and explore the depth of the GMOs debate, respectively. The team's intent was to include activities to encourage learners to document the narratives of their solution processes and to reflect on the efficiency or generality of different approaches to a problem. These included activities, along with the mathematical thinking processes above, are fundamental elements of mathematics (Mason, 1998). The tool created a way to lead discussions and compare approaches by ensuring each activity had a collective and peer review component.

As illustrated in Figure 3.1, we designed the activities to provide a holistic experience where learners would be introduced to GMOs and the GMO controversy through role-playing, jigsaw discussions, case studies, data exploration, and minds-on activities.

We created two role-playing in activities A (Figure 3.7) and C (figure 3.8), first introducing and then consolidating GMO issues and GMO controversies.

Figure 3.7: Activity A - Roleplaying to introduce issues in GMOs

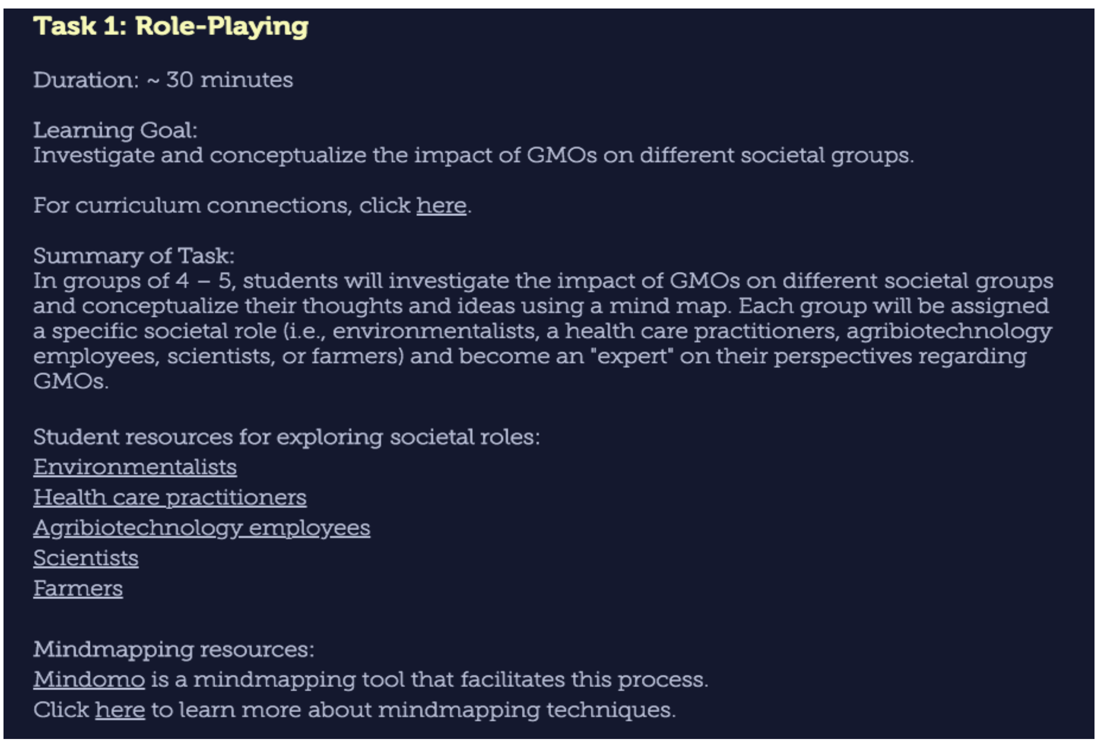


Figure 3.8: Activity C - Role playing as mediators in risk management/decision making of the impact of GMOs on the rights of Indigenous peoples of Canada

Task 1: Case Study

Duration: ~ 40 minutes

Learning Goal:
Simulate a hypothetical real-world scenario and negotiate a nondiscriminatory resolution.

For curriculum connections, click here.

Summary of Task:
In groups of 4 – 5, students will role-play as mediators in a scenario that explores the impact of planting GM crops on the rights of Indigenous peoples in Canada. Students will debate and rank the social, scientific, health, environmental, political, ethical, cultural, and economic implications of the issue and negotiate a reasonable, nondiscriminatory resolution.

Scenario:
A First Nations community in Canada grows a scared indigenous crop that has cultural and historical significance to the community. A neighbouring plot of land has recently been sold to an agricultural farming company that intends to grow genetically modified (GM) crops. The First Nations community has petitioned against this company's initiative to grow GM crops on the basis that they can contaminate and cross-breed with local crops, thus potentially modifying the sacred indigenous crops growing in their fields. Your team of mediators must negotiate a reasonable, nondiscriminatory resolution between the First Nations community and the agricultural farming company.

We wanted the learners to be immersed in issues surrounding GMOs and to ponder them from different points of view. Our intentions were for the students to investigate GMOs' impact on other societal groups and discuss their thoughts and ideas, thereby becoming experts on their roles within the role-playing simulation. We thought that this approach would elicit more awareness about the topic at hand. We also intended for students to solidify concepts visually and creatively. This would then allow students an opportunity to demonstrate their perspectives on GMOs, through creating digital reflections that consolidated, reflected and showed individualized summaries/intake. Some of the proposed digital learning tools include Powtoon, Moovly, Adobe Spark, Seesaw, and Piktochart. We thought that being creative with these activities would lead to more content saturation and greater mathematical confidence. It could also generate curiosity

(McDonald & Reushle, 2002). We planned for a written exercise to be given at the end of Activity C to help the learners communicate their decisions.

We focused on data representations in Activity B, which I will discuss in detail in the next section.

3.5 Activity B: A Focus on Data Visualization

I decided to focus my research on Activity B because of its focus on how societal issues are presented in manipulative ways using data and mathematics (equations, graphs, numbers) to mislead. Sometimes, our politicians and policymakers use graphs to misrepresent and abuse our democracy (O'Neil, 2016; Seife, 2011). The visual representations of data reveal the "story" behind the data. At the same time, the interactive nature of graphs allows users access and some autonomy in exploring the graph and powerful tools for learning when supported with questioning that fosters critical thinking (Mamolo & Ibeh, 2021).

Activity B focuses on an analytical deconstruction of the GMO controversy (Figures 3.9 and 3.10).

Figure 3.9: Introduction to Activity B: Minds-On Activity

Figure 3.10: Activity B Task Instructions for Exploring Data

Task 1: Exploring Data

Duration: ~ 30 minutes

Learning Goal:
Deconstruct and assess the contextual relevance of mathematical data related to the GMOs controversy.

For curriculum connections, click here.

Summary of Task:
In groups of 4 – 5, students will engage with graphs related to the GMOs controversy. Each group will be prompted with guiding questions to encourage students to use mathematical thinking and reasoning to analyze, interpret, and evaluate graphical data.

Accessing the GMOs Desmos Activity:
1. Create a free teacher account with Desmos.
2. Click here to navigate to the GMOs Controversy: Exploring Data Activity.
3. Create a class code for the Desmos activity and share it with your students.
4. Students can log into Desmos by visiting: https://student.desmos.com

To learn more about teaching with Desmos, click here.

The goal of Activity B was to deconstruct and assess the contextual relevance of mathematical data relating to GMOs. We aimed to show how math/numbers or graphs are being used to misinform citizens and align with personal stakeholder interest. Groups are prompted with guiding questions to encourage the use of mathematical reasoning to analyze, interpret, and evaluate graphical data. These group interactions were intended to allow students to collectively identify ways that statistics (in the given graphs) are misleading.

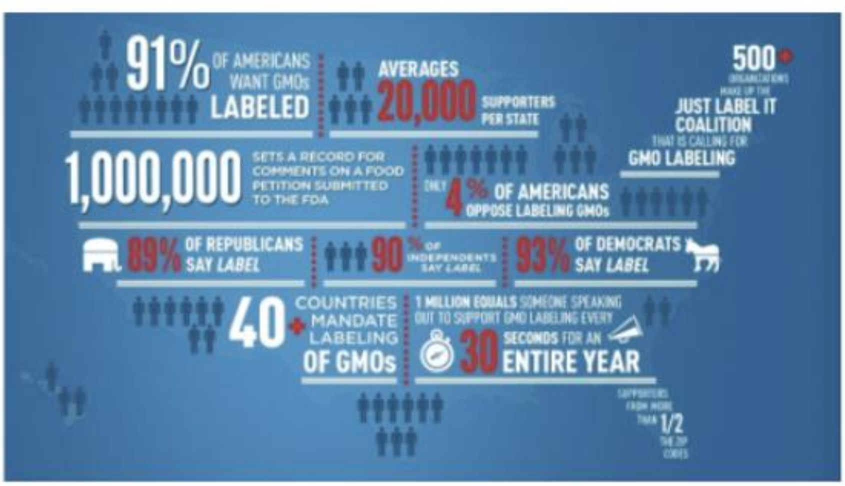
To facilitate this data exploration, we used Desmos (www.desmos.com) as a platform. Desmos is a free online graphical calculator that allows math exploration in interactive ways and consists of easy-to-use steps. Desmos provides students a visual way to understand graphs and expressions while directly supporting our inquiry-driven exercises.

We used various investigations and graphs to help immerse students in the multiple ways of misinformation/misuse of data and models in GMOs. For this thesis, I chose two of the investigations to analyse in depth. They are depicted in Figures 3.11 to 3.13 (Investigation 5: Labelling GMO Products) and 3.14 to 3.16 (Investigation 6: Prevalence of Diabetes).

Questions were included with the figures and were intended to scaffold the investigation and guide learners' attention to a deeper understanding of the proofiness (Seife, 2011) being investigated. In these two investigations, we used the same graph with a series of different questions. The questions that we posed were intended to expose the misleading nature of the graphs. Particular attention was drawn to the graphs' titles, labels on both axes (axis manipulation, two y-axes), data source, scale (does it start with zero, are the numbers equally spaced), deceptive pictographs, and cherry-picking data. Our intentions with these tasks were to illustrate the role and relevance of mathematics in understanding GMOs through our digital learning tool. Our intention was that the tool could provide its users with the experiences necessary to effectively assess the societal impact of complex issues (such as GMOs) with an analytical lens. Learners would have the potential to learn how to recognize statistical deception to avoid being misled.

3.5.1 Investigation 5: Using infographics to Mislead/Misinform

Figure 3.11: Investigation 5: Labelling Products Containing GMOs

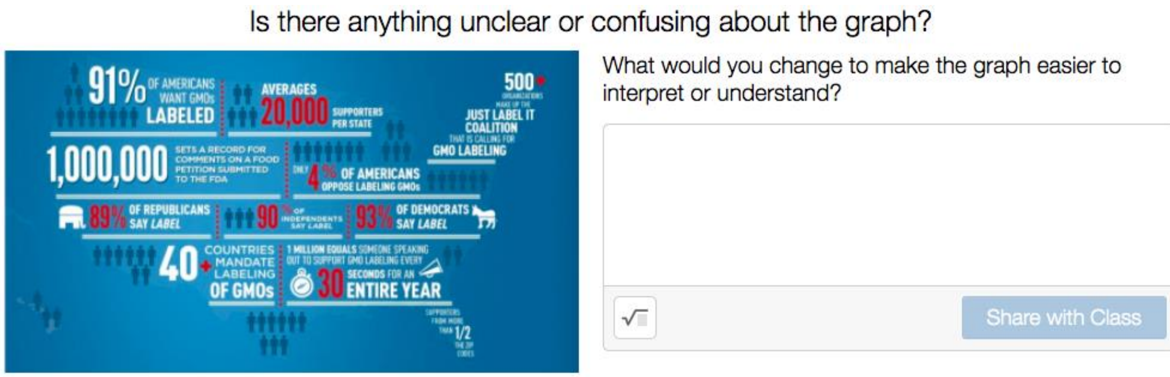


We developed Investigation 5 with the intention that students would become familiar with ways to lie with statistics using infographics. This ‘GMO labelling’ graph contains a series of numbers/statistics surrounding GMO labelling; therefore, we included questions that ask students to check for proofiness in the infographic (Investigation 5). We also included questions that ask students to brainstorm what could be changed to make the graph easier to read/interpret. The students would have to conclude their investigation by stating if the presented data are meaningful. Data are presented in this investigation in the form of an infographic. Small samples used here produce shocking statistics. How the numbers are presented influence how they are understood. The infographic does not contain all the data from which the analysis emerged. Here, the visualization is misleading because the relevant data is not clear, and there is too much text.

