TOWARDS A COMMUNITY OF PRACTICE FOR AN INFORMED CITIZENRY: SECONDARY STUDENTS’ SENSE-MAKING OF GRAPHS RELATED TO CLIMATE CHANGE

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ABSTRACT

TOWARDS A COMMUNITY OF PRACTICE FOR AN INFORMED CITIZENRY:
SECONDARY STUDENTS' SENSE-MAKING OF GRAPHS
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Although graphs are used to communicate much of the science-based issues that impact our society (e.g., climate change), citizens often do not make sense of them as intended. To help people become members in a community of *competent outsiders*, this qualitative study investigates how my participants made sense of three graphs depicting phenomena related to climate change (Keeling, Temperature, and Arctic). The analysis of my participants' interview transcripts and sketches showed that their sense-making of these graphs could be characterized by one of four approaches (figurative, literal, analytic, and analytic+) with respect to the graphing practices (interpret and analyze, explain, predict, and generalize) and set of crosscutting strategies (stories about how phenomena occur, mathematical strategies, and perceptions of graph sources and uses). The general framework for the graphical sense-making of these three graphs can be used to inform curriculum development, classroom instruction, and assessment design of concepts and practices related to those graphs.

To past, present, and future STEM learners and educators.

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My dissertation would not have been possible without the support of many people who provided perspectives on my work. First, I appreciated the patience that my dissertation co-chairs, Andy Anderson and Alicia Alonzo, showed me as they pressed me to critically assess, clarify, and articulate my reasoning and analysis of my data from beyond the "water a fish swims in." The feedback from my committee members, Christina Schwarz and Kristen Bieda, helped me to refine my scholarship and writing. My interactions with colleagues from *Carbon TIME*, *Curriculum Development Redesign*, *Scientific Practices*, *Projects & Practices in Physics*, CREATE for STEM, Sandra K. Abell Institute, science and mathematics education writing groups, CITE, *Data Nuggets*, and ISEC provided me opportunities to learn about topics related to my interests and to receive feedback on how well I could communicate my ideas about those interests. Last but not least, I owe a special note of thanks to Steve Pollock for mentoring me while I was at CU Boulder; I would not be where I am in academia today without his support.

My completion of the dissertation was also supported by pursuits not necessarily related to research. I enjoyed and appreciated the times spent talking, and doing activities, with folks from PERL, CITE, Physics Choir, WaMPS, Second Tuesday Tennis, MSU Sailing Center, and the Alma Grand Prix, in addition to my family and relatives (especially my nephew Max). A special note of thanks to Brian Hancock, Kraig Wray, Jiwon Kim, Leanne Doughty, Paul Irving, Alanna Pawlak, Mike Bennett, and Mike Obsniuk for our conversations about…pretty much anything and everything, and for being fun people to hang around with.

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PREFACE

One of the driving factors for this dissertation arises from my experiences as a former high school STEM teacher. From conversations with my former students, I found that few of them expressed interest in pursuing STEM-related careers after graduation, or even interest in knowing about how science could help explain how and why the world works the way that it does. Because I wanted to find a way to show them of the relevancy and necessity of learning science, their responses led me to think deeply about what it means to know and do science and the aspects of knowing and doing science that made it difficult for students to do. One memory that stood out was my students' struggles to apply what they already knew about line graphs to concepts addressed in my physics classes. For instance, when they plotted data gathered about the motion of a toy car, they literally said that the line is $y = \mathrm{m}x + \mathrm{b}$. However, they could not explain how that equation for the line in the graph related to the velocity of the car or its variables. Their response made me wonder about the aspects of graphical sense-making that made explaining connections between graphical representations and phenomena in the real world difficult for them to do, which ultimately led me to studying how students engage in graphical sense-making.

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KEY TO ABBREVIATIONS

CCC	crosscutting concepts
CCSS-M	Common Core State Standards – Mathematics
CO_2	carbon dioxide
NGSS	Next Generation Science Standards
O_2	oxygen
SEP	science and engineering practices
STEM	science, technology, engineering, and mathematics

CHAPTER 1: Why Should We Care about Students' Graphical Sense-Making?

Significance of Graphical Sense-Making

Scientists use graphs to communicate information about their findings with peers and the general public. Graphical sense-making can help the general public use graphs to make informed decisions, especially when presented with graphs that are intended to persuade them towards particular actions that may infringe on, or even eliminate, the rights of other people locally and globally. These types of decisions that focus on the social—rather than the individual—level require citizens to consider issues at different scales of time and systems.

Decisions at the individual level typically address local systems and short-term time scales in the immediate future, which often do not have a large impact on society nor necessitate the use of graphs. For instance, deciding whether an umbrella is needed to go outdoors does not greatly interfere with other people's activities. Citizens also do not need to engage in graphical sense-making because information about the weather can be readily attained from other sources (e.g., weather reports from news media).

Decisions at the social level typically address global systems and long-term time scales, which often have unforeseen impacts on society and are more likely to necessitate the use of graphs. For instance, deciding about the type of car to purchase may interfere with other people's activities because the carbon dioxide emitted from cars, over a large period of time, contributes to the increasing average atmospheric temperatures that lead to global consequences. Citizens are more likely to use graphs related to carbon dioxide emissions when considering concerns about minimizing the effects of their activities on the world (e.g., type of car purchased) than when considering only personal concerns.

Graphical sense-making is particularly important when making informed decisions in the context of climate change, given its potential impacts on the environment and our collective well-being. The global world we live in is a shared space with limited resources that are directly affected by decisions people make, especially decisions based on information people extract from graphs regarding Earth's climate and environmental conditions. Thus, we need to be concerned with the sense-making of graphs by the general public.

Communicating with Graphs

Scientists construct graphs—which are simplified representations of complex phenomena—for many purposes. Changes in Earth systems often occur across long periods of time, at locations in all parts of the Earth, and across systems at multiple scales, from atomic-molecular to global. The use of time-series graphs can make visible patterns in the data collected from these systems, which would otherwise not be as easily visible when represented in tables. Time-series graphs help scientists make claims about the data (e.g., explanations for the patterns, predictions and/or generalizations about their data across time and locations).

When scientists construct graphs, they want to communicate particular messages about their data. However, citizens do not need to be scientists in order to make sense of graphs. Scientists belong to communities of practice (Lave & Wenger, 1991) that rely on particular tasks, talk, and tools they have learned over time to advance knowledge in their fields (Knorr-Cetina, 1999). Duncan et al. (2018) noted the general public "will never have the deep disciplinary and methodological knowledge needed to understand the nuances of experimental designs and protocols in various fields of science" (p. 909). Thus, the general public are typically not part of the scientists' communities of practice.

Instead, the general public belongs to a community of practice for an informed citizenry. In a community of practice for an informed citizenry, the central members are *competent* *outsiders* with respect to scientific communities of practice. Feinstein (2011) described competent outsiders as “people who have learned to recognize the moments when science has some bearing on their needs and interests and to interact with sources of scientific expertise in ways that help them achieve their own goals” (p. 180). Duncan et al. (2018) indicated that the general public should be able to use evidence “to make personal and social choices despite their bounded understanding of science” (Bromme & Goldman, 2014, as cited in Duncan et al., 2018, p. 910). Since graphs are one way to display evidence, the general public needs to be able to engage with the graphical sense-making practices to become more informed citizens.

My definition of graphical sense-making focuses on a set of practices that citizens need to engage with in order to make sense of graphs. I applied to the context of graphs Odden and Russ’s (2019) definition of sense-making, which they described as “a dynamic process of building or revising an explanation in order to ‘figure something out’—to ascertain the mechanism underlying a phenomenon in order to resolve a gap or inconsistency in one's understanding” (p. 192). In order for citizens to “figure out” how to use the information from graphs to make informed decisions, they need to engage with the following practices: interpreting and analyzing, explaining, predicting, and generalizing.

The graphical sense-making practices I identified are one set of practices, amongst others, that citizens can use to help them make informed decisions. When presented with a graph, people first need to be able to determine how the displayed text and diagrammatic elements map onto aspects of phenomena in the real world (interpret and analyze). In order to make decisions about how their activities might relate to the phenomena represented in graphs, people need to be able to identify and explain the causes of the represented phenomena (explain), address the short-term and long-term consequences of decisions they make (predict), and determine the relevancy of their decisions with respect to their local contexts (generalize). Thus, I define graphical sense-making as encompassing these four practices.

Engaging in these graphical sense-making practices can help inform people of decisions they make. Interpreting and analyzing graphs involve making sense of its elements (e.g., patterns in the data, variables), which may use scientific models and principles and/or mathematical strategies. These interpretations and analyses of graphs can help people explain the causes of the represented phenomena, predict points representing future events, and generalize data to other locations by determining the relevance of the graph. One way to support the development of an informed citizenry is to have students learn to engage in graphical sense-making in school.

Role of Schools

If the primary role of schools is to prepare students in becoming members in a community of practice for an informed citizenry, then learning how to make sense of graphs is a key aspect in becoming a member of that community of practice. Although graphs are used to communicate certain information, students may not make sense of them as intended. This discrepancy may be due to differences between how scientists and students make sense of the graphs, which often depends on each of their prior knowledge and experiences with graphs and the scientific models and principles and/or mathematical strategies used to make sense of them.

Since students are often newcomers when it comes to making sense of graphs, one role of schools is to provide learning experiences that will support students' graphical sense-making. Proficiency in graphical sense-making is developed with repeated guided practice over time, consistent with the idea that learning is a process that occurs through members' continuing participation and practice in social contexts. Lave and Wenger (1991) indicated this process is an example of situated learning, which is “an integral part of generative social practice in the lived-in world” (p. 35). Thus, the *purposes* for the tasks, talk, and tools developed by specialized communities of practices to advance knowledge in their fields should be a substantial part of the students’ learning experiences to becoming an informed citizen.

A situated learning perspective to schooling reflects a shift away from the previous content-based standards, such as the 1996 *National Science Education Standards* (National Research Council, 1996), to what Ford and Forman (2006) call a “practice turn,” which focuses on meaningful engagement in science—such as graphical sense-making. The practices associated with graphical sense-making are reflected in the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) with respect to two scientific and engineering practices (analyzing and interpreting data; constructing explanations) and three crosscutting concepts (patterns; scale, proportion, and quantity; systems and system models). The *Common Core State Standards for Mathematics* (CCSS-M; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) address the graphical sense-making practices in one content domain (interpreting functions) and three practice standards (reason abstractly and quantitatively; model with mathematics; attend to precision). These aspects of the NGSS and CCSS-M standards are supported by research on learning progressions.

Learning Progressions

To help schools prepare students in becoming members in a community of practice for an informed citizenry, teachers may find it helpful to determine the approaches students use when making sense of graphs. Findings from research on learning progressions (Alonzo & Gotwals, 2012; Corcoran et al., 2009) present potential pathways of how student sense-making of scientific and mathematical content and practices advance over time. Learning progressions necessarily entail both content and practices, but researchers may foreground one over the other. The students' performances, with respect to these content and practices, typically start with what is referred to in the learning progressions literature as "lower anchors" and progress in sophistication to "upper anchors." These levels within the pathways also roughly correspond to aspects of being a newcomer or old-timer, respectively, within a community of practice. While my study does not produce a completely developed learning progression, it draws from and builds upon aspects of the learning progressions work conducted by science education researchers. In the following sections, I describe how my study reflects different aspects of learning progressions work with respect to its purpose, methods, findings, and significance.

Purpose

The purposes for research on learning progressions vary widely. For instance, they may characterize students' understanding of content through assessment items (Alonzo & Steedle, 2009; Gotwals & Songer, 2010), compare students' explanatory accounts of related phenomena (Mohan et al., 2009), identify aspects of a scientific practice that can be measured independently of context (Schwarz et al., 2009), or explore teachers' use of learning progressions to support their teaching practices (Furtak, 2012). In my study, I characterize how students make sense of three graphs with respect to a community of practice, which closely parallels the purpose of the work conducted by Duncan et al. (2018). In their study, Duncan et al. emphasized how a "lay grasp of evidence" addresses both scientists' use of evidence and laypeople's use of evidence as reported by those scientists; the latter of their purpose is the part most related to my study.

Methods

While researchers may foreground either content or practice in their learning progressions, the types of data collected (e.g., written assessments, interviews) and the analytic methods used to evaluate student performances are often similar. In the following paragraphs, I address aspects of the data collection methods and analysis from learning progression research that I emulated in my study.

In learning progressions that focus on student sense-making, data collection methods—such as interviews and/or written assessments—are often used to capture the range in students' responses. In my study, I interviewed a range of high school students, some who had already seen one or two of the graph(s) in their classes while others had not; I also interviewed one doctoral student to capture responses that could be representative of the "upper anchor." My data collection method is similar to the data collection methods used by Mohan et al. (2009).

Analytic methods used to characterize student performances and organize them into levels of sophistication often address decisions regarding the level of specificity (grain-size), inclusion of alternate conceptions, and clarification and validation of levels (Mohan & Plummer, 2012). In my study, I followed Schwarz et al.'s (2012) method of defining grain size based on its sufficiency at capturing change. Similar to other learning progressions (Alonzo & Steedle, 2009; Mohan et al., 2009), I included students' alternate conceptions as part of the less sophisticated levels. To clarify levels, I followed the three criteria Mohan et al. (2009) used to guide their theoretical and empirical validation process: conceptual coherence, compatibility with current research, and empirical criteria. Reliability evidence was not developed for coding the levels.