Figure 3.12 and Figure 3.13 depict how the infographic appeared in the tool and show the way we incorporated it into the tool for the group exercises and discussion.

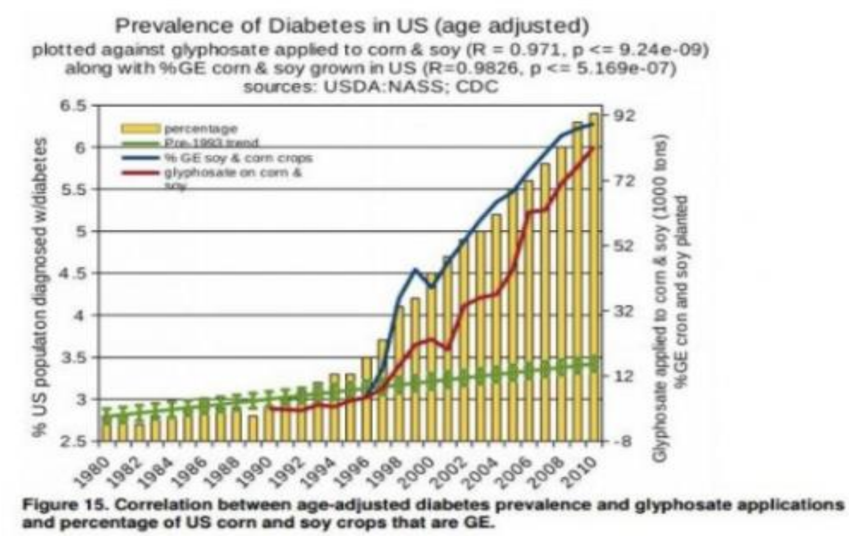
Figure 3.12: Sample Exercise for Unravelling Misleading Information

Figure 3.13: More of the Scaffolding Questions as they appeared in the Learning Tool



3.5.2 Investigation 6: Prevalence of Diabetes

Figure 3.14: Investigation 6: Prevalence of Diabetes in U.S.



We used Investigation 6 - the 'Prevalence of Diabetes' graph (Figure 3.14) with the intention that students would identify the false correlation between diabetes prevalence and percentage of GMO crops in the USA. Then, we posed questions that were intended to probe the students to determine who would benefit from creating such a graph. Afterwards, the questions we asked were designed to encourage students to determine the reasoning behind this 'Prevalence of Diabetes' graph. We also asked questions that would invite the students to address the intended impact of this data (given the way it was presented). The graphs depict numerical information about the correlation between age-adjusted diabetes prevalence (y-axis) and glyphosate applications and percentages of USA corn and soy crops (Y-axis) that are GE (genetically engineered).

Figures 3.13 and 3.14 provide examples of how the graph was used in the online tool. The figures depict how the graphs appeared in the tool and show the ways we incorporated it with some of the posed questions intended for group discussion.

Figure 3.15: Background Information

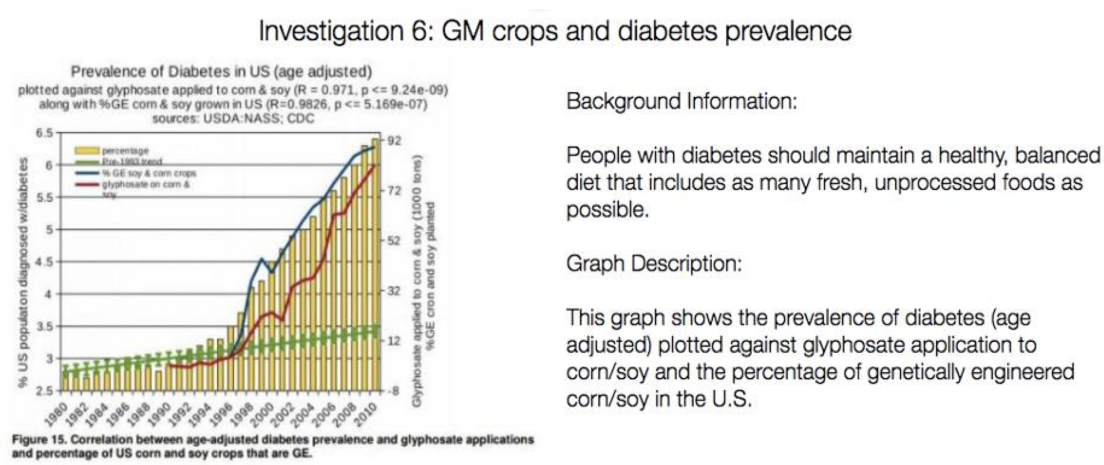
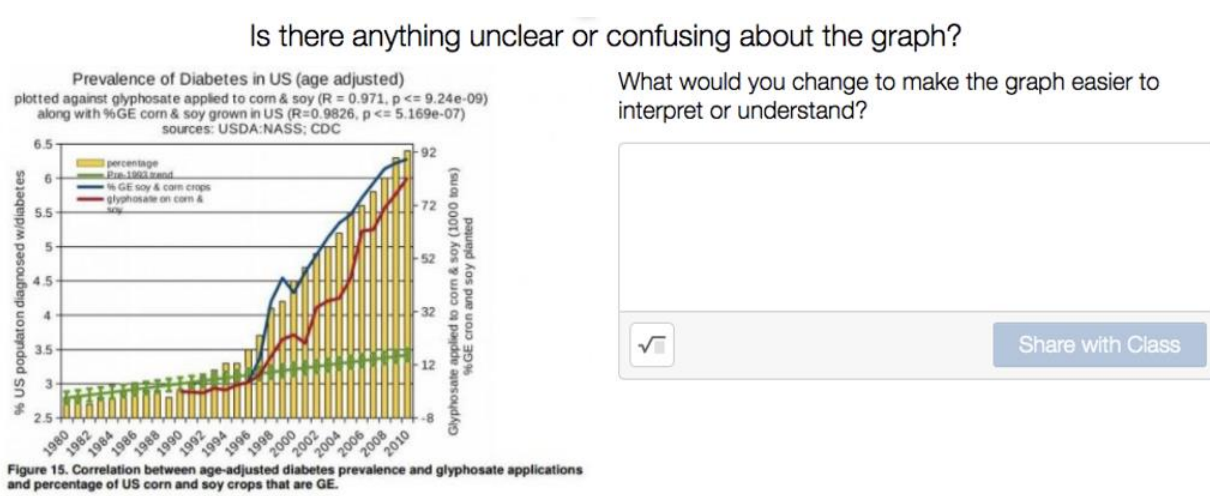


Figure 3.16: More of the Scaffolding Questions as they appeared in the Learning Tool

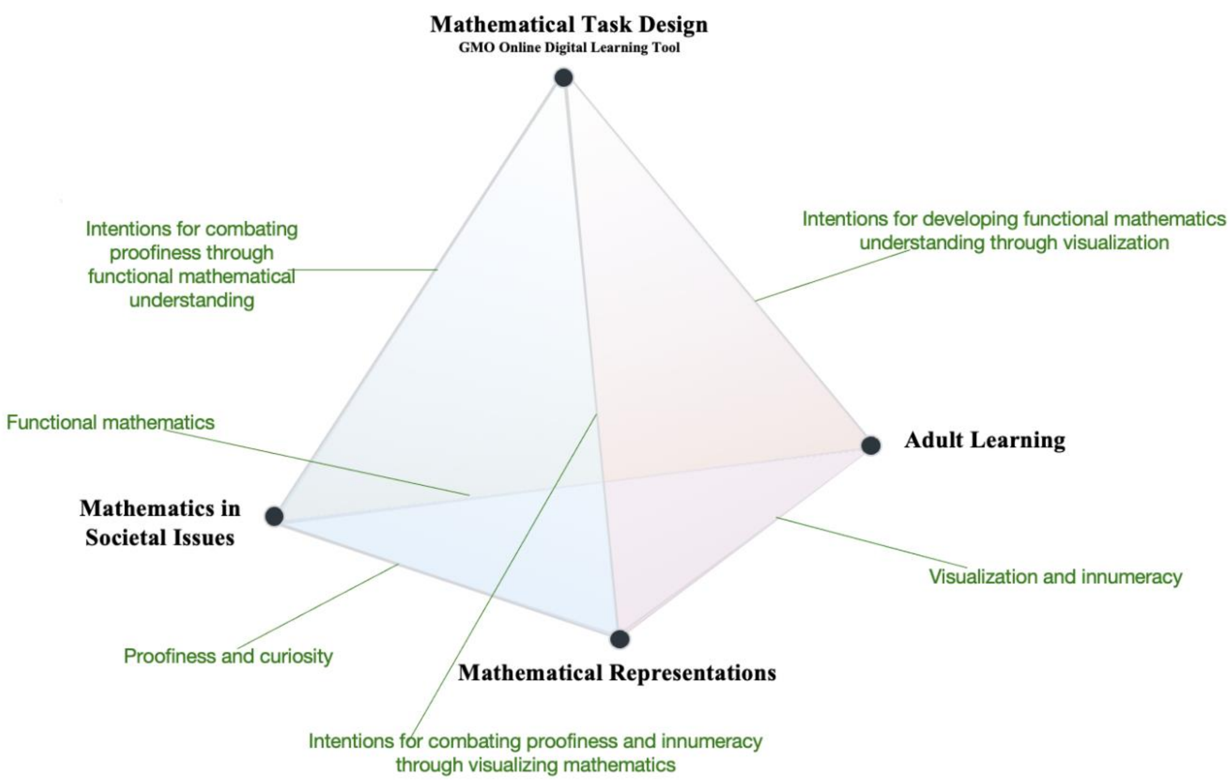


Good graphs could be powerful tools for displaying large quantities of complex data as shown above. However, some graphs mislead or misinform. All the correlations in the graphs were presented as causations. In this case, it is important to remember that correlation is not proof of causation.

Chapter 4 - Critical Analysis of GMO Tool Based on Literature Review

In this chapter, I unpack and analyze aspects of the GMO tool related to my three domain-specific frames. In Chapter 3, I introduced a model that depicted my three domain-specific frames as vertices of my Model for Framing and Analysing Intentionality in task design (MFAI); the frames informed the intentions of my task design. In this chapter, I use the MFAI (Figure 4.1) to analyze how I realized my intentions for the task design in two activities: Investigation 5 and 6, depicted in Figures 4.2 and 4.3.

Figure 4.1: The Model for Framing and Analysing Intentionality in task design (MFAI)



The research questions that I address in this chapter are:

1. How can interactive visual displays of data be designed in a task that intends to provoke curiosity and critical thinking about misleading real-world mathematics?

2. How can online mathematical tasks be designed to support adult learning about mathematics in societal issues?

I use the faces of the Model for Framing and Analysing Intentionality (MFAI) in task design to anchor my analysis of Investigations 5 and 6 as I address each of these research questions. This analysis method allows me to examine the intentionality of my task design from multiple different perspectives.

In this section, I address my first research question:

How can interactive visual displays of data be designed in a task that intends to provoke curiosity and critical thinking about misleading real-world mathematics? (about GMOs)

While working through the exercises in activities A, B & C, the tool presents graphs of different natures (misleading, confusing, convoluted), numbers that are not real, misleading data, and 'proofiness', in various ways. We designed the tool with the intention to confuse people with these tactics on issues surrounding GMO foods. The intent of our tool was to foster critical thinking and mathematical understanding by applying the same approaches that policymakers, educators, politicians, and even doctors sometimes use to manipulate the population. The goal of the activity is that learners embarking on these exercises acquire the critical skills necessary for making informed decisions on critical issues. In addition, we want to expose them to examples of proofiness, raise awareness of these issues, and provide learning experiences that utilize PBL approaches in highlighting the kinds of critically minded questions needed to provoke understanding and curiosity. Larmer (2014) stated that this pedagogy provides and prepares learners for 21^{st}-century success skills, highlights student independence and inquiry, and is multifaceted.

Next, I provide a deeper analysis of two investigations from Activity B. I also elaborate more on my intentions for (i) visualization, inquiry, and curiosity (Face B of the MFAI) and (ii) proofiness to combat proofiness (Face A of the MFAI).