Findings

Learning progressions illustrate levels of performances based on iterative refinements to the levels. These refinements may be characterized by progress variables, which are "dimensions of understanding, application, and practice that are being developed and tracked over time" (Corcoran et al., 2009, p. 37). In my study, I defined graphical sense-making as comprised of four practices (interpret and analyze, explain, predict, generalize). My refinement of these practices involved the construction of progress variables that shifted across individual practices until I developed a set of descriptions for the different levels that could account for the responses from all my participants. My findings on graphical sense-making foreground practices over content, similar to learning progressions on scientific modeling (Schwarz et al., 2009) and scientific argumentation (Berland & McNeill, 2010).

Implications and Significance

The use of learning progressions has a wide range of implications and significance. For instance, Mohan et al. (2009) addressed how the transitional levels (levels between the lower and upper anchors) in their learning progression may partly reflect "status quo teaching and curricular incoherence" (p. 693), which they used to inform curriculum development. Alonzo and Steedle (2009) indicated their learning progression could be used to formatively assess student learning, providing information to inform instructional decisions and the feedback provided to students. Similar to these studies, I envision that my study may be used to inform curriculum development and to formatively assess student learning.

Research Questions

Graphs are often used to communicate quantitative information about changes in phenomena. Because people do not make sense of them in the same ways, this indicates a need to understand how people interpret and analyze graphs, explain causes of phenomena depicted in the graph, predict points, and generalize the data in graphs to other locations. To improve our understanding of how students engage with these practices to make sense of graphs representing phenomena related to climate change, which includes changes in atmospheric carbon dioxide concentrations (Keeling graph), temperature anomalies (Temperature graph), and area of ice covering the Arctic Sea (Arctic graph), my research questions are:

1. **How do the students make sense of the graphs representing phenomena related to climate change?**
   a. How do they *interpret and analyze* the graphs? What purposes and audiences do they perceive for the graphs?
   b. How do they *explain* the causes of phenomena depicted in the graphs?
   c. How do they *predict* points on the graphs with respect to mathematical strategies and stories about how phenomena occur?
   d. How do they *generalize* the graphs to other locations?
2. **How do the students' graphical sense-making compare across the graphs?**

Dissertation Overview

This chapter introduced the rationale for my dissertation, which is one study that investigates secondary students' sense-making of three graphs of phenomena related to climate change. I started by describing the significance of graphical sense-making: to help citizens to function as competent outsiders with respect to scientific communities of practice (Feinstein, 2011). This description led to the role schools play in helping students become future members in a community of practice for an informed citizenry.

The remaining chapters in my dissertation build on this chapter. In the upcoming chapters, I present my review of the literature (chapter 2), research methods (chapter 3), findings (chapter 4), and discussion (chapter 5).

In chapter 2, I summarize the literature informing the design of my study and analysis of my findings. The reviewed studies addressed relate to the graphical sense-making practices, in addition to some key factors that influence how students generally make sense of graphs. This chapter concludes with a review of studies that address learning progressions related to the graphical sense-making practices.

In chapter 3, I describe the methods used to carry out my study. This chapter is organized into three sections, which address the participants and their recruitment, the design and implementation of the student interviews, and the analytic methods used to transform my data (interview transcripts and graphs) into claims about how my participants made sense of the graphs presented to them.

In chapter 4, I present the findings from my study. I start by presenting the narratives of four participants who illustrated contrasting approaches when making sense of the graphs presented to them during their interviews. These narratives were constructed to highlight patterns in their usage of the crosscutting strategies and graphical sense-making practices. I then summarize key aspects of these narratives into a table, which informed my development of a general framework for graphical sense-making, which account for how all my participants made sense of the graphs presented to them with respect to the crosscutting strategies and individual graphical sense-making practices. At the end of this chapter, I address how all my participants engaged in graphical sense-making with respect to the crosscutting strategies and individual practices.

In chapter 5, I define the criteria for being an informed citizen and describe how my findings relate to it. Next, I address how my findings address the main issues related to graphical sense-making—that graphs are often not interpreted as they were intended--which I raised at the beginning of this chapter. At the end of this chapter, I describe how my findings contribute to the literature, reflect on limitations in my study, address implications my work may have for researchers and educators, and propose directions for future research.

CHAPTER 2: What Do We Already Know about Students' Graphical Sense-Making?

In this chapter, I summarize findings from studies related to how students engage with the different graphical sense-making practices. While I situate my work in the sociocultural traditions, cognitive studies still provide important insights into students' language and practice; as such, my review of the literature includes studies that address both traditions.

Purposes for Learning to Make Sense of Graphs

Graphical sense-making is a learned activity because graphs are socially constructed artifacts that serve particular purposes. In the 1700's, statistical graphs (e.g., time-series graphs, bar charts) were used to analyze empirical data, primarily by political and scientific communities (Beniger & Robyn, 1978). In 1830, graphs appeared in scientific publications to support analysis of natural phenomena. Today in 2020, graphs are still used as tools to support data analysis and communications with people who may not identify as members of scientific communities and thus, may not interpret graphs as intended.

Because we live in a world where one person's activities may impact the activities of others, the development of an informed citizenry is important to our collective social well-being. Informed citizens recognize when particular types of information are relevant to their needs and interests and are able to use that information to help them achieve their goals. Feinstein (2011) described informed citizens as *competent outsiders* who are able to identify relevancies between scientific information and the things they care about.

The socialization into a community of practice is influenced by language. Lave and Wenger (1991) noted that talking *about* a practice as an outsider is different from talking *within* a practice. They emphasized that legitimate peripheral participation is about newcomers learning *to* talk and not about learning *from* talk; thus, aspects of participants' talk reveal their peripherality within a community of practice. Lave and Wenger indicated that learning to talk within a community of practice occurs through situated learning.

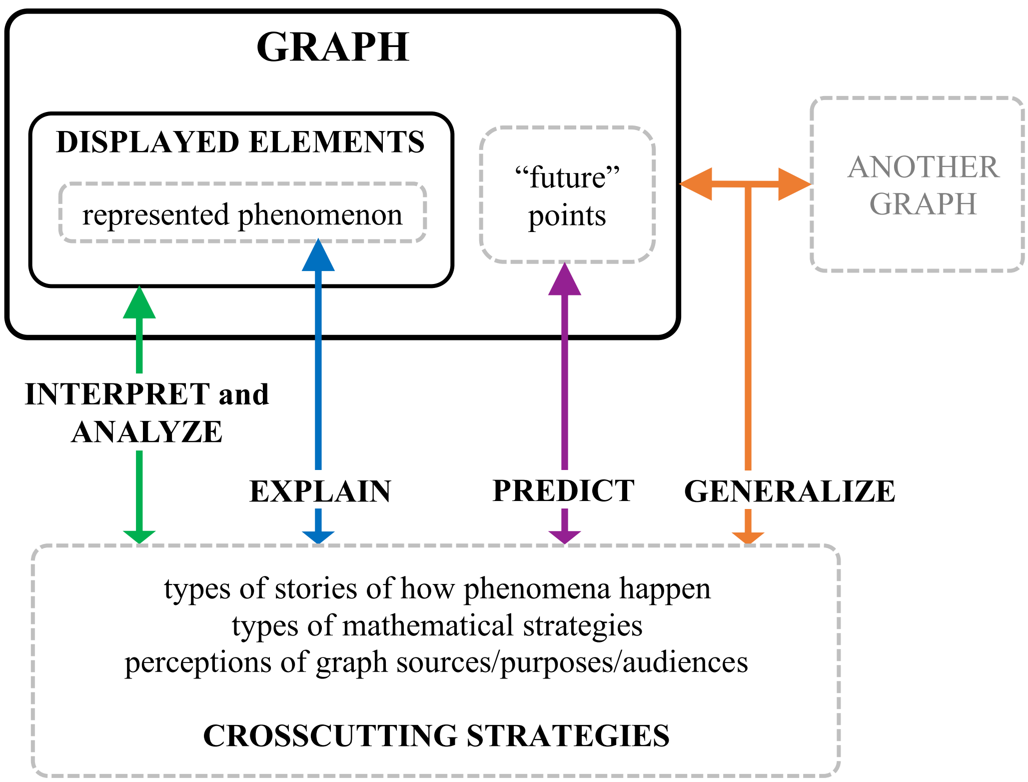
Lave (2008) emphasized that situated learning is the *process* in which communities of practices are produced, and not the product. Through this process, she said that *knowledgeability* changes through legitimate peripheral participation; she used *knowledgeability* instead of *knowledge* because *knowledgeability* addresses “knowledge in persons in practice” (p. 292). This *knowledgeability* reflects the mechanism by which citizens may become socialized within a community of practice.

Become socialized within a community requires the appropriation of certain tasks, talk, and tools associated with that community. Within a community of practice for an informed citizenry, the tasks, talk, and tools include graphical sense-making. Consistent with the current practice turn (Ford & Forman, 2006) in science education, I foreground knowledgeability, with respect to graphical sense-making, in my study. I define graphical sense-making as a process related to four practices: interpretation and analysis, explanation, prediction, and generalization. My definition is related to the idea that graphs are mediating instruments that help people make sense of the world and theories about the world (Morgan & Morrison, 1999).

If we, as science education researchers and practitioners, are concerned about helping the general public make informed decisions about global issues that affect our society, such as climate change, then we need to think about how we can help the general public learn to become members within a community of practice for an informed citizenry. One aspect of being an informed citizen is the ability to make sense of graphs. In the next section, I present my framework for graphical sense-making, followed by studies addressing the individual practices.

Conceptual Framework

When engaging in the graphical sense-making practices (tasks), students often reveal their sense-making from their responses (crosscutting strategies) about the graphs. Figure 2.1 shows key relationships between the tasks, talk, and activities for graphical sense-making, where "GRAPH" and "CROSSCUTTING STRATEGIES" are the main components.



Note: The dotted lines represent crosscutting strategies related to graphical sense-making. The double-headed arrows represent the graphical sense-making practices (tasks).

Figure 2.1 Conceptual framework for graphical sense-making

The students' use of the crosscutting strategies (stories about phenomena, mathematical strategies, and perceived sources/purposes/audiences) with respect to the practices define their graphical sense-making. I use this framework to help organize my literature review.

Graphical Sense-Making

In the introduction, I defined graphical sense-making as comprised of four practices (interpret and analyze, explain, predict, and generalize). These practices are undergirded by crosscutting strategies (types of stories about how phenomena occur, types of mathematical strategies, perceptions of sources/purposes/audience of data displayed in graph) inherent in the use of those practices. The remainder of this chapter summarizes findings from studies in science and mathematics education research that address those practices. For each practice, I present my operationalization of it and its connections to national science and mathematics standards. Afterwards, I summarize findings from studies relating to that practice. Of the studies I reviewed, interpretation and analysis had the greatest number of studies related to graphs, mostly representative of cognitive traditions. For the studies that addressed explanations, predictions, and generalizations, I focused on the most recent and relevant studies with respect to my dissertation. The crosscutting strategies that undergird the individual practices are addressed in the studies for those practices.

Interpretation and Analysis of Graphs

The practice of interpretation and analysis addresses how people engage with the displayed elements in the graph the relationships between those elements. It relates to the NGSS (2013a) scientific and engineering practice (SEP) of analyzing and interpreting data, which emphasizes the importance of making sense of data presented in different formats (e.g., mapping displayed elements in a graph to the real world). This practice is also related to the NGSS crosscutting concept (CCC) of patterns, which focuses on helping students make sense of the relationships between the displayed elements. The NGSS indicated that patterns help students “guide organization and classification…[and] prompt questions about relationships and the factors that influence them” (NGSS Lead States, 2013b, p. 413), which becomes especially relevant when I address studies focusing on students’ explanations of phenomena. In the CCSS-M (2010), the content domain of *interpreting functions*—which includes addressing quantitative features from graphs (e.g., intercepts, direction of trends within intervals, relative maxima/minima, periodicity)—and the practice standards of *reasoning abstractly and quantitatively* (e.g., decontextualizing and/or contextualizing problems with quantitative reasoning) and *attending to precision* (e.g., communicating assumptions about symbols used in graphs) are related to this practice; together, they reflect the importance of precisely communicating relationships between variables.

Many of the earlier studies related to students’ graphical sense-making identified challenges they encountered and the factors influencing their interpretation and comprehension of graphs. For instance, challenges students encountered included perceiving line graphs as literal pictures (Kerslake, 1981; Leinhardt et al., 1990; McDermott et al., 1987; Preece, 1983; Stein & Leinhardt, 1989), confusing slope of a line with its height (Bell & Janvier, 1981; Janvier, 1998; McDermott et al., 1987; Preece, 1983), and confusing intervals with points (Bell & Janvier, 1981; Kerslake, 1981). Factors influencing students’ graphical sense-making included students’ prior content knowledge of the represented phenomena (Friel et al., 2001; Glazer, 2011; Postigo & Pozo, 2004; Roth & Bowen, 1999; Wavering, 1989), prior experiences related to graph comprehension (Chinn & Brewer, 2001; Friel et al., 2001; Janvier, 1981; Pozzer-Ardenghi & Roth, 2010; Shah, 2002; Shah & Hoeffner, 2002; Trickett et al., 2009), consideration of the purpose (Friel et al., 2001; Glazer, 2011) and audience (Glazer, 2011), and even the type of graph (Shah, 2002; Shah et al., 1999; Shah & Hoeffner, 2002). In the next paragraphs, I address some of these factors and challenges.

People interpret graphs by searching for and extracting information by shifting their attention back-and-forth between the axes and main body of the graph (Carpenter & Shah, 1998; Kosslyn, 1989; Lohse, 1993). Carpenter and Shah (1998) found that skilled readers noticed and mapped more aspects of the represented phenomenon to the graphical elements than less skilled readers. Building on this work, Shah, Mayer, and Hegarty (1999) found people were more likely to accurately describe trends in line graphs than in bar or 3D wireframe graphs; their finding suggests certain graph formats communicate particular types of information better than others.

The prior knowledge of content represented in graphs also affect people's graphical sense-making. Shah and her colleagues (Shah, 2002; Shah & Hoeffner, 2002) found that when readers were familiar with the represented content (i.e., knew what to expect in the relationships depicted in the graphs) in graphs, they tended to describe the trend, ignoring idiosyncratic data points (i.e., noise); when they were not familiar with the represented content (i.e., did not know what to expect in terms of the relationship between variables), the reverse was true—they tended to describe the noise and were less likely to describe the trend.

Many studies have addressed how prior experiences with graphing affect students' graphical sense-making. One difficulty was that students perceived line graphs as literal pictures (Kerslake, 1981; Leinhardt et al., 1990; McDermott et al., 1987; Preece, 1983; Stein & Leinhardt, 1989). Bell and Janvier (1981) found that middle school students who did not have much graphing experiences tended to focus on individual points rather than the overall shape of the graph. Janvier (1981) found that middle school students who are instructed to plot graphs from tables of ordered pairs and asked questions about the graphs that can be answered with the tables do not develop a sense for the nature of the phenomenon represented in the graph; instead, they address graph components that did not help them interpret or explain the phenomena represented in line graphs. One finding from Tairab and Al-Naqbi (2004) was that high school students' struggles with interpreting graphs (i.e., perception of independent and dependent variables as separate entities instead of as covariates) could be attributed to the lack of knowledge about different types of graphs.

The interpretation of graphs are also informed by readers' perceptions of the purpose and/or audiences of the graphs (Curcio, 1987; Friel et al., 2001). Curcio (1987) found that the purpose for reading the graphs led to different levels of graph comprehension for elementary and middle school students. He described these levels as: *reading the data*, *reading between the data*, and *reading beyond the data*. *Reading the data* meant talking about the graphical elements (e.g., reading coordinates of a point). *Reading between the data* meant interpreting and integrating information drawn from at least two parts of the displayed data (e.g., comparing slopes for a function from two different time intervals). *Reading beyond the data* meant using information not explicitly displayed in the graph (e.g., effects of local factors on future atmospheric carbon dioxide concentration). As noted in this study and others, the different levels of graph comprehension allow students to answer different types of questions (Carswell, 1992; Curcio, 1987; Friel et al., 2001; Wainer, 1992).

Because graphs are often used to visually organize quantitative data, they support the identification of patterns (Bastide, 1990; Bowen & Roth, 2003) that can be used to make inferences and comprehend abstractions (Hardy et al., 2005) or to propose models that assist in explaining phenomena (National Research Council, 2012). Students can use the information from graphs to explain causes for the patterns in the data, predict points, and determine the generalizability of the data to other locations. A well-designed graph depicts data concisely

(Larkin & Simon, 1987; Leinhardt et al., 1990; Shah & Freedman, 2011; Tufte, 2001) such that it "*forces* us to notice **what we never expected to see**" (Tukey, 1977, p. vi). However, a well-designed graph does not necessarily mean it will be interpreted as intended.

The interpretation and analysis of graphs is important towards supporting the development of informed citizens because it informs and shapes the subsequent graphical sense-making practices (explanation, prediction, and generalization), which focus on producing knowledge claims about the world.

Explanations of Phenomena Represented in Graphs

Explanations address how people explain patterns in the data—data collected from a specific context. This practice relates to the NGSS (2013a) SEP of *constructing explanations*, which is the construction of "accounts that link scientific theory with specific observations or phenomena" (National Research Council, 2012, p. 67) and includes claims that address how variable(s) are related to each other to address questions regarding the causes of phenomena. This practice is also related to the CCSS-M (2010) content domain of *interpreting functions* and practice standards of *reasoning abstractly and quantitatively*. Functions "describe situations where one quantity determines another" (p. 67) that can be used to model phenomena; additionally, functions can be represented in multiple ways (e.g., graph, algebraic expression). *Reasoning abstractly and quantitatively* is the sense-making of quantities with respect to decontextualization ("to abstract a given situation and represent it symbolically and manipulate the representing symbols as if they have a life of their own, without necessarily attending to their referents" [p. 6]) and contextualization ("to pause as needed during the manipulation process in order to probe into the referents for the symbols involved" [p. 6]).

Students' explanations of phenomena may be developed through different types of reasoning, such as force-dynamic reasoning (Pinker, 2007; Talmy, 1988), covering laws (Braaten & Windschitl, 2011), and evidence-based reasoning (Brown et al., 2010). Force-dynamic reasoning describes how people talk about the world in their regular day-to-day activities (Pinker, 2007; Talmy, 1988). Students who use force-dynamic reasoning identify agentic factors as causes of the patterns, viewing the world as a stage where the actors pursue and confront challenges; this type of reasoning is often inconsistent with canonical explanations, which use scientific models and principles. Covering laws associate causes with effects without addressing causal mechanisms (Braaten & Windschitl, 2011). Students who use covering law explanations usually associate events with each other—without further explanation. Evidence-based reasoning involves the use of "theoretical statements, backed by scientific evidence, to evaluate the quality of a claim" (Brown et al., 2010, pp. 131–132); in their framework for evidence-based reasoning, Brown et al. indicated that evidence describes the relationship(s) between variables and that claims are specific outcomes, such as past observations, current observations, or future predictions. Students who use evidence-based reasoning explicitly address how data transforms into evidence and how evidence transforms into patterns and models.

Students' explanations of phenomena may also progress from less to more sophistication over time. Yao et al. (2016) described key studies that informed their development of a hypothetical learning progression for scientific explanation. Their initial framework was framed around the notion that for students to develop confidence in constructing scientific explanations, explicit guidance—such as the Claims-Evidence-Reasoning (CER) framework (e.g., McNeill et al., 2006)—was needed to help them envisage models of scientific explanations (e.g., Sandoval & Reiser, 2004). They also referenced a validated learning progression for elementary biology using the CER framework (e.g., Songer & Gotwals, 2012) and drew from the work on explanations by Braaten and Windschitl (2011) and philosophies of science (e.g., Hempel & Oppenheim, 1948; Kitcher, 1981; Salmon, 1984), in addition to studies addressing learning progressions of scientific practices related to scientific explanations—such as scientific modeling (Schwarz et al., 2009) and scientific argumentation (Berland & McNeill, 2010)—to inform their initial framework. The hypothetical framework they developed from these sources addressed four components (phenomenon, theory, data, and reasoning), whose dimensions progressed through two or three levels of sophistication.

Covitt and Anderson (2018) developed learning progressions that examined connections students made between the scientific genres of explanations, arguments, and predictions, and the different performances of the students with respect to each genre. They focused on the type of language students used (vernacular, mixed, or scientific) to characterize their level of knowledge and practice with respect to their discourse (informal, intermediate, or scientific). Their learning progression for the scientific genre of explanation progressed along two dimensions: modes of explanations and systems and scales. At the informal level (lower anchor), students' explanations relied on force-dynamic or covering law reasoning and only talked about phenomena at the macroscopic scale. At the intermediate level, students traced matter and energy with errors and demonstrated an awareness of scale, but expressed limited ways in connecting systems across scales. At the scientific level (upper anchor), students invoked scientific models and principles and connected systems at multiple scales.

Predictions of Points on Graphs

Predictions address how people forecast points beyond the displayed data. Sketched predictions, or projections, may be informed solely by mathematical strategies, or by strategies that address mathematical relationships and the causes of the referents. Although the NGSS (2013a) did not identify prediction as one of its SEP, the Framework (National Research Council, 2012) indicated that predictions are related to two other SEPs: *developing and using models* and *constructing explanations*. The Framework stated models could be "evaluated and refined through an iterative cycle of comparing their *predictions* with the real world…potentially yielding insights into the phenomenon being modeled" (p. 57) and that explanations could be used at "illuminating the nature of particular phenomena, *prediction* of future events, or making inferences about past events" (p. 67). Predictions are also related to the CCSS-M (2010) content domain of *interpreting functions* and practice standard of *modeling with mathematics* (e.g., making tentative assumptions/approximations to simplify complicated problems), which is especially relevant when making projections with noisy data, and *attending to precision*.

Students' sense-making of the displayed pattern influences the projections they sketch. Central to pattern recognition is the differentiation of signals from noise (Ben-Zvi & Garfield, 2004; Silver, 2015). Signals represent the central tendency—or average—of a data set, which point to "stable properties of a variable system—properties that become evident only in the aggregate" (Konold & Pollatsek, 2004, p. 172). Trends are often associated with signals while noise are deviations from the signal (which may include outliers or missing data). Generally, a high signal-to-noise ratio produces a clear pattern while a low signal-to-noise ratio obscures the pattern. Because the differentiation of signals from noise is a highly inferential process (Shah & Freedman, 2011), many students have difficulties differentiating signals from noise (Ben-Zvi & Garfield, 2004; Silver, 2015); less skilled readers may find it difficult to discern or describe patterns displaying noisy data, which influences their projections.

Students' prior knowledge about the represented phenomena may also influence the projections they sketch. The axis variables represent measured aspects of the real world that inform how a graph may be interpreted or constructed (Leinhardt et al., 1990). If asked to make predictions about future atmospheric carbon dioxide concentrations, responses may include addressing the worldwide rates of fossil fuel consumption (main contributor of atmospheric carbon dioxide) or the pool-and-flux model (scientific model explaining how carbon moves between sources and sinks). However, Leinhardt et al. (1990) indicated that when information about the represented phenomena was not available, the axis variables act as placeholders to bring the mathematical relationship (e.g., function) between variables to the forefront. Using the previous example, predictions students make would focus on the mathematical relationship between the variables (e.g., linear, exponential) without addressing the object of the variables (e.g., carbon dioxide concentration, time).

As noted in the previous section for explanations, Covitt and Anderson (2018) examined connections students made between scientific genres. Similar to their description of the explanation genre, their prediction genre addressed the same discourse levels (informal, intermediate, and scientific) but had three dimensions (identifying trends, dealing with uncertainty and noise, nature of sketched prediction) instead of two. At the informal level (lower anchor), students identified inappropriate trends or focused on individual data points, often without perceiving uncertainty or possibly viewing variation as the trend; their sketches were qualitative and did not attend to a model. At the intermediate level, students identified reasonable trends in "clean" data but encountered difficulties when they had to distinguish the trend from the variability in noisy data; their sketches extended the data to varying degrees of precision and did not invoke a model. At the scientific level, students identified reasonable trends in noisy data and sources of mathematical uncertainty (e.g., variation); they accurately extended the pattern, addressing uncertainty and model-based assumptions.

Generalization of Graphs to Other Locations

Generalizations address how people determine the relevance of the data collected from one location to another location. This practice is not explicitly addressed in the NGSS (2013a) and is partially addressed in the CCSS-M (2010). In the NGSS, generalization is related to the CCC of *systems and system models*, which focuses on identifying isolated systems and determining the nature of their interdependencies with each other. Although "generalize" does not appear in the definition of this CCC, its description that "the properties and behavior of the whole system can be very different from those of any of its parts" (p. 92) reflects the nature of generalizing data. In the CCSS-M, generalization is related to the content domain of *interpreting functions* and practice standards of *reasoning abstractly and quantitatively* and *modeling with mathematics*.

Nathan and Kim (2007) focused on how middle school students generalized patterns with graphs and words, addressing their representational fluency. Using cross-sectional and longitudinal data, they found that students showed a preference for reading the data (Curcio, 1987) over making predictions or generalizations. Their findings also indicated that students were more successful at generalizing when working with words rather than graphs, when the format was continuous (line graph, verbal rules) rather than discrete (point-wise graphs, lists of exemplars), or when words and graphs were combined rather than addressed singly.

Ellis (2007) developed a taxonomy for categorizing mathematical generalizations made by middle school students based on a 3-week teaching experiment and individual interviews. She indicated that previous research on generalization and transfer focused on the experts' consideration of what counts as sufficient (actor-oriented transfer), revealing more about how experts, rather than learners (object-oriented transfer), think. Using object-oriented transfer, she found the major generalizing actions students made could be categorized into three categories: (1) *relating*—forming associations between two or more problems/objects, (2) *searching*—locating similarities through repeated actions, and (3) *extending*—expanding pattern or relation to a more general structure.

In this chapter, I started by addressing a purpose for graphical sense-making: to produce informed citizens. I then presented my conceptual framework for graphical sense-making, which was comprised of a network of relationships between the crosscutting strategies and the individual practices. For the remainder of the chapter, I synthesized studies from science and mathematics education research relating to the individual graphical sense-making practices, in addition to some of the relationships between those practices. In the next chapter, I describe how I designed and carried out my study to learn more about how my participants engaged with those practices to make sense of the graphs related to climate change.