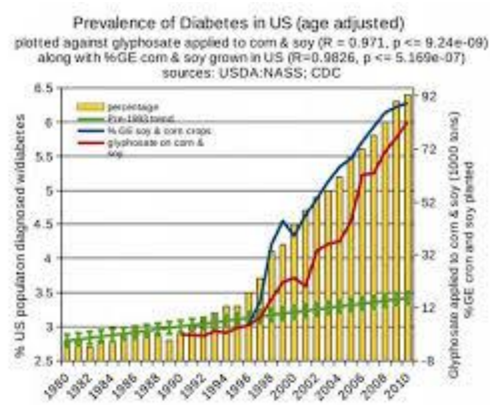
4.1 Visualization, Inquiry, & Curiosity

Visualization is a problem-solving tool used widely in our society, especially in mathematics (Presmeg, 2006: Schmitt & Lahroodi, 2008). Within mathematics, visualization is used as a cognitive strategy in solving problems (Piggot & Woodham, 2011; Rieber, 1995) and as a pedagogical strategy to scaffold and advance understanding (Mamolo et al., 2015). Our objective for using data visualization in our GMO learning tool, was to elicit curiosity about GMO facts, consequences, and implications (Activity B) (Harford, 2017; Rosling, 2006). The tool is interactive and is designed to draw learners' attention to different features or misleading information with the graphs and visuals by asking them critically-minded questions (McDonald & Reushle, 2000). The open-ended questions of our investigations are intended to expose new concerns and develop outwards as ripples or as trajectories of inquiry. The questions were designed to provoke curiosity and draw attention to specific GMO features and controversies, such as labelling requirements, stakeholders' interests, government policies, political interests, and stakeholders' and politicians' intentions. The questions were designed to lead learners to new insight and understanding of GMOs, and in this way, provoke curiosity as a positive intellectual force (Dewey, 1997, p. 33).

We can find examples of such questions below. We used these questions in both investigations I report on in this research. Investigation 5 (Figure 4.2) and Investigation 6 (Figure 4.3) are intended to encourage curiosity and inquiry, and demonstrate to learners how to read visual representations and recognize when the visuals are misleading or contain misinformation.

Figure 4.2: Labelling of GMOs

Figure 4.3: GMO & diabetes investigation



Find below some of the questions used in the learning tool's activities to provoke curiosity and critical thinking

- What do you notice about this graph?
- What story is this graph trying to tell?
- Is this data accurate? Do we believe this information is true?
- Is there anything confusing or unclear about the graph?
- Is the data meaningful? Do we believe this information is important?
- What choices did the person who created this graph make and why?
- Who do you think is responsible for this graph?
- Explain your reasoning and write a catchy headline that captures the main idea of the graph.

We used this research to inform our intentions for provoking curiosity and deep learning surrounding GMOs. We incorporated all aspects of the inquiry cycle in our tool, though not all of them were mathematical. For example, the tool invites learners to investigate and conceptualize the impact of planting GM crops on the rights of Indigenous peoples in Canada. The learners then use their findings to create a written proposal (Activity C, Figure 3.8).

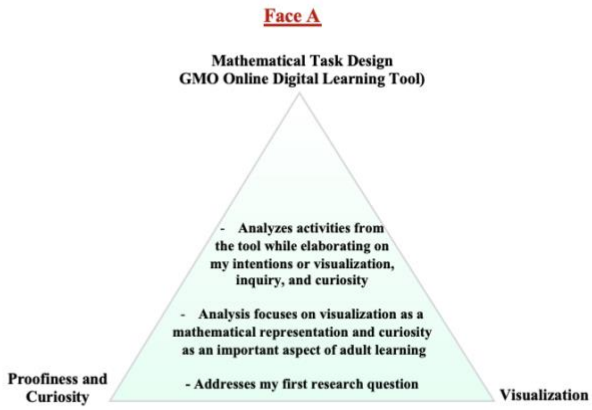
The proposal-writing included less math than I originally intended. Prior research has demonstrated how such an approach can be used to develop mathematical understanding and application (Mamolo, 2018), and I had intended to keep a more mathematical focus for this part of the learning activity. This was an area where my group members and I had different goals and intentions for the tool. I discuss this group difference in more detail in Chapter 5.

In line with Piggot and Woodham (2011), we intended to use visualization for the purpose of guiding users to step into a problem, model, and plan. Mathematical questions can use infographics to foster deep critical thinking and understanding of the mathematics and how it applies to the situation (Mamolo & Ibeh, 2021). Our intention was to elicit a sense of curiosity and critical thinking amongst the learners by incorporating infographics (which are forms of visualization). The design intends to carry out the proposed exercises to help adults appreciate the different ways GMOs are discussed and help adults know what questions to pose about GMOs. We developed questions that aimed to engage learners and incite their curiosity about GMO facts, an important part of learning emphasized by Schmidtt and Lahroodi (2008). Craik and Lockhart (1972) also noted the connection to deeper learning. For this purpose, our questions aimed to invite learners to think deeply.

Exercises that involve Investigations 5 & Investigation 6 also make use of such questions. According to Terry Heick (2020), good learning questions posed to students should open their minds, shift paradigms and force the uncomfortable but transformational cognitive dissonance that can help create thinkers on GMOs and similar real-life issues.

The above analysis speaks to the Face A of my MFAI (*Mathematics in Societal Issues + Mathematical Representations + Mathematical Task Design*). Specifically, my analysis focuses on visualization as a mathematical representation and curiosity about proofiness as an important aspect of adult learning.

Figure 4.4: Face A - Task design analysis – Proofiness to combat proofiness



We intentionally used this idea in Investigations 5 and 6, as discussed below. The primary ways that a visualization can mislead learners are: hiding relevant data, presenting too much data, distorting the presentation of data and describing the data inaccurately in annotations, title, or within the visualization itself (Hemsley & Snyder, 2018; Hogle, 2018; Huff, 1954). I present each of the primary ways as they relate to our tool's visuals. I first discuss Investigation 5 and our intentions to include misrepresentation and hiding of data. I then discuss Investigation 6 and the intentions to include distorting data, hiding data, truncating of Y-axis, and confusing causation and correlation in datasets.

It is important to note that these investigations were designed and informed by my three domain-specific frames, (i) Mathematics in societal issues, (ii) Mathematical representations, and (iii) Adult Learning.

In Investigation 5, we present an infographic where we observe that the numbers and the percentages given are illogical when grouped (see Figure 4.2 – Labelling of GMOs). This means that visualizations could also distort, obscure or misrepresent data (Szafir, 2018). The creators of this infographic placed the symbols at random with no explanation. The numbers do not tell the complete story, and there is no explanation of the symbols and what they represent. Moreover, the authors used deceptive pictographs with too much text and information, while the map contains accurate values, it does not proportionally and mathematically reflect American citizen support for labelling. We included this infographic to showcase how proofiness is reflected through the misrepresentation of numbers.

Furthermore, authors (e.g., Barocas & Selbst, 2016; Kroll, 2015; Citron & Pasquale, 2014; Feldman et al., 2015; O'Neil, 2016) highlighted that misrepresented numbers are often used to influence our decisions on important social topics such as public policy and health legislature. Due to a lack of confidence in numbers and measurements as a society, we could be easily misled by stakeholders into believing bogus mathematical arguments as long as they are presented in a visually appealing manner (Seife, 2011). Here, we challenge the learner to identify these faulty representations of reality while examining the given numbers in the proper context. As mentioned earlier, this is an example of where two MFAI faces are intertwined. Faces A and B in this situation speak to how individual frames can overlap to inform and realize design intentions.

To understand the implications of such misleading graphs in the above example, it is crucial to outline that GMO labelling is not mandatory, and many companies make large profits from GMOs. Thus, the companies that profit from GMOs do not want labelling legislation. For example, in the USA, national organizations in Vermont who oppose a GMO labelling law for genetically engineered foods (as they would be negatively affected by it) filed a lawsuit challenging the measure's constitutionality (Cournoyer, 2014). While most companies want to boast about their products, companies that produce GMO products spend millions hiding these details. Investigation 5 is designed to encourage individuals to look beyond the surface level of attractive infographics and delve into the actual implications (and stakeholders) of the data presented.

In Investigation 6 (see Figure 4.3 GMOs & diabetes investigation), the given graph is supposed to tell a story about the correlation between genetically engineered (GE) crops, glyphosate, and the deterioration of health in the United States of America. The graphs seem logical, but there are other features of the graphs that make them doubtful. Some of the tactics used to mislead are:

- Distorting data- According to O'Neil (2016), this can be done by showing too little or too much data, which results from choosing the wrong format or scale for the data visualization. In this GMO graph, our intention was to distort data by using different scales when graphing different variables or starting the Y-axis at a non-zero point, which de-emphasizes differences in values.

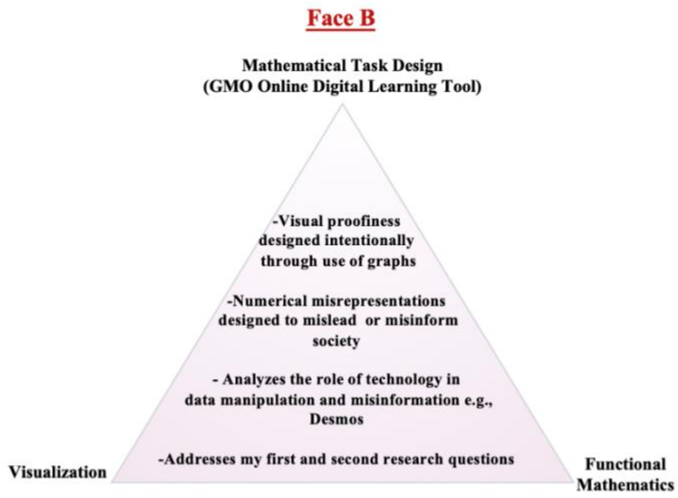
- Hiding relevant data- Data is left out from the story at the expense of an accurate understanding of the bigger picture (Barocas & Selbst, 2016; Citron & Pasquale, 2014; Eubanks, 2018; Feldman et al., 2015; Kroll, 2015; O'Neil, 2016). Also, sometimes showing the big picture can make it difficult to identify or hide salient data or stories (O'Neil, 2016). In our task, we chose graphs that purposefully hid relevant data. For instance, Figure 15a hides the number of polled people, and Figure 15b omits some years that could tell different stories, and we used questions that provoked curiosity to draw attention to this tactic.

- Truncation of Y-axis and having two Y axes – Truncation of Y-axis means that the Y-axis does not start from zero. This tactic is used to create the impression of significant change where there is relatively little change (Yang et al., 2020). In investigation 6, our graph (Figure 15b) uses two truncated y-axes, each with a different scale and which start at a different non-zero place. The scales are adjusted, and the graph purports to illustrate a temporal correlation between various diseases and the use of glyphosate. All these tactics can mislead or confuse the viewer.

- Confusing causation and correlation in datasets – The assumption that causation is correlation is a well-documented misunderstanding (Seife, 2011). However, correlation is not causation. With this graph, the authors assert that the prevalence of diabetes can be directly linked to the percentage of GE soy and corn grown in the US, but this claim is unsubstantiated.

The above analysis speaks to the Face B of my MFAI (*Mathematical Representations + Adult Learning + Mathematical Task Design*).

Figure 4.5: Face B - Task design analysis – Visualization and Functional Mathematics



4.2 Visual Proofiness to Combat Proofiness

Proofiness is "the art of using bogus mathematical arguments to prove something that you know in your heart is true, even when it's not" (Seife, 2011, p. 4). Seife shows how numbers can be used to deceive audiences. According to Seife, understanding proofiness means you can uncover many truths that a haze of lies obscure. I will focus specifically on Investigation 6 for my analysis.

The learning goal in Activity B, Task 1, is to deconstruct and assess the contextual relevance of mathematical data related to the GMOs controversy. The tool invites learners to use mathematical thinking and reasoning to analyze, interpret, and evaluate graphical data using Desmos and thought-provoking questions.

Zeese & Flowers's (2014) study showed that GMOs are linked to 22 diseases with very high correlation, and the authors use graphs to show the wide range of diseases. We focused explicitly on diabetes for our learning tool because diabetes is the most prevalent of all the outlined diseases. Here, for my research analysis on proofiness, I will focus on issues that were prevalent in all of the graphs, especially causation and correlation.