CHAPTER 3: How Did I Design and Carry Out My Study?

In this chapter, I describe the research methods used to describe how my participants engaged in graphical sense-making. First, I describe the participants, including their recruitment. Next, I describe the interviews with respect to how I selected the graphs, designed the interview protocol, and carried out the interviews. I conclude by describing how I transformed the data into the findings, which includes my preparation of the data for analysis and description of the analytic methods.

Participants

My participants were 18 high school students (5 male students, 12 female students, and 1 non-binary student) and one male doctoral student. I focused on high school students because the content and practices associated with the selected graphs aligned with national science education benchmarks for students at this level (National Research Council, 2012; NGSS Lead States, 2013a). The participants and their schools are identified using pseudonyms. Table 3.1 shows demographic information about the student populations for each high school and the university for the doctoral student; the names of the schools are all pseudonyms.

Table 3.1 Descriptive information about the participants' schools

		Oak HS	Pine HS	Maple HS	Beech Uni
Gender	female	54%	51%	50%	52%
	male	46%	49%	50%	48%
Race/Ethnicity	White	66%	60%	79%	75%
	African-American	17%	18%	11%	8%
	Hispanic	8%	7%	4%	5%
	Asian	4%	7%	2%	6%
	American Indian/Alaska Native	<1%	1%	<1%	<1%
	Hawaiian Native/Pacific Islander	<1%	<1%	<1%	<1%
	Two or more races	5%	7%	4%	3%
% from Low-Income Families		23%	29%	23%	NA

In my initial recruitment efforts (May 2018 to June 2018), I contacted a science outreach coordinator and local high school science teachers through e-mail (see Appendix A for template of recruitment e-mail). The individual teachers were ones I had previously worked with through my institution's teacher preparation program. Three science teachers from two high schools (Oak High School and Pine High School) invited me to introduce my study to their students (see Appendix B for student recruitment script).

During the introductions of my study, students received two copies of the study information/consent form (see Appendix C for information/consent form), one to keep for their records and the other to return to their teachers to indicate their interest in participating in the study. I collaborated with the teachers to arrange times (before, during, or after school hours) and locations (school classrooms or offices) convenient for students who expressed an interest in participating in the study. Six students from Oak High School (Anne, Annika, Greg, Macy, Nick, and Susan) were interviewed in July 2018, and eleven students from Pine High School (Ally, Courtney, Erica, Esmerelda, Everest, Mindy, Ozzy, Sherry, Tara, and Walter) were interviewed from September 2018 to October 2018; the loss of one audio-recording due to technical difficulties resulted in the ten transcribed interviews from Pine High School. All student names are pseudonyms.

My remaining recruitment efforts in November 2018 led to two additional interviews. One interview was the son of a friend of my sister's family (Shane, Maple High School). The other was a graduate student from the theoretical physics department who has a background in mathematics (Bob, Beech University). My purpose for recruiting the graduate student was to have him serve as an example for sophisticated responses in graphical sense-making.

Interviews

In this qualitative study, I collected my data through cognitive interviews to gather information about how my participants made sense of the graphs. Cognitive interviews provide strong evidence of individual reasoning (Seidman, 2005) and how people think (Glesne, 2015). In the following sections, I address my rationales for the selection of the graphs, explain the design of the interview protocol, and describe the interviews that were conducted.

Selection of Graphs

The three graphs I chose—Keeling, Temperature, and Arctic—are simplified representations of complex phenomena commonly used to address climate change (see Appendix D for graphs and explanations of displayed patterns in the data). Each graph displays features (e.g., direction of trend, signal-to-noise ratio) that present potential interpretive and explanatory challenges for students. Table 3.2 summarizes these features for each graph.

Table 3.2 Key features of the selected graphs

	Keeling	**Temperature**	**Arctic**
Location	Mauna Loa, Hawaii	New Zealand	Arctic Sea
Dependent Variable (Range)	concentration of atmospheric CO_2 (310-450 ppm)	temperature anomalies (-1.5°C to +1.0°C)	area of ice (8.5-12.5 million km^2)
Independent Variable (Years)	1957-2015	1909-2015	1980-2013
Data Point Time Interval	monthly	annually	annually
Trend	positive	positive	negative
Signal-to-Noise Ratio	high	low	medium

The Keeling graph depicts changes in atmospheric carbon dioxide concentrations over Hawaii. The Temperature graph depicts changes in atmospheric temperatures in New Zealand; it was originally a bar graph but was converted into a time-series line graph to make comparisons across graphs more systematic. The Arctic graph depicts changes in area of ice in the Arctic Sea. These graphs show data collected on land mass(es) surrounded by water, which provides opportunities for students to talk about the represented phenomena at local and global scales. The scientific models and principles associated with the phenomena represented in the graphs are in Appendix E.

The graphs were sourced from two research projects: *Carbon: Transformations In Matter and Energy (Carbon TIME)* and *Data Nuggets*. The Keeling and Arctic graphs were from *Carbon TIME*, which is a project that investigates how middle school to collegiate students talk about key carbon cycle processes that transform matter and energy in living and Earth systems using data representations at various scales. The Temperature graph was adapted from an activity developed by *Data Nuggets*, which is a project that designs activities to promote K-16 student interactions with authentic data in the life sciences (Schultheis & Kjelvik, 2015).

Across the three graphs, the dependent variables showed varied long-term trends, signal-to-noise ratios, and ranges. The Keeling graph displays a relatively high signal (increasing trend, superimposed sinusoid) and low noise, i.e., a high signal-to-noise ratio; the Temperature graph (increasing trend) and Arctic graph (decreasing trend) both display lower signal-to-noise ratios, compared to the Keeling graph. The time range of the data collection was not a main consideration in selecting the graphs but did provide an opportunity for students to address overlapping time periods between graphs if they chose to do so.

Design of Interview Protocol

To broadly elicit my participants' ideas and sense-making of the graphs, and to prevent undue bias from the interviewer, I used open-ended prompts in my interview protocol. Table 3.3 lists these prompts and their connections to the components of my research questions; the complete interview protocol, adapted from the *Carbon TIME* interview protocols for the Keeling and Arctic graphs, is in Appendix F.

The prompts in the interview protocol were organized into three sets (IMPRESSIONS, ASPECTS, APPLICATIONS). Prompts from the first set (IMPRESSIONS) were posed first in order to ascertain students' initial impressions of the graphs without undue influence from the interviewer. The order of the remaining prompts was presented based on the students' responses to that first set of prompts. For instance, if a student indicated the pattern was important to notice (prompt 1e), then the next prompt would follow-up on the student's thoughts about pattern (prompt 2f). Aspects of the graph that students did not address spontaneously were asked by the interviewer prior to the introduction of the next graph or by the end of the interview.

Table 3.3 Connections between sets of interview prompts and research questions

Sets of Interview Prompts	Associated Research Question
1. IMPRESSIONS	
a. What is this graph about? b. Who created this graph? How did they create it? c. Where might you see a graph like this being used? d. Who would this graph be useful for? e. What was the most important thing to notice about this graph?	1a. How do they interpret and analyze the graphs? What purposes and audiences do they perceive for the graphs?
2. ASPECTS	
a. **Title**: What does this tell you about the graph? Why was this location chosen? b. **Y-axis:** What does this tell you about the graph? Why was this variable chosen? c. **X-axis:** What does this tell you about the graph? Why was this time interval used? d. **Data Point:** What does this point tell you about the graph? Does it represent a single measurement or multiple measurements? e. **Data Set:** What do these points, as a whole, tell you about the graph? Were they measured from the same place? f. **Line:** What does this line you drew tell you about the graph? g. **Pattern:** Describe one pattern you see in this graph. What makes you describe the pattern that way? Are there other patterns or anything interesting in this graph that you noticed?	
3. APPLICATIONS	
a. What caused this pattern? How do you think that [cause] relates to this pattern? b. What connections do you see to this [Keeling and/or Temperature] graph?	1b. How do they explain the causes of phenomena depicted in the graphs?
c. On the graph, make predictions for where you think a data point would be one year later, 5 years later, and 50 years later. What made you choose to put your predictions in those places? d. How certain are you that each prediction will come true?	1c. How do they predict points on the graphs with respect to mathematical strategies and stories about how phenomena occur?
e. Would this pattern be the same, similar, or different in other locations? f. Do the relationships represented by this pattern connect with things you've seen or done in school or at home? Are there things you do that might cause this pattern?	1d. How do they generalize the graphs to other locations?

Description of Interviews

At the start of the interview, the students were provided with a pen, ruler, and paper copies of each graph. Each student addressed two or three of the graphs, starting with the Keeling graph and ending with the Arctic graph. The audio-recorded interviews ranged in duration from 28 to 64 minutes, with an average duration of 44 minutes. Due to the participants' schedules, some only had time to respond to two graphs whereas the remainder of the participants had time to respond to all three graphs. After the interview, each student received a small gift of appreciation for their participation. The audio-recordings were sent to an external source for transcription.

Because the recruitment of participants occurred in an approximate six-month time span, the analysis of the first six interview transcripts started before the later participants were interviewed. From the preliminary analysis of the initial set of interviews, a few refinements (i.e., Who created the graph? How did they create the graph?) were added to the original set of interview prompts to elicit more information about students' initial impressions of the graphs. Table 3.3 contains the final set of prompts.

Analysis

In this section, I describe how I transformed my data (participants' verbal and sketched responses) into my findings (narratives and general graphical sense-making framework). I elaborate on the methods used to analyze the data I collected, as described in the previous section. More specifically, I describe the stages of how I characterized my participants' responses and constructed and developed the preliminary codes and themes to produce the narratives and general graphical sense-making framework. These stages occurred iteratively and in parallel throughout my analysis, leading to refinements in my research questions and consequently, my findings.

Characterizing Responses and Excerpts

In my initial readings of the transcripts, I highlighted and made notes of excerpts that seemed common, unique, or interesting with respect to my research questions. This process helped me become familiar with the types of responses participants could provide in their interviews. Afterwards, I systematically organized the interview questions and corresponding responses by graphical sense-making practice (e.g., blue text = explain, purple text = predict, green text = generalize). The responses to each interview prompt could address more than one practice. For instance, the response to a generalization prompt could include an explanation of the represented phenomenon. In this case, the text for the response would correspond to the generalization practice (green text) except for the excerpt corresponding to the explanation practice, which would correspond to the explanation practice (blue text).

Constructing Preliminary Codes and Themes

Once the excerpts were labeled by graphical sense-making practice, I clarified how my participants engaged in each practice by developing preliminary codes and themes based on my characterization of the responses. This process of identifying and developing codes and themes was repeated for each practice and across practices through content analysis, a technique for making inferences based on patterns in written data (Krippendorff, 2012). In content analysis, written data (e.g., excerpts from interview transcripts) are condensed to promote systematic comparisons. The condensation of my written data became codes, which are "tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study" (Miles & Huberman, 1994, p. 56).

To identify attributes (themes) that were common across my codes, I used key ideas from the interview prompts (e.g., "purpose of graph") and *a priori* expectations (i.e., studies addressed in the literature review, my prior teaching experiences). Below, I describe the general procedures I used for the different types of responses.

Verbal Responses

The analysis of their verbal responses is applicable to each graphical sense-making practice. Here, I focus on one practice as an example—explanation. Some of my descriptive codes regarding the students' explanation practice included: *explains causes for incremental changes in the random variability instead of explaining the trend*, *explains relationships between causes and effects at the macroscopic level*, and *provides mechanistic explanations for the trend*. These codes addressed one attribute of the explanation practice, which I labelled *rationales for the displayed trend and variability*; this label represents the theme for these codes. This process was repeated for the remaining practices, with each theme associated with two to four codes.

Sketched Responses

Although analysis of the sketched responses is applicable to each graphical sense-making practice, the sketches had the greatest role for the prediction practice. I had more descriptive codes regarding students' talk for this practice as compared to the other practices. Some examples of codes for the predict practice were: *sketched points are accurate with respect to both axes, periodic variability is sketched in all graphs,* and *uses displayed trend to locate future* *points*. These codes initially corresponded to three themes: *accuracy of sketches, manifestation of variability,* and *apparent source of information for sketches*. Similar to the verbal responses, each theme was usually associated with two to four codes.

Responses Bridging Graphical Sense-Making Practices

In addition to analyzing my participants' responses with respect to each individual practice, I was also interested in seeing if there were commonalities in their graphical sense-making across practices. As described above, the codes were initially developed with respect to one practice. Based on comparisons of the codes and themes across practices, I found that some of the codes for one practice were partially reflected in the codes for other practices, creating bridges across those practices. For instance, the code *provides mechanistic explanations for the trend* for the explanation practice was partially expressed in the code *compares outcomes of causal mechanisms from local factors to address generalizability of trend to other locations* for the generalization practice. Further comparisons were made to identify these types of bridges between the practices and types of responses (verbal and sketched).

Refining the Codes and Themes into Levels

As additional responses were analyzed, new codes and themes emerged while others decayed. Throughout this process, I constructed memos, storylines, and concept maps to help me refine the codes and themes to address my research questions, where each construction served a different purpose. The memos were organized by my research questions and included my answers to those questions for that participant. The storylines were created to organize the students' responses by graphical sense-making practice, which made for more readily visible comparisons across practices. The concept maps provided a diagrammatic representation of how the individual graphical sense-making practices may connect to each other.

After iterations of alternating between these different constructions, I created a summary table to assist with the systematic comparison and organization of codes and themes across practices and participants, which was difficult to do with my previous constructions. Table 3.4 shows a partial structure of an initial version of this summary table for the explanation and prediction practices, using examples described previously, as well as additional codes for the predict practice.

Table 3.4 Summary table of codes and themes organized by practice

Practice	Theme	Code 1	Code 2	Code 3
explain	*rationales for the displayed trend and variability*	*explains causes for changes in random variability instead of explaining trend*	*explains relations for causes and effects at the macroscopic level*	*provides mechanistic explanations for the trend*
predict	*accuracy of sketches*	*sketched points are accurate with respect to both axes*	*sketched points are accurate with respect to one axis*	*sketched points are accurate with respect to neither axes*
	manifestation of variability	*periodic variability is not sketched in any graph*	*periodic variability is sketched in all graphs*	*periodic variability is sketched in some graphs*
	apparent basis for sketches	*uses displayed trend to locate future points*	*uses displayed variability to locate future points*	*uses trend and variability to locate future points*

In this table, the rows correspond to the practices and associated themes, while the columns corresponded to different codes associated with those practices and associated themes. The cells for each code characterize responses from one or more participants.

The first consideration in my refinement of the codes was to determine how they could be organized, within themes, from most to least peripheral with respect to a community of practice of an informed citizenry (i.e., levels of sophistication in sense-making). The codes in Table 3.4 are not necessarily organized with respect to peripherality to that community of practice. In the next section, I describe how I organized the codes within each theme.

Defining Levels as Approaches

To sort the codes, I used the criterion of increasing sophistication with respect to their engagement with the practices. Codes identified as least sophisticated were grouped together; this group of codes was identified as representing a *figurative* approach to graphical sense-making. Codes identified as most sophisticated were also grouped together to represent an *analytic* approach. The remaining codes were grouped together to represent the *literal* approach.

The refinement process also addressed revisions to codes and themes. As noted earlier, the number of codes for each theme ranged from two to four. Themes with two codes meant that one of the approaches may not have been present. Themes with four codes were usually re-analyzed to see if would be more productive to redefine three codes or to leave the original four codes; if it was not possible to redefine the responses into three codes, an extra unnamed approach was set aside as a tentative placeholder for further analysis. Additionally, some of the initial themes were present in multiple graphical sense-making practices (e.g., perception of purpose or audience of graph); in these cases, the themes were also re-analyzed and either assigned to the practice that would be the best fit or identified as applicable across practices.

Once a tentative ordering of the codes and list of themes had been determined, I considered other criteria to define and foster clear distinctions between the approaches. These criteria included comparing a participant's response for a practice to: (1) the same participant's response to other practices for a graph—to address internal coherence within an approach, (2) the same participant's responses to the same practice across graphs—to determine the potential effects of context on that practice, (3) other participants' responses for the same practice—to help differentiate between the approaches, and (4) findings in the literature—to determine how well the responses from the participants of this study reflect and build upon previous findings.

Constructing the Narratives

To further illustrate distinctions between the students' approaches, I wrote narratives for exemplar participants—participants with a relatively consistent approach across the graphical sense-making practices for the three graphs. In these narratives, I focused on differences between their stories of how phenomena occur (e.g., covering law), mathematical strategies used during their sense-making of the graphs (e.g., use of statistical methods, differentiation between trend and variabilities), and the connections they made between human activities, Earth systems, empirical data, and the graphs. Of the high school students who were interviewed, three exemplar participants (Susan, Annika, and Esmerelda) were chosen as the foci for the narratives because they showed the most contrast in their approaches.

Throughout the development of these narratives, I constructed a summary table to characterize the exemplar participants' graphical sense-making. The rows described these students' crosscutting strategies (themes that span across individual practices) or individual graphical sense-making practices while the columns corresponded to the exemplar participants. The cells described the exemplar participants' use of the crosscutting strategies or individual practices. The organization of this table provided a bird's-eye-view of the similarities and differences in graphical sense-making for each exemplar participants that helped to answer my research questions. For instance, the columns in the table reminded me to seek coherence within an approach while the rows reminded me to show an increasing proficiency with respect to particular progress variables. From constructing this table, I concluded an additional approach was needed to represent the most sophisticated responses; thus, a narrative for a fourth exemplar (Bob) was constructed and included in the table, using the same procedures described above.

The final version of the summary table presents the approaches from most to least sophisticated. The rows represent the exemplar participants, starting with Bob and ending with Susan, and there is only one column representing the responses for the crosscutting strategies or individual practice. Table 3.5 shows part of the structure for the final version of the table; this structure was repeated for the remaining practices.

Table 3.5 Structure for summary table of key characteristics from exemplar participants' crosscutting strategies and interpret and analyze practice

crosscutting strategies	
Bob	
Esmerelda	
Annika	
Susan	
interpret and analyze	
Bob	
Esmerelda	
Annika	
Susan	

Building the General Framework of Approaches to Graphical Sense-Making

The general framework summarizes how all the participants engaged in graphical sense-making. I used the final version of summary table and relabeled the exemplar participants' names (Bob, Esmerelda, Annika, and Susan) with general descriptors characterizing their approaches to graphical sense-making (analytic+, analytic, literal, and figurative). The four exemplar participants were generally representative of the four levels in the general framework, but the analysis of each additional participant led to a few changes in the characterizations of the different levels. Although I did not construct narratives for the other participants, I identified excerpts from their interviews that reflected the characterizations. When the themes within the cells were robust enough to address the responses from all the participants, the general framework was considered to be complete. Table 3.6 shows part of the structure for the general framework, crosscutting strategies and the interpret and analyze practice; this structure was repeated for the remaining practices.

Table 3.6 Structure for the general framework of approaches for the crosscutting strategies and interpret and analyze practice

crosscutting strategies	
analytic+	
analytic	
literal	
figurative	
interpret and analyze	
analytic+	
analytic	
literal	
figurative	

Summary

I used the analysis described above to answer my research questions—which I present in my findings as three parts: (1) narratives for exemplar participants, (2) summary table of exemplar participants, and (3) general framework of approaches to graphical sense-making. The narratives illustrate what the approaches to graphical sense-making may look like from the perspectives of four exemplar—or archetypical—students. The summary table for the exemplar participants provide a way to see contrasts between the graphical sense-making approaches taken by the students. And lastly, the general framework refines the summary table to represent the perspectives from all my participants.

CHAPTER 4: What Were the Approaches to Graphical Sense-Making?

In the first part of this chapter, I present the narratives of four participants—Bob, Esmerelda, Annika, and Susan. They were selected because they showed the most contrast—and were the most consistent—in exemplifying the approaches to graphical sense-making. Using their responses, I describe each participant's engagement with respect to each practice, and across practices, for the Keeling, Temperature, and/or Arctic graphs; the complete interview transcripts for these four participants, along with any graph of theirs not shown in this chapter, are in Appendix G. I also compare their sense-making for the Keeling graph (higher signal-to-noise ratio) to their sense-making for the Temperature and/or Arctic graphs (lower signal-to-noise ratio). The bulk of this chapter is comprised of the narratives for the exemplar participants.

In the last two parts of this chapter, I present a summary of the narratives (second part) and my general framework for the participants' graphical sense-making of the graphs (third part). In the second part, I summarize the responses from the exemplar participants and organize them into a table to illustrate the overall patterns in their responses, describing contrasts across the exemplar participants. In the third part, I present the general framework characterizing the participants' graphical sense-making of the graphs presented to them during their interviews. I also address key patterns in their graphical sense-making with respect to their use of approach(es) across practices within a graph and for a practice across graphs. These findings lead up to the discussion in the last chapter of my dissertation.

Bob as a Competent Scientist

Bob was a doctoral student in a physics department. He treated the three graphs as representations of data selected by research groups making a point about patterns of change in Earth systems, speculating about the purposes these scientific organizations had for selecting and representing the data. Bob used scientific models and principles to make connections across systems and scale in order to compare how the elements and patterns in these graphs mapped onto, and could help explain, phenomena in the real world. When he encountered a lack of information (outcomes with multiple causes or locations, vagaries of human activities) or noisy data, Bob suggested likely outcomes using multiple lines of evidence-based reasoning. Below, I present Bob's responses with respect to the graphical sense-making practices for the three graphs.

Interpretation and Analysis: Speculation about the Sources

During the interview, Bob consistently speculated about purposes scientific organizations had for selecting and representing the patterns in the data. These speculations often addressed relationships between graph construction and data collection and analysis. For instance, Bob's speculations about the meaning of a point in the Keeling graph connected how the point was represented (graph construction) with methods of data analysis:

Interviewer: **…And then the dot that I circled, do you think that the people that created this graph used a single measurement or multiple measurements to represent that dot?**

Bob: Well, I would think it would be good practice to take a lot of measurements, but I don't really see—if you take a lot of measurements, you should propagate your error and put error bars. I don't really see error bars, but that could also be because it's so small maybe the errors are so small that you can't see it or they took away the error bars because it would've confused the overall message of the graph. Or they didn't (chuckles) calculate the error or they only took one measurement. But I'd imagine they're maybe – I don't know if they're constantly taking measurements or in a periodic fashion and then they average it over – I don't know, it looks like they take one – maybe once a month. One, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve [counted points in the inset from January to December]. Yes. Maybe average it once for the month or they could just take one measurement a month, but I would imagine they take more and do some type of averaging.

Interviewer: So, is the dot on this part of the graph that I circled, is that the same as the dot that's inside that inset or is it different?

Bob: My theory is that this is a blowup of one of these sections here. I don't know if it's specifically the one where this dot is. I would've liked if they had labeled what year this was. Maybe it could be a specific year or it could be an average of all of the years normalized in some fashion just to show you these jagged lines more look like this.

Bob's response that multiple measurements requires propagation of error—and proposal of explanations for why it was not used—describes actions scientists make when constructing graphs, which is not necessarily a concern for informed citizens. His response signals his *science insider* status, which was also reflected in his interpretation and analysis of the other two graphs, and is also consistent with the *reading beyond the data* level described by Curcio (1987).

Explanation: Evidence-Based Reasoning across Systems and Scales

Bob consistently used scientific models and principles, explicitly stating his sources of evidence (or lack thereof), to construct his explanations for the phenomena represented in these graphs. His explanations often addressed connections across multiple systems and scales. When he did not have enough information to express a conclusive explanation, he used scientific models or principles to suggest consequences for hypothetical if-then scenarios. Below, I share examples of his explanations for the Keeling and Temperature graphs to illustrate these characterizations.

In the Keeling graph, Bob suggested the trend was *likely* due to human activities and that the periodic variability was associated with seasonal natural phenomena. He indicated that he did not have data to conclusively determine the cause of the trend, reflecting his caution about making claims without evidence:

Interviewer: Do you have ideas about what might be causing the increase?

Bob: Well, the graph itself doesn't really have any information about that. I can tell you about things that I've heard such as human activity that could be causing this, but from the graph, I don't see any indication of any hypothesis about what's causing it.

Interviewer: Mm-hmm (affirmative). Yes, okay. What about the jagged lines you were talking about? Do you have ideas about what might be causing that?

Bob: Yes, well, if I'm right where this is kind of a blown up—because the scale here is in years and it looks like these jags probably take place pretty much once a year. So I'm guessing that there's something about the seasons or the temperature of the air that changes the readings. Or maybe it's a natural, cyclical phenomenon. I don't know enough about atmospheric science or CO_2 to really have a good hypothesis about why'd that be happening, but I'd guess it'd have to do with – let's see, it looks like it's higher in maybe the warmer months and a little lower in the colder months. So I'd guess that it would have something to do with temperature.

Bob explicitly stated his presumption that the trend was likely related to human activities but that, without evidence (i.e., human activities graph), he could not provide a conclusive cause for the pattern in the data. He couched his response as a hypothetical explanation supported by scientific concepts. Although he did not address the scientific models related to the trend here, he did so when he talked about the Temperature graph (which I address when I discuss Bob's response to the Temperature graph).

Similar to his explanation for the trend, Bob hypothesized multiple reasons for the cause of the periodic variability:

Interviewer: …What about the jagged lines you were talking about? Do you have ideas about what might be causing that?

Bob: Yes, well, if I'm right where this is kind of a blown up—because the scale here is in years and it looks like these jags probably take place pretty much once a year. So, I'm guessing that there's something about the seasons or the temperature of the air that changes the readings. Or maybe it's a natural, cyclical phenomenon. I don't know enough about atmospheric science or CO_2 to really have a good hypothesis about why'd that be happening, but I'd guess it'd have to do with—let's see, it looks like it's higher in maybe the warmer months and a little lower in the colder months. So, I'd guess that it would have something to do with temperature.