The presence of a correlation between the use of glyphosate, GE crop growth, and the increase in a multitude of diseases does not mean causation. This is "casuistry" (Seife, 2011) which is "the art of making a misleading argument through seemingly sound principle …implying that there is a casual relationship between two things when in fact there isn't any such linkage" (p. 44). Data do not show causes. Often, we are able to recognize patterns more easily through the graphical representations, but it is more difficult to show causality. The proxies used in the algorithmic processing of the data are hidden, preventing us from knowing the whole narrative of the visuals

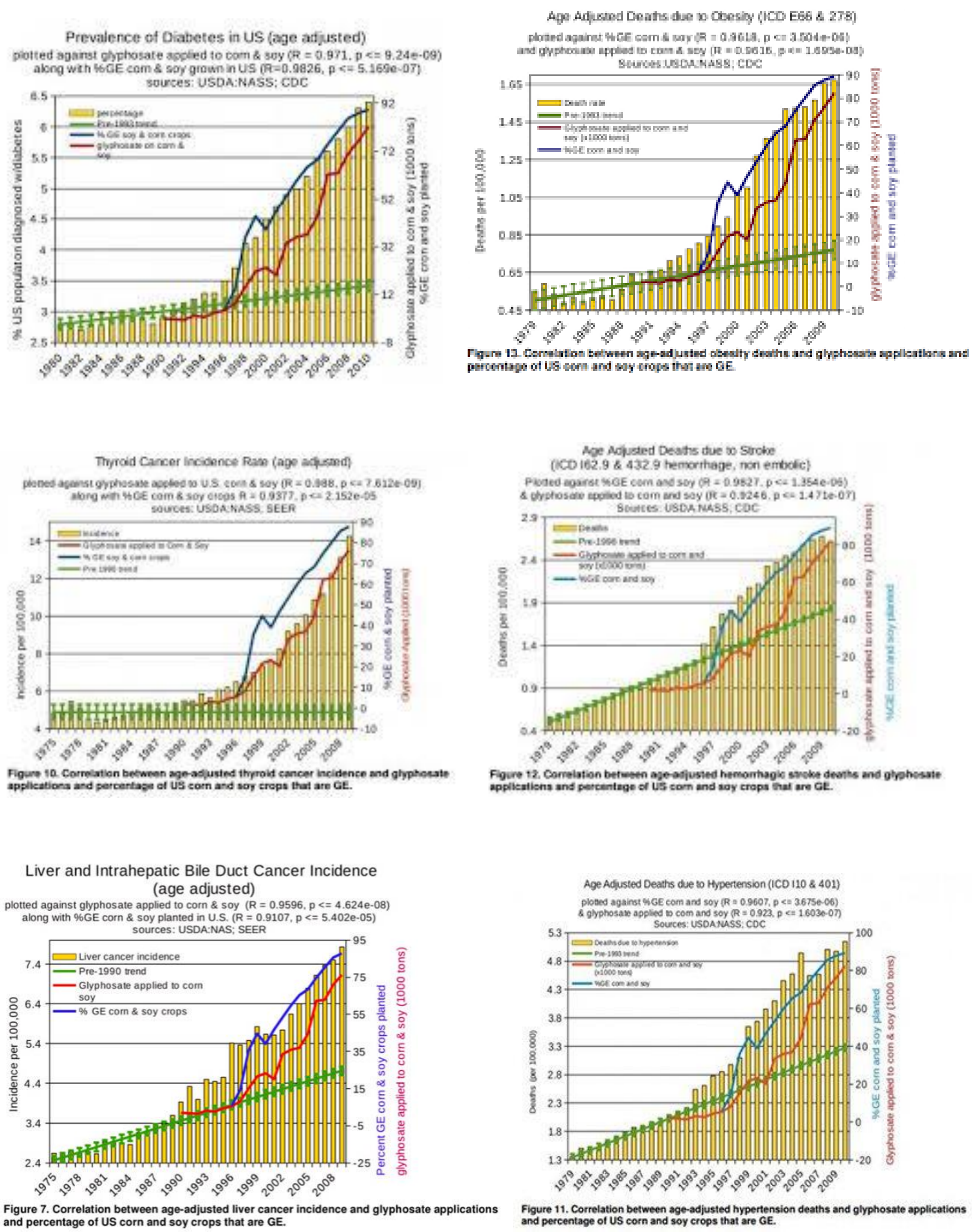
(Barocas & Selbst, 2016; Citron & Pasquale, 2014; Feldman et al., 2015; Kroll, 2015; O'Neil, 2016). Thus, the graphical models in Activity B are quite opaque and unfairly shown, thereby making them subjective. This is a faulty representation of reality (as stated in my literature review). Therefore, we are not sure and cannot say that the increase of GMOs is directly related to the increase of the diseases mentioned above. Forms of 'proofiness' are used here for the manipulation of data in order to make and present the arguments that the authors prefer.

Our tool used these thought-provoking exercises to expose the misinformation and misleading notions about GMOs used by policymakers, stakeholders, business persons, and researchers. As mentioned in my literature review, injustice is done when valid data is put in the wrong context (Bundy, 2013; Eubanks, 2018; O'Neil, 2016). Viewing the graphs through a mathematical lens illustrates that they were meant to mislead the audience. Some of the tactics used to mislead include:

- Axis manipulation and scaling -Y-axis does not start from zero, two y-axes
- Missing data points
- Incomplete data - Cherry-picking data
- Describing the data inaccurately in annotations, title, and within the visualizations themselves
- Source of the data

All the above tactics are used in all the graphs (see below).

Figure 4.6: Set of graphs in which misleading tactics were used



The visual supports provided by our tool and the interactive nature of the graphs are meant to help strengthen the effect of visual representation and make a difference in the learning process

(process of decision making) (Piggot & Woodham, 2011). This process can be applied to other issues of life that will allow the merging of visualization and mathematics in learning. Exploring proofiness via visualization serves as an agent of change, a learning approach that, when combined with mathematics, could significantly impact people's views and opinions. The graphs, visuals, and data collected on GMOs were all meant to help the learners in their decision-making processes. At the end of our activities, learners should understand the intricacies of GMOs and make informed decisions on what they consume.

As previously mentioned, curiosity normally enhances academic learning. Schimitt & Lahroodi (2008) stated: "that we take curiosity to be instrumental to and even essential for education, inquiry, and knowledge is confirmed by the fact that teachers often prefer techniques of instruction that excite curiosity…stimulating curiosity is central to education and learning" (p.48). Thus, curiosity leads us to facts, which help us fight issues such as devastating global ignorance, social injustice, as well as health and finance mismanagement, to name a few. As such, the use of visualizations to inspire curiosity could apply to any world issue that interests us. As stated in my literature review, in his TED Talk, Hans Rosling (2006) addresses how numbers in different life issues mislead society, and he showed this by using captivating visuals. He used visualization to educate.

In this section, I address my second research question:

How can online mathematical tasks be designed to support adults learning about mathematics in societal issues? (while focusing on fostering functional mathematical understanding)

Numeracy is an important by-product of schooling and a foundational skill for adults. It is all about how people decipher the mathematical, statistical, and quantitative demands of adult life.

Therefore, functional mathematics is a constituent of numeracy. Here, I will illustrate how our tool's activities could foster functional mathematics understanding of GMOs and its malleable application to other social justice issues.

In addition to addressing the pedagogical approaches, technologies, and activities that informed the design of the digital tool, Face C also addresses the adult learning that takes place in this technological medium.

In all the activities and tasks of the digital tool, exploration of data and use or choice of technology are all required. Technology and mathematics are interrelated (Pinkham, 1996; Hansson, 2020). Math needs technology, and technology needs math. Functional math skills are skills we use to live independently (Forman & Steen, 1999). This digital tool is meant to facilitate (in GMOs) the understanding of what foods to eat and deciding what is healthy or unhealthy. In the tasks, the goal is for the learners to use technology tools like Mindomo, Powtoon, Piktochart, Desmos, Padlet, etc., for data collection, data organization, conjecturing, data presentation, and reflection. Using Desmos could enable people to better comprehend ways that graphs could mislead or be manipulated for one's self-interest. Understanding the controversies of GMOs can be made possible from the data exploration using Desmos. Moreover, many data visualization sources can serve as tools for learners to explore various social issues from a data science or math lens, such as gapminder.org and informationisbeautiful.com.

As stated previously, our digital tool was created for adults and, therefore, should be self-directed, transformative, experiential, and contextualized (Herod, 2002, 2003; Knowles, 1980; Loeng, 2020). The tool includes activities that offer opportunities for students to investigate the GMO controversy through a mathematical lens with latitude for interdisciplinary adaptations (e.g., science, geography, history, etc.) and scaffolding to expand the scope and explore the depth of the

GMOs debate respectively. By asking themselves a series of questions, learners are expected to be guided down a variety of paths. Any of these paths could lead them to negotiate mathematical meaning, model mathematical thinking and apply reasoning. This type of active learning structure is flexible for use in other contexts.

Herod (2002) categorizes adult learning features according to self-directive, transformative, experiential, or contextual. In Table 1 (below), I analyze the features of the activities in relation to Herod's (2002) categorization of adult learning features. In my analysis, I categorize activities as self-directed, transformative, experiential, or contextual, provided they included the following features:

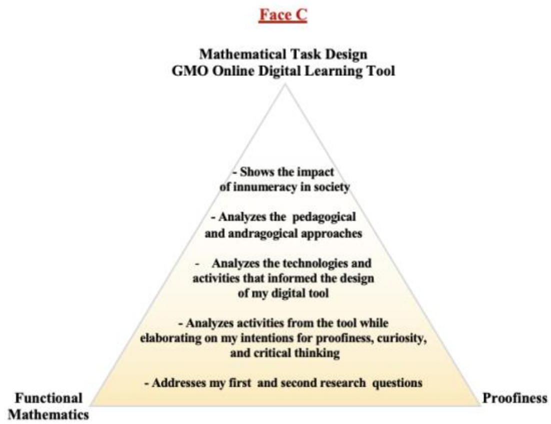
Table 1: Digital Tool Features for Adult Learning

Activities	Self-directed	Transformative	Experiential	Contextual
Minds-on activity			✓	✓
Role-playing		✓	✓	✓
Jigsaw discussions		✓	✓	✓
Exploring data	✓	✓		✓
Group presentations	✓	✓	✓	✓
Case Study		✓	✓	
Debrief/Reflection	✓	✓		✓
Scaffolding				✓
Collaboration				✓
Graph manipulation		✓	✓	
Technology use/choice	✓	✓		✓

Planned group assignments for this tool include role-playing, jigsaw discussions, scaffolding, and collaboration which are all to occur in groups of 4-5 students. In all activities, the students are expected to tackle mathematical ideas in a way that could build the necessary conceptual understanding and develop procedural fluency over time. In Activity A, Task 1, the intended learning goal in the role-play is for learners to investigate and conceptualize the impact of GMOs on different societal groups. Role-playing is a technique that is useful for addressing complex social issues (e.g., Lawson & Bodle, 2010) and for developing mathematical knowledge and communication (Mamolo, 2017). Therefore, one of our objectives in designing this role-playing activity was that learners could become experts in their roles. The intention is that learners could develop and display skills that will help foster functional math understanding on GMOs and other similar life issues. Activity 1, Task 2 reinforces this process of learning, which includes jigsaw discussions. The planned goal here is to articulate, prioritize, and present the collective impact of GMOs from different perspectives. Students from the "expert" group in Task 1 can then reorganize into new groups where there is a representation of each societal role. The design intention of the jigsaw technique is to foster cooperative learning in small groups. As such, this technique could provide students with the opportunity to become "experts" in a particular subject (Task 1) and share that knowledge with their peers (Task 2). These activities involve elements of story-telling (narratives), experience, and reflection, as well as rigorous scaffolding and collaboration. These activities are meant to foster functional math understanding in adults by using methods that are self-directed, transformative, experiential, or contextual in nature.

The above analysis speaks to the Face C of the MFAI (*Adult Learning + Mathematics in Societal Issues + Mathematical Task Design).*

Figure 4.7: Face C - Task design analysis – Functional Mathematics and Proofiness



In conclusion, classroom teachers could use this tool to introduce real-life issues to students through a mathematical lens. It is a learning tool that is designed to potentially inform and guide teachers and students in their everyday decision-making. Other real-life issues could flexibly use Activities A, B, & C with a focus on fostering functional mathematical understanding for adult learners. The tool potentially supports learning functional mathematics because it could provide learners the skills that are needed for mastering and reading mathematical spreadsheets, data analysis, and statistical quality control. It could also address (using exercises and visualization tools) neglected needs, including the technical and problem-solving needs of the modern demands of active citizenship. As mentioned earlier, most of the “sins” of proofiness and Weapons of Math Destruction were portrayed rigorously in multiple ways within our learning tool exercises.