Bob suggested the cause of the periodic variability could be related to seasons or temperature due to information he gathered from the inset, or that it could be a natural phenomenon that he does not know about due to his self-expressed lack of knowledge about atmospheric sciences. Despite his expressed lack of knowledge, he identified multiple causes that matched to the displayed pattern in the data to explain the periodic variability. Based on the evidence he identified, Bob concluded that the cause of the periodic variability is probably related to temperature. Later in the interview, he provided additional information relating to the cause of trend and the relationship between periodic variability and changing temperatures:

Interviewer: **… What about the CO_2 that they're measuring? Do you have ideas about why they might be measuring the CO_2 as opposed to, say, something else?**

Bob: Just from my general knowledge of what I've heard that the climate scientists like to track CO_2 because I think it gives a good – I don't exactly remember why it's related to the warping of the climate, but as I mentioned earlier I think it has to do with the light rays come in instead of – some of them always go all the way out of the atmosphere, but some of them are bounced back in and kept in the Earth's atmosphere. Maybe CO_2 is really good, kind of like a blanket either deflecting the light back in, or trapping it, or the light scatters so much that it doesn't get back out of the atmosphere leading to warmer. But I'd imagine carbon dioxide is a naturally abundant thing in our atmosphere. Used in our oxygen-CO_2 cycle for trees and us to breathe and live. So it's probably fairly easy to detect because I'd imagine it makes quite a large percentage of the molecules in the atmosphere. So it's probably easy to detect and maybe the CO_2 is one of the things that – we're probably putting a lot of CO_2 into the air maybe through our current energy creation methods. That'd be my hypothesis, but I haven't looked at this in a while so I'm not exactly sure.

Interviewer: **Yes. You mentioned O_2-CO_2 cycle with the trees. Can you say a little bit more about that like how you were thinking about it? (chuckles)**

Bob: I'm thinking middle school. Well, I know us humans breathe oxygen and I think we breathe out carbon dioxide. I think the trees are opposite where they take in carbon dioxide and output CO – no, sorry, take in, yes, carbon dioxide and output the oxygen for us to breathe. But I don't think this is caused because people are breathing out a lot more than they're breathing in. That's what I remember from that cycle. I don't know if that's right.

Bob's first explanation involved the scientific model of heat transfer by radiation (related to light rays bouncing in the atmosphere) to explain the trend in changing temperatures, which is one of the effects of increasing atmospheric carbon dioxide concentrations. He also talked about the oxygen-carbon dioxide cycle, which is a model-based explanation partly related to the cause of the periodic variability. These responses reflect his use of evidence-based reasoning.

In the Temperature graph, Bob explicitly indicated the cause of its trend was connected to the data from the Keeling graph:

Interviewer: … What about that upward trend that you saw? Do you have ideas on what might be causing that?

Bob: Well, again, I think these from the theory that I learned that these are linked. The more CO_2 you have traps more heat and increases the temperature. It seems like the accelerating of the slope in the CO_2 correspond to a sharper increase in the temperature as well. But it's tough to really say that conclusively.

Similar to his explanation of the trend in the Keeling graph, Bob referenced the heat transfer by radiation to explain the trend in this graph ("more CO_2 you have traps more heat and increases the temperature"). He compared the temperature trend with the trend in the Keeling graph to explain his response, noting that the comparison was "tough to really say that conclusively"; this response is reflective of his use of evidence-based reasoning. He further elaborated on the connection between the trends from both graphs in the excerpt below:

Interviewer: What kinds of stuff were you thinking that people did to increase that [worldwide] energy consumption?

Bob: Burning more fossil fuels. Because I recall – I have to look at a graph of things over time – that the human population has kind of exploded. In 1900, it was still maybe around three or four billion and now it's really increasing quite rapidly now. So more people need more energy and we haven't switched over to more renewable sources to keep up with that. So we're burning more fossil fuels, which I think the theory goes these release more CO_2 which traps more heat and increases the temperature.

Bob indicated that, together, the combined effect of burning of the use of fossil fuels and the exploding human population caused the increasing temperatures in the Temperature graph.

With respect to random variability in this graph, Bob considered multiple approaches to analyze the pattern in the data before sharing his conclusions:

Interviewer: **… Do you have ideas about what might be causing it [noise] as opposed to what's not?**

Bob: Yes, I was trying to think about that. It seems like the wavelength, the period, is over the – well, it's not even really a regular period, but maybe it seems to be three or four years or something. Three or four years. I don't really know what happened cyclically there in New Zealand. I would guess that because I can't really think of anything that's cyclic with that time period. It could just be statistical noise or it could just be that they're so many factors that go into the temperature that it's tough to – Yes, that could be causing this. Also, it's quite a small scale.

Interviewer: **For the y-axis range?**

Bob: Yes. On the order of ones as opposed to the order of 10s.

Similar to his response for the Keeling graph, Bob explicitly addressed how patterns in the data could map onto phenomena in the real world.

Overall, Bob's responses reflect his connections among systems across scales through scientific models and principles and careful consideration of evidence before making claims regarding the causes of patterns in the data. His explanations are consistent with the upper anchor of the explanations learning progression described by Covitt and Anderson (2018), invoking scientific models and principles and connecting systems at multiple scales.

Prediction: Triangulation of Strategies and Accountability

Bob's projections in the three graphs were sketched with relative precision, consistent with the time scale. He consistently used mathematical strategies *and* scientific models or principles to inform his projections, addressing—when applicable—systemic randomness inherent within phenomena, insufficiency of information to determine the outcome of multiple causes, or vagaries of human activities. Bob accounted for the constraints by sketching increasing confidence intervals around his projections in all three graphs. Below, I show how these characterizations are reflected in his responses to the Keeling and Temperature graphs.

For the Keeling graph, Bob's projections are shown in Figure 4.1:

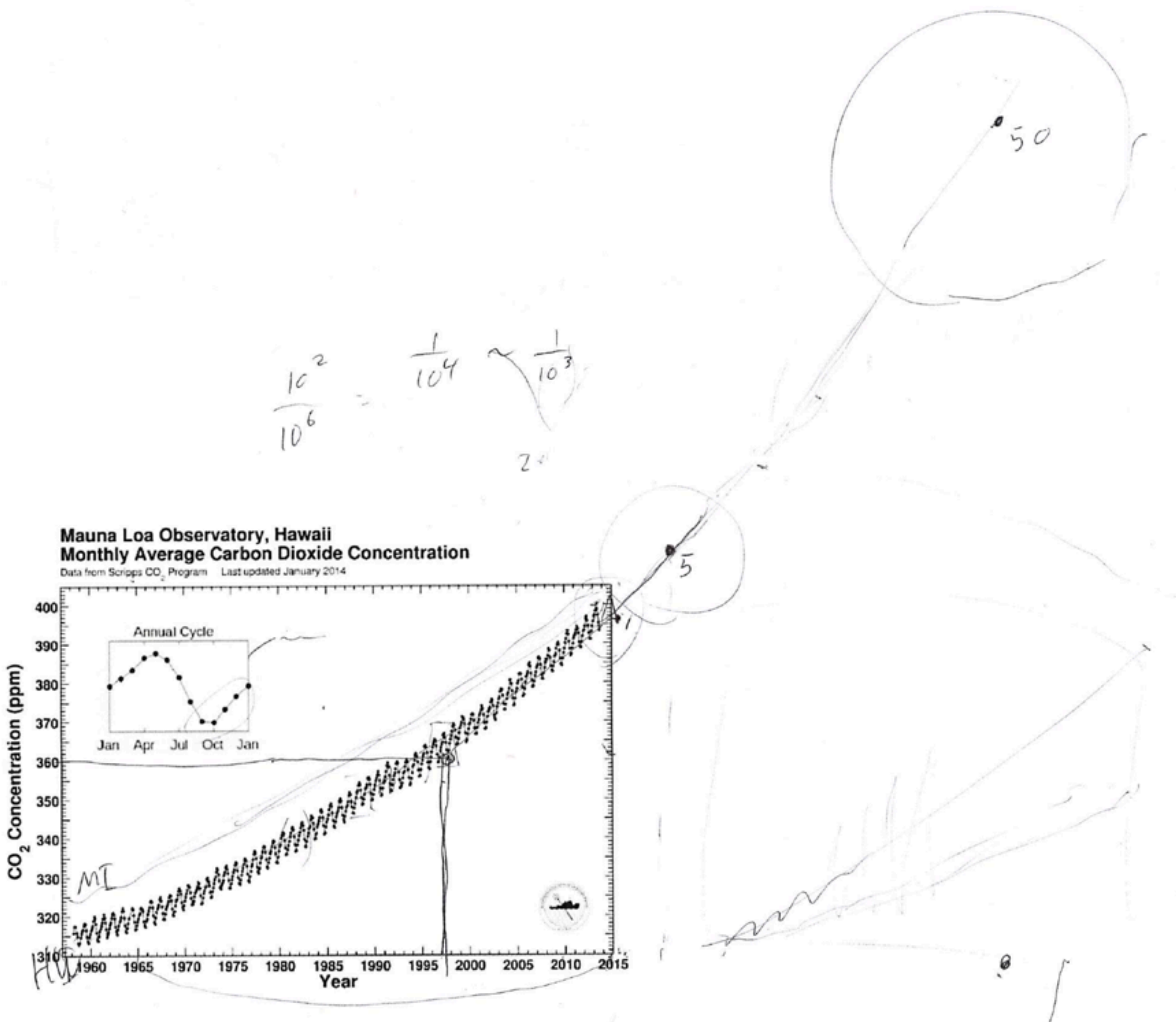


Figure 4.1 Bob's Keeling graph

Bob was the only exemplar participant whose projections (1) were accompanied with increasing ranges of confidence intervals (as indicated by the increasing radii of the circles he sketched around each successive projection) across graphs, (2) included confidence intervals for the Keeling graph, and (3) did not include any sketched oscillations between projections. The first two characteristics of his projections suggest that Bob considers measurement errors inherent within all data collection and thus, confidence intervals should be used to reflect these errors.

Bob's rationale for his projections in the Keeling graph addressed ideas related to mathematical strategies and scientific concepts:

Interviewer: …So, my next question is going to be, can you talk a little bit about how you made the decisions to put down the one, five, and 50 where you did?

Bob: Mm-hmm (affirmative). I made the assumption that this could be fitted loosely as an exponential function. Tried to sketch that best I could and then put a dot at the corresponding time.

Interviewer: I know you talked about the jagged edges and you mentioned it for the one-year predictions, your one-year mark. Between the one and five years and five and 50, do you imagine that the jagged edges would continue?

Bob: Yes, it's because of an annual cycle. I would imagine that they would continue. It seems, though, it's been jagged the whole time and I think the phenomenon we're seeing is there's kind of a smaller cycle of the CO_2 concentration due to the seasons. And then a more global trend that the jagged lines are going up. So, if you were just looking at a very small sample, blowing that up it would look like this and I would say, "Oh, well, this is just cyclic. Nothing's happening. It's not really going up." But only when you step back and look at a large half a century period do you see it increasing.

Although Bob did not sketch any oscillations in this graph, he indicated they would persist due to the cyclical nature of the seasons (related to scientific concepts). His response that larger samples ("look at a large half a century period") made the trend more visible suggests his awareness of the relationship between scale and trend visibility (related to mathematical strategies).

Bob also talked about how the lack of information in the Keeling graph contributed to the difficulty of extrapolating points for a distant future:

Interviewer: …And then when you made these, one, five, and 50, how certain are you that these values are going to come true?

…

Bob: If I said maybe gave myself these margins of error probably – well, it depends on what we do to curve this, but I would imagine we might do a little bit but probably not enough. Maybe 70 percent chance that it lands within here. But I don't really have any statistics to back that up.

Interviewer: I noticed your margin of error, the circle that you drew around the one point, is smaller than the one for your 50 (chuckles).

Bob: Yes, well, it's tougher to extrapolate further and further into the future.

Interviewer: Why is that? Or why do you think it is?

Bob: Yes. Well, two reasons. One is that if we start doing something to curb this, today it will take some time for that to ripple through the environment and change it. So even if we did something now, it would still maybe take five or ten years to start to reverse the trend. But I imagine we're not going to curb it enough tomorrow. Maybe when it gets direr, we'll curb it. So it's really hard to tell how dire it's going to get. How many people's minds are going to change. What the world governments are going to look like. As the future goes on, the divergent possibilities just grow exponentially. The second reason is that there could be some not human effect, but some physical effect. Or maybe when the Earth reaches certain CO_2 parts per million that a new function would better fit it. So maybe it becomes a cubic function or maybe it caps off somehow for some other physical reason and not a human reason then that wouldn't be seen at this low of a ppm respectively.

Bob justified his response by providing two scientific reasons why extrapolating points into the future is complex. His first reason was implementation lag time, which is the amount of time needed for an intervention to show an effect. His second reason was tipping point, which is the threshold value that triggers the variable into a new state or activity pattern. His identification of these two reasons address the nature of phenomena across systems and scales.