Chapter 5 - Conclusion

5.1 Research Contributions and Limitations

My research in task design aimed to identify and analyse ways in which educators' mathematical intentions can inform the design of interactive visual displays of data in a task that tries to provoke curiosity and critical thinking about misleading real-world mathematics. To do this, I began with a historical review of task design research in mathematics education. This led me to the theoretical lens of task design by intention (Kieran, 2014) and to the need for domain-specific frames through which I could conceptualize and articulate my design intentions. I conducted a literature search to understand how society needs numeracy skills and what can happen when those skills are underdeveloped. This context helped me situate my study and informed my intentions for how to incorporate technology. I co-developed an online learning tool geared towards adult learners that intended to highlight ways numeracy skills can be used and misused in society so as to help adults understand real-world issues through mathematics. I also analyzed the role technology could play in facilitating the intentional design of learning experiences that could develop numeracy skills, particularly for adult learners.

My findings suggest that it is possible to develop a digital tool that has the potential to combat elements of innumeracy in society and that to do so requires negotiating multiple domain-specific frames. The tool was designed to focus on understanding GMO-related data, however other real-life issues could be addressed through Activities A, B, and C with a focus on fostering functional mathematical understanding for adult learners. The tool was designed with the intention to offer self-directed, transformative, experiential, and contextual learning opportunities with a focus on fostering critical mathematical understanding. My analysis of the tool highlights how technologies can be used to realize these intentions within the task design. In addition, the importance of visualization and curiosity were key aspects of my design intentions. Notably, injustice is done when valid data is put in the wrong context (O'Neil, 2016; Eubanks, 2018; Bundy, 2013), subsequently visuals that could provoke curiosity about the context of the data and its validity formed a central element of my tool.

My thesis extends prior research in task design as intention into a new area, which is a contribution of my work. The development of instructional tools for combating mathematical misinformation in society is an important new direction for education researchers, and my study illustrates ways that technology can be used with the intention to foster critical mathematical understanding of societal issues. Another key contribution of my research is in the development of the MFAI. The model (MFAI) I developed is valuable in this field as it is a heuristic for task design research when integrating multiple domain-specific frames. Researchers seeking to design and analyze a digital learning tool to address complex social issues can benefit from my MFAI model by using it to understand and delineate the complex relationships involved in designing a mathematical task. Design researchers can use my findings in their research to inform their intentions and designs.

A limitation of my research is that the study did not include design as implementation. There was no empirical data from users to test the task design and analyse whether the design intentions were realized from a learner's point of view. Collecting empirical evidence of how adult learners of different backgrounds might engage with this tool would provide a fuller picture of how design intentions may, or may not, be realized in an online learning environment. Another limitation was that the tool we created relied on a small selection of digital tools and (mis)information. We note that there are many more ways that other digital tools could be manipulated by politicians, stakeholders, policymakers, and business owners in areas of adult (in)numeracy, especially as it relates to real-life issues. Including a broader selection of tools and (mis)information could be more realistic and more meaningful for learners.

5.2 Reflections on My Experiences as a Task Designer

During my journey conducting this research, I began to reflect on how my experiences working collaboratively with a group of task designers influenced my intentions and my abilities to realize some of those intentions. It seemed that my prior experiences, identity, and perspectives as a mathematics educator came into question during this process. In this section, I reflect on the following question:

> ***How did my experiences and the group makeup impact the intentionality and design process?***

I came to this question while reflecting on my mathematical task design intentions that were fulfilled and the ones that were not fulfilled. I thought about what occurred and how I felt about my experiences creating this tool in a group setting. As I reflected on my experiences, it raised new ideas and questions that led me to explore new areas of research that were unfamiliar to me, such as *intersectionality*. Intersectionality research includes a deliberate focus on multiple interlocking identities of oppression that people experience throughout their lifetimes (Cheshire, 2013; Crenshaw, 1989). Reflecting on my own multiple interlocking identities, the intersections of my identities include an experienced mathematics tutor and teacher, a researcher in mathematics education, a Nigerian immigrant with an accent, a single working mother, a Bulgarian-trained engineer, and a business owner. According to Pliner et al., (2011), acknowledging intersectionality can be a valuable way to promote a reflective, collaborative, and engaging educational environment that can enrich learning and teamwork by incorporating a diverse range of identities.

Through the lens of my personal experiences and intersectional identities, my reflections expose some of the obstacles I experienced while trying to realize my task design intentions.

There are three incidents that stood out as moments where I felt that my identity as a mathematics educator was unfairly challenged. These moments impacted my sense of identity in the task design team and the strategies for coping the microaggressions I felt as the lone woman of colour in a group of three. From the very beginning of the collaboration, I felt diminished by my interactions with group members, and I believe that by sharing my critical reflections on these experiences, I can shed some light on issues that can hide behind the surface of task design research. In the next section, I will describe the dynamics that existed in the group which impacted the intentions of the online learning tool. The names used in the following sections are pseudonyms.

5.2.1 Initiating a Group Dynamic - Sarah and I Narrative

Sarah and I were friendly to each other before our course. We took other classes together in the past, and she knew my educational background is mathematics. When we started the course, the instruction was to form groups of two or three people. Sarah texted me on the first day and asked if she could form a group with me; I accepted her request. However, a day later, I understood that two other people from our class wanted to create another group with her. Without telling me, Sarah accepted their requests.

Over the following 2-3 days, Sarah avoided communication with me. It was not until another member of Sarah's new group contacted me that I became aware that they formed a new group without me. The other member contacted me to tell me that I could not be part of their formed group because they were at capacity. Knowing that they asked to join my group with Sarah, and that now I was being removed from my own group, took me aback. When Sarah and I finally spoke, she told me that she preferred not to join the others, but they were convincing her to be with them. They had created a WhatsApp group without me and had begun to discuss different topics. Sarah told me that she did not like their choice of the topic any longer and preferred the topic I had suggested. Her reason was that my topic was more mathematical than the topic of the other group. Privately, Sarah expressed remorse for how she handled the situation forming groups. In an email, she told me that the other group members were not very mathematical, and she was no longer interested in working with them. She apologized to me for her behaviour, and subsequently, the two of us formed a group. Other students had already formed their groups by this time, and I was obliged to work with her.

The treatment I received from Sarah made me feel like an outcast, and I desired to work alone instead of in a group. I felt that this treatment diminished my identity as a mathematician and math teacher. Sarah knew that I was strong in mathematics and very familiar with the expectations for this course and group project. Before we joined a group together, I had helped Sarah with math and other assignments in the program, as she was struggling and approached me for support. Nevertheless, she was ready to drop me from my own group, which would have left me without any collaborator, without providing a reason or explanation. I was unhappy with how Sarah had treated me, but in the end, I agreed to work with her because of the project requirements. Unfortunately, this experience had me question my place in the collaboration and how Sarah saw me. Numerous studies have shown that feeling a sense of community within a STEM program (Rincón & George-Jackson, 2016), college (Lambertus, 2010), or within the discipline itself (Ong, 2005) is vital for success of women. Women associate perceived identity compatibility and social support with a greater sense of belonging in STEM and their institution (Rosenthal et al., 2011). I did not feel belonging with Sarah, and more than that, my intentions for designing a task with a collaborative group already felt compromised as it was clear that I could no longer trust Sarah to be forthcoming and upfront about her decisions for this project.

5.2.2 A New Group Dynamic – Introducing Betty

During our next class, we were told that Betty was looking for a group to join. I approached Sarah and asked if we could accept her. That day the three of us – Sarah, Betty, and I – met to decide on our topic. I suggested a cancer-related topic, Sarah suggested the anti-vaccine controversy, and Betty suggested GMOs. We could not agree. Sarah and Betty said that they were not leaning towards cancer-related topics because the mathematics that would be involved was unfamiliar to them. I remember being surprised that my collaborators wanted to avoid choosing a topic because of the mathematics learning it would involve, despite us being in a mathematics course. Additionally, Sarah originally (prior to Betty joining the group) was on board with my topic.

Betty was very adamant about not choosing cancer as our topic, so again, she and Sarah said we should research and suggest other topics. I came up with women in STEM, Sarah came up with literacy testing, but Betty still stood firm on her GMO idea. The negotiation process took two weeks of our time, and we had to ask for an extension for our proposal, something with which I was not comfortable. I thought the topic of GMOs was inappropriate for the project because of the lack of mathematical connections. As the person in the group with the richest mathematical background, I felt that I had good insight to offer about which topics we could choose. However, Betty and Sarah continuously found fault in every subsequent topic that I suggested. Betty was unmovable, and we eventually had to go with GMOs, irrespective of the challenges in looking at that topic through a mathematical lens. I later found out that Betty's background is in an applied science that she could use to understand GMOs, and that was her reason for wanting to work on GMOs.

Although I did not know it at the time, this early exchange foreshadowed the working dynamic of the group throughout the design process. Betty and Sarah were continually finding faults in my contributions, and they consistently paired against me in these situations. This included major decisions about the project as well as minor issues. For instance, at one point they objected to my spelling of the word "artefact" (despite this being the spelling used by our professor). I understood this on-going behaviour as a form of microaggression, which according to Sue et al. (2007) are described as "brief and commonplace daily verbal, behavioural, or environmental indignities, that communicate hostile, derogatory, or negative racial slights and insults toward people of colour" of which the perpetrators are often unaware (p. 273; see also Sue, 2010). Research has shown that within STEM, common aggressions from classmates against women of colour could be subtle (Parker, 2013; Shehab et al., 2007) like I experienced. Another aggression experienced by women of colour is the withholding of recognition that women of colour are competent as emergent scientists (Brown, 2008; Camacho & Lord, 2011: Carlone & Johnson, 2007; Parker, 2013). By discrediting my contributions, from major issues to minor ones, I felt that my competency as a mathematics "knower" and educator was disregarded.

I was surprised by how adding a third member to our group seemed to shift the dynamic. Sarah had always been pretty respectful and appreciative of my skills when it was only the two of us because I had helped her with the math assignments of this course in the beginning. However, our group was now two white women and one Black woman, and the two of them consistently sided against me and my mathematical contributions. This created a constant stress and anxiety for me, and I grappled with this throughout the project.

5.2.3 Process of Task Design -- Two against One

Betty and Sarah made it clear that the mathematical concepts for GMOs would be my responsibility in the project. I had no issues with this and agreed. We all had our parts to complete for the task, but it seemed that mine would usually be heavily scrutinized and put up for debate whenever we met. When it came to deciding how to make our tasks mathematical and what math topics to choose, I remember a lot of arguments. For activity A, I suggested topics from grade 9, including percentages, ratios, fractions, and linear equations. I also suggested using functions (linear, exponential), exponential growth, and data management for Activity C. My groupmates did not accept my suggestions but rather included non-mathematical activities like writing letters and reflections in our project. I knew that these activities would not bring out any mathematical concepts bearing in mind that the course is a math course, but they did not consider my opinion. I felt frustrated that they did not want to listen to the mathematician amongst them, however I also felt outnumbered and did not want to always argue over issues. Over time, it felt as though asking for my view or input on anything during the project became more of a ritual (Yosso et al., 2009), as my opinions and contributions were consistently devalued or excluded. Keeping this in mind, I learned to respond by saying, “whatever you guys decide is fine for me.” While I was actually thinking, “please, let's just move on." There were conflicts in our priorities, which led to activities A and C having very little mathematical content. Our difference of opinion and arguments impacted the mathematical intentions of our tasks, and hence, I felt that these watered-down our activities. At the same time, the mathematics that I did manage to include in Activity B was well done and applauded by our instructor.

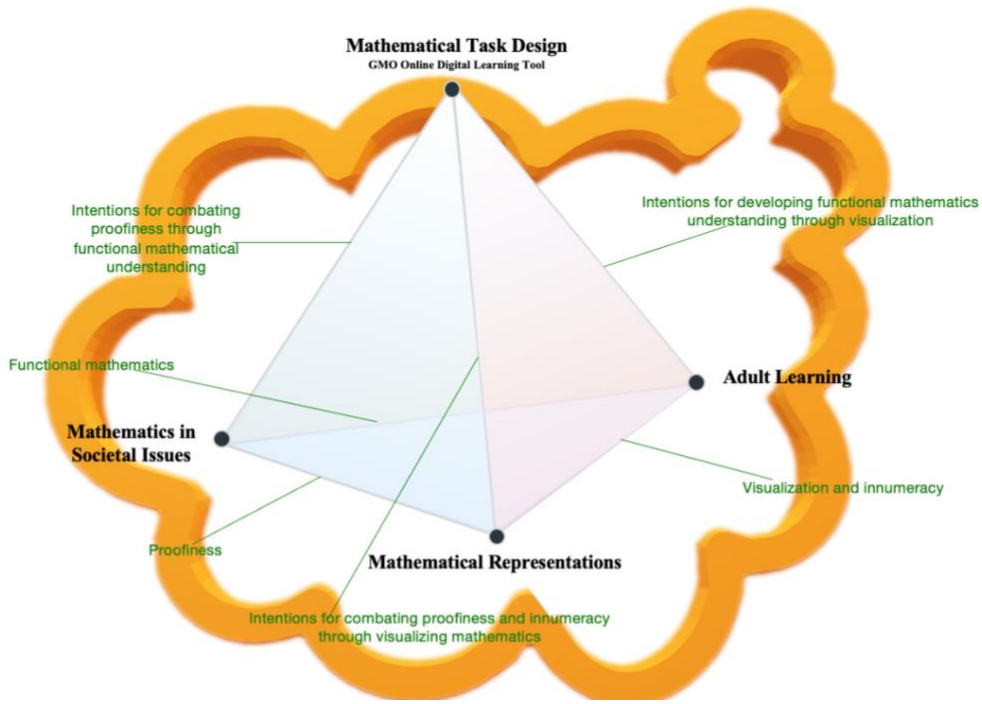
I felt that my group members’ disregard for my opinions was a clear form of microaggression (Brown, 2008; Camacho & Lord, 2011; Parker, 2013). Although their approach was incorrect, and the lack of mathematical focus in their parts was detrimental to the project, I went along with them simply to avoid conflict. My decision to compromise is a typical response of a woman of colour experiencing microaggressions. I had to choose between ignoring them or responding and risked being seen as “too sensitive” (Yosso et al., 2009, p. 661). Microaggressions exacerbate the sense of not belonging and, in this way, are linked to the isolation felt by women of colour and members of other underrepresented groups in STEM education (Joseph, 2012; Justin-Johnson, 2004; Shain, 2002; Valenzuela, 2006). I felt disrespected in this project, and I got to a point where I just wanted to fly under the radar. I felt that playing along with them would make me a ‘good’ team player. I was quite concerned that our final product would not be as mathematical as expected and required throughout our project. According to Charleston et al. (2014) and Yosso et al. (2009), such negative experiences may penalize women of colour academically and professionally. Lee (2013) points out that women can overcome stereotypes and bias by focusing on their identity, self-concept, self-efficacy, and a strong sense of community.

We were already a group working under the umbrella of social justice. However, I experienced the group as being far from being equitable and inclusive. This highlights some of our blind spots, even with our great mathematical intentions. However, in trying to navigate the underlying equity intentions for our task, our group stopped realizing the same equity intentions for our interactions.

5.3 Future Directions

My experiences facing microaggressions, and the ways I tried to cope with these, highlights a need for further research on the interactions that support design intentions. My 28 years of experience teaching mathematics to all levels and ages of students ignited my passion for numeracy and supported my task intentions. However, the challenges I faced as a design team member negatively impacted how I tried to realize my mathematical intentions for the task. Overall, my mathematical intentions were different from the actual outcome of the whole task. I have asked myself the question of "why did this happen?" numerous times. In Figure 5.1, I illustrate the impact that my experiences and group make up had on the MFAI.

Figure 5.1: Bubble around a MFAI



This bubble explains the pressure that is put on different features of the digital tool, as tensions emerge ingroup interactions. Whichever issue experienced within the group subsequently puts pressure on each aspect of the MFAI—the mathematics in societal issues, the mathematical representations, and on the adult learning pieces. The group's dynamics put pressure on different pieces and sometimes all of them at once. I believe there is a need for more research into the collaborative experiences of women of colour in white-majority settings in STEM education. My research also introduced me to the idea of couterspaces, which are "safe social spaces" that underrepresented groups (e.g., women of colour, racialized or marginalized people, and people with disabilities) use for emotional and mental support (Solórzano et al., 2000). Counterspaces are environments outside of mainstream spaces, such as educational institutions, that allow individuals from marginalized groups to have conversations and discussions about the discrimination and marginalization experienced by the members of the group. According to Sue et al. (2007) experiences of microaggression necessitate counterspaces for women of colour. According to Ong, Smith, & Ko (2017), researchers are still identifying counterspaces in higher education for women of colour in STEM departments and classrooms, and I believe this is an important area for future research.

Exploring the experiences of marginalized or racialized individuals working in a collaborative setting would benefit from narrative approaches (e.g., Clandinin & Connely, 2000; Riessman, 2008) which could allow for in-depth study of the experiences and events that helped shape the story of the task design. In particular, there is a need for autoethnographic research that uses story-telling methods to give personal accounts of cultural experiences that other methods cannot capture (Adams et al., 2017). Adams et al. (2017) state that an autoethnography can "articulate insider knowledge of a cultural experience" (p.3) and "describe moments of everyday experience that cannot be captured through more traditional research methods" (p.4). It should be noted that:

> "Insider knowledge does not suggest that an autoethnographer can articulate more truthful or more accurate knowledge as compared to outsiders, but rather that as authors we can tell our stories in novel ways when compared to how others may be able to tell them" (Adams et al., 2017, p.3).

For example, Boylorn (2011) and Ellis (2009) used autoethnographies to research ways that racism was experienced in mundane settings, such as college classrooms or the grocery store because other research methods such as interviews or surveys could not fully capture experiences of racism.

Likewise, my reflective analysis provides a narrative of how a mathematician with multiple identities can face racial challenges, and emphasizes a need for more research. In particular, there are limited studies and data on the experiences of racialized Canadian women in STEM, and there is a need to investigate more.

References

Adams, T. E., Ellis, C., & Jones, S. H. (2017). Autoethnography. *The international encyclopedia of communication research methods*, 1-11.

Adenle, A. A., Aworh, O. C., Akromah, R., & Parayil, G. (2012). Developing GM super cassava for improved health and food security: future challenges in Africa. *Agriculture & Food Security*, *1*(1), 1-15.

Ananny, M., & Crawford, K. (2018). Seeing without knowing: Limitations of the transparency ideal and its application to algorithmic accountability. new media & society, 20(3), 973-989.

Arcavi, A. (2003). The role of visual representations in the learning of mathematics. *Educational studies in mathematics*, *52*(3), 215-241.

Artigue, M., & Perrin-Glorian, M. J. (1991). Didactic engineering, research and development tool: some theoretical problems linked to this duality. *For the learning of Mathematics*, *11*(1), 13-18.

Artigue, M. (2009). Didactical design in mathematics education. In *Nordic research in mathematics education* (pp. 5-16). Brill Sense.

Ayob, A. & Yasin, R.M. (2017). Factors affecting attitudes towards Mathematics. *International Journal of Academic Research in Business and Social Sciences*, 7(11), 1100-1109.

Bathaee, Y. (2017). The artificial intelligence black box and the failure of intent and causation. Harv. JL & Tech., 31, 889.

Bartell, T. G. (2013). Learning to teach mathematics for social justice: Negotiating social justice and mathematical goals. *Journal for Research in Mathematics Education*, *44*(1), 129-163.

Beck, D., & Hughes, C. (2014). Engaging adult learners with innovative technologies. In *Adult and Continuing Education: Concepts, Methodologies, Tools, and Applications* (pp. 296-311). IGI Global.

Barocas, S., & Selbst, A. D. (2016). Big data's disparate impact. Calif. L. Rev., 104, 671.

Boylorn, R. M. (2011). Gray or for colored girls who are tired of chasing rainbows: Race and reflexivity. *Cultural Studies? Critical Methodologies*, *11*(2), 178-186.

Boylorn, R. M. (2011). Black kids' (BK) stories: Ta (l) king (about) race outside of the classroom. *Cultural Studies? Critical Methodologies*, *11*(1), 59-70.

Brookes, G., & Barfoot, P. (2018). GM crops: global socio-economic and environmental impacts 1996-2016. *PG Economics Ltd, UK*, 1-204.

Brookes, G., & Barfoot, P. (2020). Environmental impacts of genetically modified (GM) crop use 1996–2018: impacts on pesticide use and carbon emissions. *GM Crops & Food*, *11*(4), 215-241.

Brown, S. W. (2008). The gender differences: Hispanic females and males majoring in science or engineering. Journal of Women and Minorities in Science and Engineering, 14(2), 205– 223. https://doi.org/10.1615/JWomenMinorScienEng.v14.i2.50

Bryant, W. L. (2014). *Education and technology in the 21st century experiences of adult online learners using Web 2.0* (Doctoral dissertation, Capella University).

Bundy, A. (2013). The interaction of representation and reasoning. Proceedings of the Royal Society of London Series A, 469(2157), 20130194-20130194.

Burrell, J. (2016) How the Machine "Thinks": Understanding Opacity in Machine Learning Algorithms. Big Data & Society, 3, 1-12. https://doi.org/10.1177/2053951715622512

Camacho, M. M., & Lord, S. M. (2011). "Microaggressions" in engineering education: Climate for Asian, Latina and White women. Paper presented at Frontiers in Education Conference (FIE), Rapid City, SD. htps://doi.org/10.1109/FIE.2011.6142970

Campbell, C. (2014). Problem-based learning and project-based learning. Australian Council for Educational Research–ACER.

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. Journal of Research in Science Teaching, 44(8), 1011– 1245. https://doi.org/10.1002/tea.20237

Charleston, L. J., Adserias, R. P., Lang, N. M., & Jackson, J. F. L. (2014). Intersectionality and STEM: The role of race and gender in the academic pursuits of African American women in STEM. Journal of Progressive Policy and Practice, 2(3), 273– 293. Retrieved from http://caarpweb.org/wp-content/uploads/2014/12/Charleston-Adserias-Lang-Jackson-2014.pdf

Cheshire, L. (2013). Reconsidering sexual identities: Intersectionality theory and the implications for educating counsellors. Canadian Journal of Counselling and Psychotherapy, 47(1).

Clandinin, D. J., & Connelly, F. M. (2000). Narrative inquiry: Experience and story in qualitative research. San Francisco, CA: Jossey-Bass Publishers [Google Scholar]

Clandinin, D. J., & Connelly, F. M. (2004). *Narrative inquiry: Experience and story in qualitative research*. John Wiley & Sons.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13.

Cockcroft, W.H. (1982). Report of the Committee of Inquiry into the Teaching of Mathematics in Schools. London: HMSO.

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of verbal learning and verbal behavior*, *11*(6), 671-684.

Crenshaw, K. (1989). Demarginalizing the intersection of race and sex: A black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. *u. Chi. Legal f.*, 139.

Dede, A. T. (2019). Arguments constructed within the mathematical modelling cycle. International Journal of Mathematical Education in Science and Technology, 50(2), 292-314.

Desai, M. (2019). *How finance works: The HBR guide to thinking smart about the numbers*. Harvard Business Press.

Dewey, John. 1997. How We Think, Revised ed. Mineola, N.Y: Dover Publications.

Doyle, W. (1983). Academic work. Review of educational research, 53(2), 159-199.

Drum, K. (2016, November). How to Mislead with Statistics: GMO Crops, *MotherJones* https://www.motherjones.com/kevin-drum/2016/11/how-mislead-statistics-gmo-crops-edition/

Ellis, C. (2009). Fighting back or moving on: An autoethnographic response to critics. International Review of Qualitative Research, 2(3), 371-378.

Eubanks, V. (2018) *Automating Inequality: How High-Tech Tools Profile, Police, and Punish the Poor*. New York, NY, St. Martin's Press.

Fatima, R. (2015). Role of Mathematics in the Development of Society. http://www.ncert.nic.in/pdf_files/Final-Article-Role%20of%20Mathematics%20in%20the%20Development%20ofSociety-NCER-.pdf

Feldman, M., Friedler, S. A., Moeller, J., Scheidegger, C., & Venkatasubramanian, S. (2015, August). Certifying and removing disparate impact. In proceedings of the 21th ACM SIGKDD international conference on knowledge discovery and data mining (pp. 259-268).