For the Temperature graph, Bob also used mathematical strategies and scientific models or principles to inform his sketches; however, instead of using the long-term trend to sketch his projections, as he did for the Keeling graph, he used the most recent trend. Figure 4.2 shows his projections for the Temperature graph:

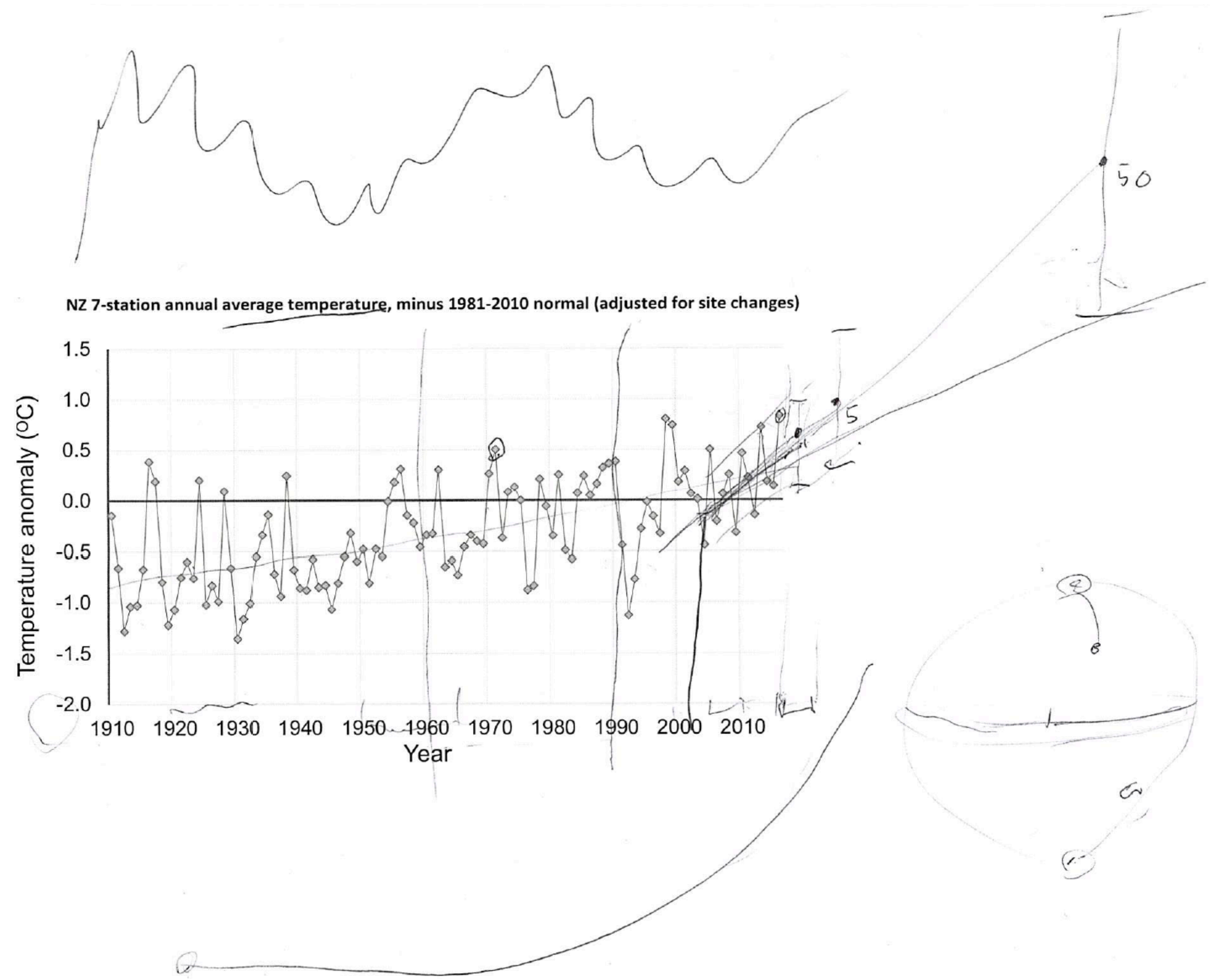


Figure 4.2 Bob's Temperature graph

Bob sketched the points based on the recent trend, as indicated by the darkened trend line he sketched from 2000 onward; his use of the recent trend was not a strategy used by the other exemplar participants. Similar to his projections for the Keeling graph, his projections for this graph were also bounded by increasing ranges of confidence intervals. His rationale for these projections was:

Interviewer: … Can you say a little bit about how you decided where to put the ranges, and the points, and all of that?

Bob: Yes. I drew a line that best fits starting at 2000 and extended that line and put points at the various times were asked. Again, here this range is based off how high or the size of these jumps here.

Interviewer: **So, your one-year range is based on the ranges of previous?**
Bob: Yes. And five's extended a little bit. Not that I'm thinking that the jags are going to get bigger but that's just my error. Again, because it's tougher to extrapolate further into the future.
Interviewer: **So, I'm kind of curious. You used it from 2000 on and then previously you had a best fit line that went from 1910, the beginning. What was your thinking on choosing to base it off of that more recent line?**
Bob: Yes. I think they showed such a long period to suggest that this steeper trend is not part of some overall more global thing that's going like that. So if this is the world we live in now, physics doesn't really care about what happened earlier. So I would imagine that this sharp increase isn't part of some cyclic nature before. So this part doesn't really play. The part before 2000 doesn't really play that much of an influence. Maybe this line is a little too steep, but yes, the current physical state doesn't really care about what's happened earlier. I would imagine whatever's causing this increase if it is human activity, is likely to continue as our population grows.

Bob's rationale relates to the context of the represented phenomenon. He stated that his strategy was to first identify potential patterns in the random variability (related to mathematical strategy) before assessing the strength of his response (using scientific concepts). He explicitly stated the necessary assumptions in order for his projections to be true. Based on this process, he dismissed the cause of the variability to talk about the trend, or signal, in the graph, evaluating the significance of different sections of the pattern in the data ("this line is a little too steep … current physical state doesn't really care about what's happened earlier"). Similar to his responses for the Keeling graph, Bob made connections between the graph and represented phenomena across systems and scales. Overall, Bob's projections in these graphs are similar to the upper anchor described by Covitt and Anderson (2018) in their learning progression for predictions: extending patterns and addressing reasonable trends in noisy data and sources of mathematical uncertainty.

Generalization: Local is Representative of the Global

Relatively consistently across the three graphs, Bob used scientific models to compare the outcomes of local factors to each other and connect those outcomes to global systems in his generalizations. He used these outcomes to determine the extent to which the trends *and* variabilities would be generalizable, which I illustrate with his responses to the Keeling and Arctic graphs.

For the Keeling graph, Bob addressed the generalizability of the trend and variability across locations:

Interviewer: … So if you could imagine the people who created the graph wanted to do this in Michigan, do you think the graph would be similar, different? What would that data look like?

Bob: I would imagine it would probably have the same overall global trend and it would also have jagged lines because – it might even be more jagged because we have more pronounced seasons, greater variance in our temperature. But maybe the global trend wouldn't be as clear. There might be more noise, if you will, from other pollutants that are put in the air.

Interviewer: Do you think that the range for the CO_2 and ppm … would be similar? Do you think it would be higher or lower?

Bob: I would say maybe slightly higher because going off of my theory that there might be more pollution in a place that's surrounded by land with more people that are producing more things as opposed to an island that's surrounded by water.

Bob indicated the displayed trend for data collected from Hawai'i would be similar for data collected in Michigan, while the variability for data collected in Michigan would be more pronounced. His description of the trend as "global" suggests the pattern in the data is representative of atmospheric carbon dioxide concentrations around the world. His generalization of the periodic variability involved a comparison of a local factor (pollutants) and reference to the scientific principle that pollution is more constrained in a land-locked area rather than "an island that's surrounded by water."

For the Arctic graph, Bob also addressed the generalizability of the trend and variability across locations:

Interviewer: **… Do you think there are things that people do that might affect the shape of this graph?**
Bob: Yes, I think the…humans do things that cause an increase in CO_2 concentration, which causes an increase in temperature, which would melt the ice, which would decrease the area of ice in the Arctic Sea.
…
Interviewer: **If we were to plot this in, say, Antarctica as opposed to the Arctic Sea, do you think the graph would be similar?**
Bob: Well, I know that Antarctica is an actual continent. So, there's land there with a sheet of ice on it. Whereas the Arctic Sea is just ice on top of the water. So, I'd imagine that…it…well, so if you're on land in Antarctica and the ice melts, it would probably just decrease its height but still be the same area because it's fixed by the land. But if you're on the water, then whole chunks could melt or fall off into the sea so that would decrease the area. So, you'd probably wouldn't see as much of a decrease. I know Antarctica, maybe, here's the land and the ice sticks out. So, some of it is on the water. So, that part is probably receding to look more like that. It's probably not as drastic as in the Arctic.
Interviewer: **Okay. So, you think the slope would be less.**
Bob: Yeah.

Bob noted that the trend would be similar, with less variability, for data collected in Antarctica. His remark that Antarctica is a land mass whereas the Arctic Sea is a body of water had a significant role in his evaluation of the generalizability of the pattern in the data for this graph. He talked about how the area of ice would change based on the physical properties of their geographic landforms (e.g., relative size). He also used scientific principles (buoyancy of ice in water) to relate local factors (geographic landform) to global factors (increasing temperatures). Of all the participants, Bob was the only one who indicated that the generalizability of the Arctic graph to Antarctica was not comparable due to differences in geographic landforms, which reflects his general evidence-based reasoning approach to making claims.

Esmerelda as a Capable Citizen

Esmerelda was a high school student who did not have explicit instruction for any of the three graphs. She treated the graphs as representations of local data showing patterns of change in Earth systems. Her responses often addressed the data collection methods and analysis used to construct the graphs, suggesting her familiarity with some of the activities of scientists. She analyzed the graphical elements systematically, used scientific models and principles in her explanations, and precisely sketched her projections. When faced with a lack of information (outcomes with multiple causes or locations, vagaries of human activities) or noisy data, she used strategies to account for those uncertainties. Below, I show how Esmerelda's responses reflect these descriptions of her engagement with the practices.

Interpretation and Analysis: Addressed Changes through Systematic Mappings

Esmerelda's mapping of the three graphs onto aspects of the real world drew from information she systematically elicited from its elements. In her mappings, she often addressed aspects of the data collection or analysis to support her interpretation and analysis of the graph. For instance, in the Temperature graph, she discussed the significance of the dark horizontal line ("zero line")—an element central to making sense of the graph:

Interviewer: … So what do you think this [Temperature] graph is about?

Esmerelda: It looks like it's about temperatures from year to year. It's the average temperature for each year, and it looks like it's kind of—it's looking at the difference, I guess, in average temperatures, from the 1981 to 2010 normal, which I'm guessing is, like, the determined average temperature from that point in time. And I'm guessing that's what the dark line in the middle represents. What the normal temperature is. And then, points that are above it had an average temperature for that year that were a little bit higher, and points that were below it had an average temperature that were a little bit lower, I think, is what it represents.

…

Interviewer: … What do you think is the most important thing they should notice about the graphs?

Esmerelda: I think it's important to notice that the zero was in the middle. That's a little bit unusual. And that the dots on the graph—the points on the graph, they don't necessarily represent—they don't represent the—the actual temperature. They represent the difference from the, of that temperature for the, for that year from the normal temperature.

Interviewer: Mm-hmm.

Esmerelda: So, that's—that kind of shows why it makes sense that the temperature scale should be only a few degrees Celsius, instead of a much wider range.

Esmerelda talked about how the average temperatures changed over the years with respect to the zero line, using information from different parts of the graph. When she said the graph is "about temperature from year to year," she used information related to the axes. When she said "average temperature for each year…from the 1981 to 2010 normal," in reference to the zero line, she used information from the title. Her comments about the zero line being unusual and the y-axis not representing actual temperatures reflects her systematic evaluation of the information represented in the graph.

Esmerelda provided more details about the zero line later on during the interview when she was prompted to consider the nature of the data represented in the graph:

Interviewer: … Do you think this [data] was taken in one location, or in multiple locations?

Esmerelda: I noticed that, in the title, it said, "adjusted for site changes." So, it seems like they didn't take it all in the same location. But they say "adjusted for site changes," so, I'm guessing that they might have changed the, what the normal temperature was like, based on where they were recording the temperature at the time.

Interviewer: Mm-hmm. Can you say a little bit more about changing the—how you were imagining they were changing the normal temperature?

Esmerelda: So, the normal temperatures, like, is represented by the zero that's the zero line. That's the least amount that the average temperature could be, different from the normal temperature. If the average temperature for a year was exactly the same as the normal temperature, then they would be on the zero line. And the normal temperature for 1981 through 2010? That's, like, the average temperature for all of those years, I'm guessing, based on the location. So, if they took a lot of data samples from one location throughout that, between 1981 and 2010, then that would be their normal average. And then, the—if they had a different site that had a slightly different climate, then they would take the normal from that. So, what they—it says what they do is they take the—this is minus the 1981 to 2010 normal temperature. So, what I'm imagining they do, is they take the average temperature for a single year, and then they subtract the normal or the average temperature for the location that it was taken. And then that's the deviation from the normal location.

Interviewer: Mm-hmm. Do you have ideas about, like, why they are plotting it against a zero line as opposed to just plotting against the actual temperatures?

Esmerelda: I think that the plotting it against the zero line, it also—it helps adjust for the—what'd they say, "adjust for site changes"? If you're plotting the actual temperature, then the temperature is just the raw data, and it would definitely—I'm guessing it would change based on where they were taking the data. And it looks like that's not the variable that they're trying to look at here. They're not trying to see what the different temperature—checked temperatures are in different places. They're trying to see how the temperature, in general, changed over a time period.

In her explanation of the zero line, Esmerelda talked about how the scientists who created the graph probably "took a lot of data samples from one location…[then] take the average temperature for a single year, and then they subtract the normal or the average temperature for the location that it was taken" and repeated that process for the different sites—suggesting her familiarity with data collection and analysis. Her statement that the scientists were "trying to see how the temperature, in general, changed over a time period" reflects her treatment of the graph as a representation of local data that shows patterns of change in Earth systems, which could also be seen in her interpretation and analysis of the other two graphs. Similar to Bob's responses, Esmerelda's responses are reflective of the *reading beyond the data* level described by Curcio (1987), which was to use information not explicitly displayed in the graph.