Fioramonti, D. L. (2014). How numbers rule the world: The use and abuse of statistics in global politics. Zed Books Ltd.

FitzSimons, G., & Godden, G. L. (2000). Review of research on adults learning Mathematics in "Perspectives on Adults Learning Mathematics: Research and Practice" (Eds. D. Coben et al.), Kluwer Academic Publishers, p. 13-45.

FitzSimons, G. E. (2013). Doing Mathematics in the Workplace: A Brief Review of Selected Literature. Adults Learning Mathematics, 8(1), 7-19.

FitzSimons, G.E. (2014). Commentary on Vocational Mathematics Education: Where Mathematics education confronts the realities of people's work. *Educational Studies in Mathematics*, 86(2), 291-305.

Flowers, N., Mertens, S. B., & Mulhall, P. F. (2000). What makes interdisciplinary teams effective? Middle School Journal, 31(4), 53-56.

Forman, S. L. & Steen, L. A. (1999). Beyond eight grade: Functional mathematics for life and work. University of California, Berkeley: National Center for Research in Vocational Education

Forman, S., & Steen, L. A. (1995). How school mathematics can prepare students for work, not just for college. *The Harvard Education Letter*, *11*, 6-8.

Gal, I., Grotlüschen, A., Tout, D., & Kaiser, G. (2020). Numeracy, adult education, and vulnerable adults: a critical view of a neglected field. *Zdm*, *52*(3), 377-394.

Gal, I. (1995). Big picture: What does "numeracy" mean? GED, 12 (4/5). http://forum.swarthmore.edu/teachers/adult.ed/articles/gal.html

Rodríguez-Gallegos, R. (2015). A differential equations course for engineers through modelling and technology. In Mathematical modelling in education research and practice (pp. 545-555). Springer, Cham.

Galligan, L., & Taylor, J.A. (2008). Adults returning to study Mathematics in "Research in Mathematics Education in Australasia 2004-2007" (Eds. H. Forgasz, A. Barkatsas, A. Bishop, B, Clarke, S. Keast, W. Seah & P. Sullivan), *Sense Publishers Rotterdam*, p. 99 - 118.

Ganter, S. L., & Barker, W. (2004). A collective vision. *The Curriculum Foundations Project: Voices of the Partner Disciplines*, 1-10.

Geiger, V., Goos, M., & Forgasz, H. (2015). A rich interpretation of numeracy for the 21st century: A survey of the state of the field. *ZDM*, *47*(4), 531-548.

Gorard, S. (2014). The widespread abuse of statistics by researchers: What is the problem and what is the ethical way forward? Psychology of education review, 38(1), 3-10.

Greefrath, G., & Siller, H. S. (2017). Modelling and simulation with the help of digital tools. In Mathematical modelling and applications (pp. 529-539). Springer, Cham.

Greer, B. (2001). Understanding probabilistic thinking: The legacy of Efraim Fischbein. Educational Studies in Mathematics, 45(1-3), 15-33.

Greer, B., & Verschaffel, L. (2007). Modelling competencies—overview. Modelling and applications in mathematics education, 219-224.

Grote, T., & Keeling, G. (2022). On algorithmic fairness in medical practice. Cambridge Quarterly of Healthcare Ethics, 31(1), 83-94.

Gutstein, E., & Peterson, B. (Eds.). (2005). Rethinking mathematics: Teaching social justice by the numbers. Rethinking Schools.

Hadford, T. (2017). Statistics: Why the truth matters. University of Oxford: Oxford https://podcasts.ox.ac.uk/statistics-why-truth-matters-tim-harford

Hall, S. (1997). Representation: Cultural representations and signifying practices. Chapter 1: Representation, meaning, and language. London Thousand Oaks, Calif: Sage in association with the Open University. Pp. 15-64.

Hansson, S. O. (2020). Technology and mathematics. *Philosophy & Technology*, *33*(1), 117-139.

Heick, T. (2020). What is Bloom's taxonomy. *A definition for teachers. Retrieved on October*, *17*, 2020.

Hemsley, J., & Snyder, J. (2018). Dimensions of visual misinformation in the emerging media landscape. *Misinformation and mass audiences*, 91-106.

Henn, H. W. (2007). Modelling pedagogy—overview. Modelling and applications in mathematics education, 321-324.

Herod, L. K. (2002). A Curriculum Database for the Canadian Adult Literacy Community: Preliminary Technical and Educational Considerations.

Herod, L. K. (2003). Adult learning from theory to practice. Family Literacy Events Committee.

Herod, L. K. (2012). Adult learning: From theory to practice. https://jarche.com/wpcontent/uploads/2015/12/adult_learning.pdf

Hilbeck, A., Binimelis, R., Defarge, N., Steinbrecher, R., Szekacs, A., Wickson, F., & Wynne, B. (2015). No scientific consensus on GMO safety. Environmental Sciences Europe, 27(1), 4.

Hogle, P. (August 15, 2018). Misleading Data Visualizations Can Confuse, Deceive Learners. Learning Solutions. Retrieved from: https://www.learningsolutionsmag.com/articles/misleading-data-visualizations-can-confuse-deceive-learners

Huff, D. (1954). How to Lie with Statistics. New York: W. W. Norton & Company.

Johannssen, A., Chukhrova, N., Schmal, F., & Stabenow, K. (2021). Statistical Literacy—Misuse of Statistics and Its Consequences. Journal of Statistics and Data Science Education, 29(1), 54-62.

Johnson, P. & O'Keeffe, L. (2016). The effect of a pre-university mathematics bridging course on adult learners' self-efficacy and retention rates in STEM subjects. Irish Educational Studies, 35(3), 233-248.

Joseph, J. (2012). From one culture to another: Years one and two of graduate school for black women in the STEM fields. International Journal of Doctoral Studies, 7, 125– 142. Retrieved from http://ijds.org/Volume7/IJDSv7p125-142Joseph344.pdf

Justin-Johnson, C. (2004). Good fit or chilly climate: An exploration of the persistence experiences of African–American women graduates of predominantly White college science programs. Doctoral dissertation.

Karge, B. D., Phillips, K. M., Jessee, T., & McCabe, M. (2011). Effective Strategies for Engaging Adult Learners. Journal of College Teaching & Learning, 8(12), 53-56.

Ke, F., & Xie, K. (2009). Toward Deep Learning for Adult Students in Online Courses. Internet and Higher Education, 12(3-4), 136-145.

Kelly, E. A., Lesh, R. A., and Baek, J. (Eds.) (2008). Handbook of design research methods in education: Innovations in science, technology, engineering and mathematics learning and teaching. London: Routledge.

Kieran, C. (2019). Task Design Frameworks in Mathematics Education Research: An Example of a Domain-Specific Frame for Algebra Learning with Technological Tools. ICME-13 Monographs.

Kieran, C., Doorman, M., & Ohtani, M. (2015). Frameworks and principles for task design. In Task design in mathematics education (pp. 19-81). Springer, Cham.

Kirk, A. (2016). *Data visualisation: A handbook for data driven design*. Sage.

Knowles, M. S. (1980). The Modern Practice of Adult Education: From Pedagogy to Andragogy (Revised and Updated). Cambridge.

Kroll, J. A. (2015). Accountable algorithms (Doctoral dissertation, Princeton University).

Lallanilla, M. (2019). What are GMOs and GM foods. *Live Science*.

Lambertus, A. J. (2010). *Characterizing gender diverse graduate mathematics departments as communities of practice*. North Carolina State University.

Landy, D., & Goldstone, R. L. (2007). Formal notations are diagrams: Evidence from a production task. *Memory & cognition*, *35*(8), 2033-2040.

Landy, D., & Goldstone, R. L. (2007). How abstract is symbolic thought? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(4), 720.

Larmer, J. (2014). Project-based learning vs. problem-based learning vs. X-BL. Retrieved March, 8, 2024.

Lee, J. (2013). 'You know how tough I am?' Discourse analysis of US Midwestern congresswomen's self-presentation. Discourse & Communication, 7(3), 299-317.

Lee, S., Kwon, B. C., Yang, J., Lee, B. C., & Kim, S. H. (2019). The correlation between users' cognitive characteristics and visualization literacy. *Applied Sciences*, *9*(3), 488.

Litman, J. A., & Spielberger, C. D. (2003). Measuring epistemic curiosity and its diversive and specific components. Journal of Personality Assessment, 80, 75-86.

Loeng, S. (2020). Self-directed learning: A core concept in adult education. Education Research International, 2020.

Loewenstein, G. 1994. The psychology of curiosity: A review and reinterpretation. Psychological Bulletin, 116: 75–98.

Almeida Luna, A. V. D., Souza, E. G., & Souza Lima, L. B. D. (2015). Mathematical texts in a mathematical modelling learning environment in primary school. In Mathematical Modelling in Education Research and Practice (pp. 535-543). Springer, Cham.

Ma, L. (1999). *Knowing and teaching elementary mathematics: teachers' understanding of fundamental mathematics in China and the United States*. Mahwah: Lawrence Erlbaum.

Madison, B. L., & Steen, L. A. (Eds.). (2003). Quantitative literacy: Why numeracy matters for schools and colleges. Woodrow Wilson National Foundation.

Mamolo, A. (2018). Eyes, ears, and expectations: Scripting as a multi-lens tool. In Scripting Approaches in Mathematics Education (pp. 229-248). Springer, Cham.

Mamolo, A., & Ibeh, N. (2021). Infographics: A remixing approach. Gazette-Ontario Association for Mathematics, 60(1), 36-40.

Mamolo, A., Ruttenberg-Rozen, R., & Whiteley, W. (2015). Developing a network of and for geometric reasoning. ZDM, 47(3), 483-496.

Mason, J. (1998). Enabling teachers to be real teachers: Necessary levels of awareness and structure of attention. *Journal of Mathematics Teacher Education, 1*(3), 243–267.

Mayer, S., & Stirling, A. (2004). GM crops: good or bad? Those who choose the questions determine the answers. EMBO Reports, 5(11), 1021–1024.

McDonald, J., & Reushle, S. (2000). Engagement in web-based education: designing for models of student learning. Indian Journal of Open Learning, 9(3), 287-298.

McLoughlin, C., & Krakowski, K. (2001, September). Technological tools for visual thinking: What does the research tell us. In *Apple University Consortium Academic and Developers Conference* (pp. 128-139). Townsville, QLD, Australia: Apple University Consortium (AUC).

Menning, S. F. (2019). Exploring an alternative justification for the importance of curiosity in education: social curiosity and Løgstrup's sovereign expression of life. *Studies in Philosophy and Education*, *38*(3), 241-260.

Miller, H. J., & Goodchild, M. F. (2015). Data-driven geography. GeoJournal, 80(4), 449-461.

Morris, T. H. (2019). Adaptivity through self-directed learning to meet the challenges of our ever-changing world. Adult Learning, 30(2), 56-66.

Niss, M. (1989). Aims and Scope of Applications and Modelling in Mathematics Curricula. In Blum, W., Berry, J.S., Biehler, R., Huntley, I.D., Kaiser-Messmer, G. & Profke, L. (eds.), Applications and Modelling in Learning and Teaching Mathematics. Chichester: Ellis Horwood.

Niss, M. (2010). Modeling a crucial aspect of students' mathematical modeling. In Modeling students' mathematical modeling competencies (pp. 43-59). Springer, Boston, MA.

O'Neil, C. (2016) *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy*. New York, NY, Broadway Books.

Ong, M. (2005). Body projects of young women of color in physics: Intersections of gender, race, and science. Social Problems, 52(4), 593– 617.

Ong, M., Smith, J. M., & Ko, L. T. (2018). Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success. Journal of research in science teaching, 55(2), 206-245.

Parker, A. D. (2013). Family matters: Familial support and science identity formation for African American female STEM majors. Doctoral dissertation. Retrieved from ProQuest Dissertations and Theses database. (Publication No. AAT 3594079).

Pasquale, F. (2015). The black box society: The secret algorithms that control money and information. Harvard University Press.

Paulos, J. A. (1988). *Innumeracy: Mathematical illiteracy and its consequences*. Macmillan.

Pentland, A. S. (2013). The data-driven society. Scientific American, 309(4), 78-83.

Piggot, J. & Woodham, L. (2011). Thinking through, and by, visualization. URL, https://nrich.maths.org/6447.

Pinkham, R. S. (1996). Mathematics and modern technology. *The American mathematical monthly*, *103*(7), 539-545.

Pliner, S. M., Iuzzini, J., & Banks, C. A. (2011). Using an intersectional approach to deepen collaborative teaching. New Directions for Teaching and Learning, 125, 43–51. http://scholar.google.com/scholar_lookup?hl=en&volume=125&publication_year=2011&pages=43-51&author=S.+M.+Pliner&author=J.+Iuzzini&author=C.+A.+Banks&title=Using+an+intersectional+approach+to+deepen+collaborative+teaching&doi=10.1002%2Ftl.432

Pluck, G. and Johnson, H. L. (2011). Stimulating curiosity to enhance learning. GESJ: Education Sciences and Psychology , 2 (19). ISSN 1512-1801

Power, D. J. (2015). Creating a data-driven global society. In Reshaping Society through Analytics, Collaboration, and Decision Support (pp. 13-28). Springer, Cham.

Presmeg, N. (2006). Research on visualization in learning and teaching mathematics: Emergence from psychology. In *Handbook of research on the psychology of mathematics education* (pp. 205-235). Brill Sense.

Radford, L. (2003). On the epistemological limits of language: Mathematical knowledge and social practice during the Renaissance. *Educational Studies in Mathematics*, 52, 123-150.

Restivo, S. (1992). Mathematics in society and history: Sociological inquiries. *Dordrecht: Kluwer Academic Publishers*.

Rieber, L. P. (1995). A historical review of visualization in human cognition. *Educational technology research and development*, *43*(1), 45-56.

Riessman, C. K. (2008). Narrative methods for the human sciences. Thousand Oaks: Sage

Rincón, B. E., & George-Jackson, C. E. (2016). Examining department climate for women in engineering: The role of STEM interventions. Journal of College Student Development, 57(6), 742-747.

Rogers, A. & Horrocks, N. (2010). Teaching Adults Fourth Edition. Open University Press, p.80.

Rosa, M., & Orey, D. C. (2015). Social-critical dimension of mathematical modelling. In Mathematical Modelling in Education Research and Practice (pp. 385-395). Springer, Cham.

Rosenthal, L., London, B., Levy, S. R., & Lobel, M. (2011). The roles of perceived identity compatibility and social support for women in a single-sex STEM program at a co-educational university. *Sex roles*, *65*(9), 725-736.

Rosling, H. (2006). The best stats you've ever seen. TED Talk. Available here: https://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen?language=en.

Rosling, H. (2006). *Debunking third-world myths with the best stats you've ever seen*. TED.

Rosling, H. (2006). Stats that reshape your worldview. *TED talk-online video*.

Rosling, H., Rosling, O., & Rönnlund, A. R. (2018). Factfulness: Ten reasons we're wrong about the world - and why things are better than you think.

Rubel, L. H., Nicol, C., & Chronaki, A. (2021). A critical mathematics perspective on reading data visualizations: reimagining through reformatting, reframing, and renarrating. *Educational Studies in Mathematics*, *108*(1), 249-268.

Sailing Olesen, H. (2008). Workplace learning. In P. Jarvis (Ed.), *The Routledge international handbook of lifelong learning* (pp. 114-128). London: Routledge.

Sailing Olesen, H. S. (2010). Guest editor's introduction. *Journal of Workplace Learning*, 22(1/2), 5-12.

Sala Sebastià, G., Font Moll, V., Giménez Rodríguez, J., & Barquero Farràs, B. (2017). Inquiry and modelling in a real archaeological context. In Mathematical Modelling and Applications (pp. 325-335). Springer, Cham.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. The interdisciplinary Journal of Problem-based Learning, 1(1), 9-20.

Schield, M. (2021, July). Statistical Literacy for Policy Makers. In Proceedings 63rd ISI World Statistics Congress (Vol. 11, p. 16).

Schmitt, F. F., & Lahroodi, R. (2008). The epistemic value of curiosity. *Educational theory*, *58*(2), 125-148.

Seife, C. (2010). Proofiness: How you're being fooled by the numbers. Penguin.

Shain, C. H. (2002). Revisiting the problem of engineering school persistence in African-American women students. Doctoral dissertation. Retrieved from ProQuest Dissertations and Theses database. (Publication No. 304798888).

Shehab, R., Murphy, T., Davidson, J., Foor, C., Reed Roads, T., Trytten, T., & Walden, S. (2007). Experiences as a non-majority engineering student. Paper presented at the 2007 American Society for Engineering Education Annual Conference & Exposition. Atlanta, GA: American Society for Engineering Education.

Sierpinska, A. (2004). Research in mathematics education through a keyhole: Task problematization. *For the learning of mathematics*, *24*(2), 7-15.

Smith, J. (2013). Genetically Engineered Foods May be Far More Harmful than We Thought https://www.westonaprice.org/health-topics/modern-foods/genetically-engineered-foods-may-be-far-more-harmful-than-we-thought/

Solórzano, D., Ceja, M., & Yosso, T. (2000). Critical race theory, racial microaggressions, and campus racial climate: The experiences of African American college students. The Journal of Negro Education, 69(1), 60– 73. Retrieved from http://www.jstor.org/stable/2696265

Spielberger, C. D., & Starr, L. M. (1994). Curiosity and exploratory behavior. In H. F. O'Neil, Jr. & M. Drillings (Eds.), *Motivation: Theory and research* (pp. 221–243). Lawrence Erlbaum Associates, Inc.

Stein, M. K., & Lane, S. (1996). Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform mathematics project. *Educational Research and Evaluation*, *2*(1), 50-80.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American educational research journal*, *33*(2), 455-488.

Stewart-Rozema, J. (2019). *Careful Curiosity: Curiosity as an Epistemic and Ethical Virtue* (Doctoral dissertation, Emory University).

Stillman, G. (2007). Implementation case study: Sustaining curriculum change. In Modelling and applications in mathematics education (pp. 497-502). Springer, Boston, MA.

Sue, D., Capolidupo, C. M., Torino, G. C., Bucceri, J. M., Holder, A. M., Nadal, K. L., & Esquilin, M. (2007). Racial microaggressions in everyday life. American Psychologist, 62(4), 271– 286.

Sue, D. W. (2010). Microaggressions in everyday life: Race, gender, and sexual orientation. Hoboken, NJ: John Wiley & Sons.

Sung, E. (2017). The influence of visualization tendency on problem-solving ability and learning achievement of primary school students in South Korea. *Thinking skills and Creativity*, *26*, 168-175.

Szafir, D. A. (2018). The good, the bad, and the biased: Five ways visualizations can mislead (and how to fix them). *interactions*, *25*(4), 26-33.

Tanase, M., & Lucey, T. A. (2015). Interdisciplinary connections: teaching mathematics for social justice and financial literacy. Journal of Mathematics & Culture, 9(1), 108-118.

Tarmizi, M. A. A., Tarmizi, R. A., & Mokhtar, M. Z. B. (2010). Humanizing mathematics learning: Secondary students beliefs on mathematics teachers' teaching efficacy. *Procedia-Social and Behavioral Sciences*, *8*, 532-536.

Trigo, E. J., & Cap, E. J. (2003). The impact of the introduction of transgenic crops in understanding the world through Math. https://asiasociety.org/education/understanding-world-through-math

Valenzuela, Y. (2006). Mi fuerza/my strength: The academic and personal experiences of Chicana/Latina transfer students in math and science. (Doctoral dissertation).

Villarreal, M. E., Esteley, C. B., & Smith, S. (2015). Pre-service mathematics teachers' experiences in modelling projects from a socio-critical modelling perspective. In Mathematical Modelling in Education Research and Practice (pp. 567-578). Springer, Cham.

Watson, A., & Ohtani, M. (2015). *Task design in mathematics education: An ICMI study 22* (p. 339). Springer Nature.

Widjaja, W. (2013). Building awareness of mathematical modelling in teacher education: A case study in Indonesia. In Teaching mathematical modelling: Connecting to research and practice (pp. 583-593). Springer, Dordrecht.

Wittmann, E. C. (1995). Mathematics education as a 'design science'. *Educational studies in Mathematics*, *29*(4), 355-374.

Yang, B. W., Restrepo, C. V., Stanley, M. L., & Marsh, E. J. (2021). Truncating bar graphs persistently misleads viewers. *Journal of Applied Research in Memory and Cognition*, *10*(2), 298-311.

Yoshimura, N. (2015). Mathematical modelling of a social problem in Japan: The income and expenditure of an electric power company. In Mathematical Modelling in Education Research and Practice (pp. 251-261). Springer, Cham.

Yosso, T. J., Smith, W. A., Ceja, M. & Solórzano, D. G. (2009). Critical race theory, racial microaggressions, and campus racial climate for Latina/o undergraduates. Harvard EducationalReview, 79(4), 659– 91. http://doi.org/10.17763/haer.79.4.m6867014157m707l

Zeese, K. & Flowers, M. (2014). Dramatic Correlation shown between GMOs and 22 Diseases. *Truthout*. https://truthout.org/articles/dramatic-correlation-shown-between-gmos-and-22-diseases/

Appendices

Appendix A: Themes involved in my Conceptual Construct

Appendix A: Overview of how the themes from Chapter 2 emerged across all of the activities and the research literature that informed my task design intentions.

Themes involved in my Conceptual Construct		
Theme	**Was applied in**	**Research connections include…**
Models: Interacting with models and creating models	Activity 1A Activity B: exploring data	Harford, 2017 Mamolo & Ibeh, 2021 Piggot&Woodham, 2011 Rosling, 2006; O'Neil, 2016 Eubanks, 2018
Algorithms	Activity B: Exploring data	O'Neil, 2016 Eubanks, 2018 Bundy, 2013 Piggot & Woodham, 2011
Misleading nature of numbers	Activity A: culminating task – personal digital artifact Activity B: culminating task-GMOs infographic, Desmos activity	Seife, 2011 Paulos, 2001
Faulty representations of reality	Activity A: Culminating task – personal digital artifact Activity B: Analytical deconstruction	Seife, 2011 Hal, 1997 Bundy, 2013
Fostering mathematical understanding	Activity A: minds-on activity Activity B: exploring data Activity C: debrief and reflection	Radford, 2003; Restivo, 1992 Sailing Olesen, 2010 Forman & Steen 1999 Galligan and Taylor's 2008 Gal 1995
Math attitude and identities	Activity A: Culminating task Activity B: Graph manipulation	Sheldon & Epstein (2005); Ayob & Yasin, 2017 Haladyna, Shaughnessy, & Shaughnessy (1983)
Context for adult learning	Activity A: Role-playing Activity B: data exploration Activity C: debrief and reflection	Craik and Lockhart (1972) Schmidtt and Lahroodi (2008)

Appendix B: List of Definitions

Counterspaces	Counterspaces are environments outside of mainstream spaces, such as educational institutions, that allow individuals from marginalized groups to have conversations and discussions about the discrimination and marginalization experienced by the members of the group
Curiosity	Curiosity is defined as a desire for acquiring new knowledge and new sensory experience that motivates exploratory behavior
Design as intention	Design as intention emphasizes the original design and the clarity and coherence of the intentions it expresses
Design as implementation	Design as implementation is the process by which a designed sequence is integrated into the classroom environment and subsequently is progressively refined
Functional Mathematics	Functional mathematics is about mastering the mathematical skills required for working in the digital economy, such as spreadsheets, data analysis, and statistical quality control
Humanizing Mathematics	Humanizing mathematics is when mathematics is taught with emotions, contexts, vulnerability, and curiosity.
Intersectionality	Intersectionality research includes a deliberate focus on multiple interlocking identities of oppression that people experience throughout their lifetimes
Mathematical modelling	Mathematical modeling is a process that uses mathematics to describe, represent, analyze, and make predictions about real-world problems or occurrences
Numeracy	Numeracy is the ability, confidence, and willingness to engage with quantitative information to make informed decisions in all aspects of daily living and real-life situations
Problem Based Learning (PBL)	PBL is based on constructivist-based learning, and it is a teaching pedagogy that is very student-centred
Proofiness	Proofiness is "the art of using bogus mathematical arguments to prove something that you know in your heart is true, even when it's not"
Visualization	Visualization is the visual representation of data. it is the ability and skill to read and interpret visually represented data in and to extract information from data visualizations