Explanation: Use of Scientific Models and Principles

Esmerelda used scientific models or principles to explain the displayed trends and periodic variability, which at times were incorrectly associated with descriptions of relationships between variables in the real world. Below, I share examples of her explanations for the Keeling and Temperature graphs to illustrate these characterizations.

For the Keeling graph, Esmerelda's explanations of the trend and periodic variability both addressed different parts of the scientific model for carbon cycling. The following excerpts show her explanations for the trend:

Interviewer: …Do you have ideas about what might be causing this pattern to go up?
Esmerelda: I'm thinking it probably has a correlation with the technology increase. It—I mean, it increases at kind of a shallow curve from 1960 to 2015. But I know that people have definitely been using more technology that uses electricity, which is basically harnessed through fossil fuels. And there's also a lot of—I know there's a lot of—like, a lot of cattle farming on Hawai'i, and I'm wondering if that has something to do with the carbon dioxide release. Because cattle farming tends to produce a lot of carbon dioxide. So I'm thinking that might—those might be some of the major causes.
…
Esmerelda: …I think that since most of our electricity comes from fossil fuels, and that the burning of fuels releases carbon dioxide, that an increased use in electricity will cause an increase in carbon dioxide. But I'm not really sure what percentage of the carbon dioxide that's in the atmosphere at any given moment, really, is affected by people. It seems like it's—the amount—the lifestyles of humans has [*sic*] affected the carbon dioxide significantly, because it seems to be increasing. But I'm not exactly sure to what degree.

Esmerelda talked about how the increasing use of technologies related to more electricity usage, which related to the amount of fossil fuels burned and amount of carbon dioxide released into the atmosphere. She also said cattle farming contributed to the increasing atmospheric carbon dioxide concentration. In both explanations, the movement of carbon between pools is implied in her explanations; this response is reflective of the upper anchor described by Covitt and

Anderson (2018) in their learning progression for explanations (addresses scientific models, connects systems across scales).

Esmerelda provided the following explanation for the period variability:

Interviewer: … And then you also mentioned this pattern within the shallow curve. Do you have ideas about what might be causing that pattern?

Esmerelda: Well, there's a smaller graph within that says—that goes between January—well, that goes throughout a year, and it shows how it curves up and down. And it looks like it—the—I mean, assuming that the scale on the side is similar to the carbon dioxide concentrations scale that, up higher, is a lot more carbon dioxide than—it shows that, throughout the spring and summer, there's an increase in carbon dioxide, and then, around late summer and fall, it decreases. And I think that might be due to, maybe, the season cycles on Hawai'i. Like, maybe—I don't really know how their, how the seasons work in more tropical regions. But I know that if there's, like, maybe a more rainy season, then plant growth will be more vigorous and probably use up more of the carbon dioxide. So I'm guessing that might have something to do with it throughout every year, when plant growth is most active. That causes the carbon dioxide to increase or decrease.

Interviewer: Mm-hmm. Okay. Earlier, you had mentioned that you possibly thought that photosynthesis might have something to do with this. Can you say a little bit more about that now? Like, how you were thinking?

Esmerelda: Well, I know that plants use carbon dioxide for their metabolism. So the fact that the, within the curve, the graph goes up and down, kind of like a sine wave. It probably has to do with the plants. And also I know that there's a certain range in which plants prefer their carbon dioxide to be for their optimal growth. Because if they don't have enough carbon dioxide, then they can't really control their metabolism, and they can't grow very much. But if there's too much carbon dioxide, I know that plants don't really grow that well, either. And I'm not really sure why. But they might—scientists might also be looking at this using this graph to figure out in what range plants grow the best, and maybe why plant growth has changed, possibly.

When asked to explain the periodic variability, Esmerelda analyzed the pattern, stating her observation (i.e., inset scale), before identifying possible local causes and scientific principles relating carbon dioxide concentrations to plant growth (e.g., more vigorous plant growth during rainier seasons, range of CO_2 concentrations for optimal plant growth). Similar to Bob, her explanations did not include photosynthesis, which is the main cause of the periodic variability.

For the Temperature graph, Esmerelda also used scientific models to explain the trend:

Interviewer: **… And then, do you think there are things that people do on, in their daily activities, that might influence this graph? The shape of the graph?**
Esmerelda: I think maybe similar to the first graph [Keeling graph]. Things like energy consumption. It seems like there's a, definitely a correlation between greenhouse gas emissions and temperature increase. So, I think that may be a reduction. Greenhouse gas emissions would cause the temperature to increase more slowly.

Esmerelda correctly indicated that the cause of the trend was human activities related to energy consumption, commenting that the increasing emissions "would cause the temperature to increase more *slowly*" rather than more *quickly* (which would have been consistent with the heat transfer by radiation model). However, this response is consistent with her account of how carbon dioxide traps heat on Earth:

Interviewer: **… Do you have ideas about what that connection [between the Keeling and Temperature graphs] might be? Or what might be—yeah like.**
Esmerelda: I think that the carbon dioxide concentration probably help (ph)—probably, from what I've learned at school, has to do with the—it can trap heat on the Earth. So, that would cause the temperature to increase.
Interviewer: **Mm-hmm. Does it matter that this one, the measurements are taken in Hawaii, and the measurements here are taken in New Zealand? If, like, when you were saying, like, CO_2 concentration traps heat, so it would increase temperature, does the difference in location matter, do you think?**
Esmerelda: I think maybe it matters a little bit, but I remember seeing a graph, once, with, like, global temperature increase. And it seems like the carbon dioxide, since gas travels around the Earth, and I think it—the greenhouse gases tend to concentrate around the poles. And they, the gases, travel around. They're not static. They're not going to stay in the same place. They—it probably affects places all around the world, but it would probably have more of a connection if they were in the same place, I would guess.

Esmerelda's rationale that carbon dioxide travels to the poles (description of relationships between variables) suggests she related temperature to heat energy, which, when dispersed around the Earth, "would cause the temperature to increase more slowly." Her explanations for the trend reflect the intermediate level described by Covitt and Anderson (2018) in their learning progression for explanations (demonstrated awareness of scale, limited ways in connecting systems across scales). Her incorrect explanation is significant because she later applied it to her generalization of this graph and overall engagement with the Arctic graph.

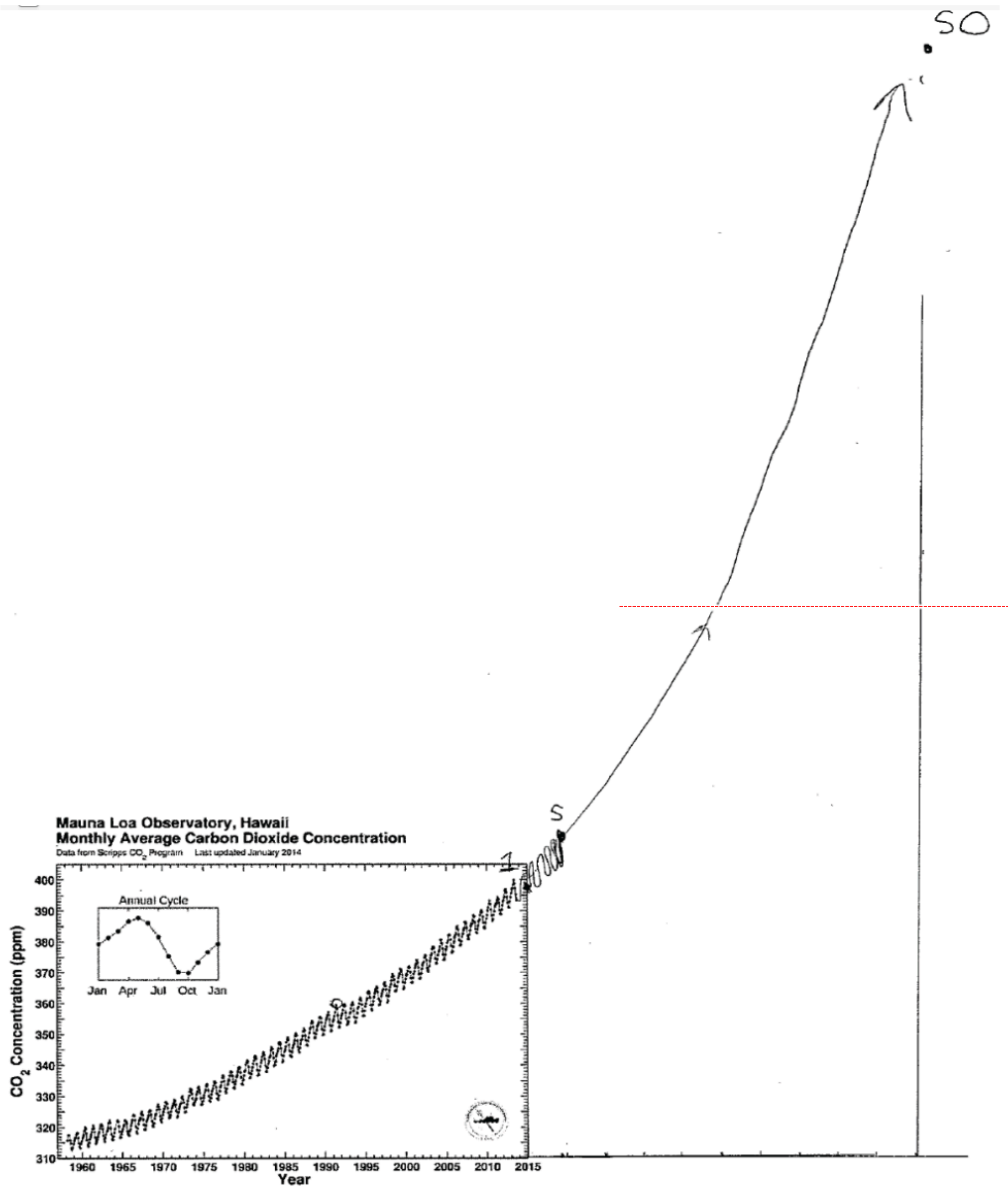
In contrast to her detailed explanations for the trend, an explanation Esmerelda provided for the random variability in the Temperature graph addressed non-specific causes:

Interviewer: **So, is that [confidence interval] range [for predictions]?**
Esmerelda: Yeah. And—(pause)—five-year. That would be like—five-year would be about the same, but just slightly higher, with the similar kind of range. And the 50-year would be even higher, but still not that much higher. (pause) Probably with the similar range. Because I'm guessing that, since the temperature's influenced by a lot of different factors, it goes up and down from year to year.

Prediction: Focus on Precision

Esmerelda's projections were precise and consistent with the time scale (and frequency, if sketched). She was the only exemplar participant who used a ruler to help sketch her projections. When faced with insufficient information (i.e., determining outcomes with multiple causes, vagaries of human activities) to sketch the projections, she used confidence intervals (mathematical strategy) to account for those uncertainties. Below, I show how these characterizations are reflected in Esmerelda's responses to the Keeling and Temperature graphs.

For the Keeling graph, Esmerelda's projections are shown in Figure 4.3:



Note: The red dotted line indicates where an additional piece of paper was attached.

Figure 4.3 Esmerelda's Keeling graph

As shown in Figure 4.5, Esmerelda constructed tick marks along the x-axis, which led to her attachment of another piece of paper (indicated by the dotted line) to place her 50-year projection; this response reflects her attention to the precision of her projections. The rationale for Esmerelda's projections was as follows:

Esmerelda: I kind of generalized it based on the, what seemed like an exponential curve. And I know exponential curves: they keep increasing faster. So, I knew the five would be a little bit higher than the one, and the fifty would be a lot higher than the five. (pause) And as far as the [part of the] year, I wasn't really sure. I'm assuming that when they—that the new—the beginning of each year's—since the beginning of the year each year's in January—and it looks like at this part of the graph, it's kind of in the middle. So, I tried to kind of start it in the middle, and end it in this one. It looks like it's kind of at the top. But—

Interviewer: But you meant for it to be in the middle.

Esmerelda: Yeah. I meant for it to be in the middle.

Esmerelda described the mathematical strategy she used to extend the trend, addressing how the rate of change in an exponential curve is constantly increasing. In contrast to Bob, she did not address the represented phenomenon as part of the rationale for her projections.

With respect to her confidence in the projections, Esmerelda identified the lack of access to data as a constraint, consistent with a response a scientist engaging in the same task might make:

Interviewer: …How certain are you that these predictions will come true?

Esmerelda: I'm not really that certain, because for one thing, I don't really have any number-based math to back it up. But also because I'm guessing that the carbon dioxide concentration, when it gets too high, it could cause other things to happen, such as, like, decreased plant growth. Or maybe people—a change in, like, the technology used could also cause a change in maybe the carbon dioxide concentration, or a change in lifestyle. And there are so many factors that'd influence it. It's likely that it's going to follow the same pattern that it has, but I can't really be sure.

In spite of this constraint, Esmerelda concluded that if the pattern in the data due to those phenomena continued, her projections would also likely continue in a similar fashion. This response reflects her use of mathematical strategies.

For the Temperature graph, Esmerelda's projections contrasted to the ones she sketched for the Keeling graph, as shown in Figure 4.4:

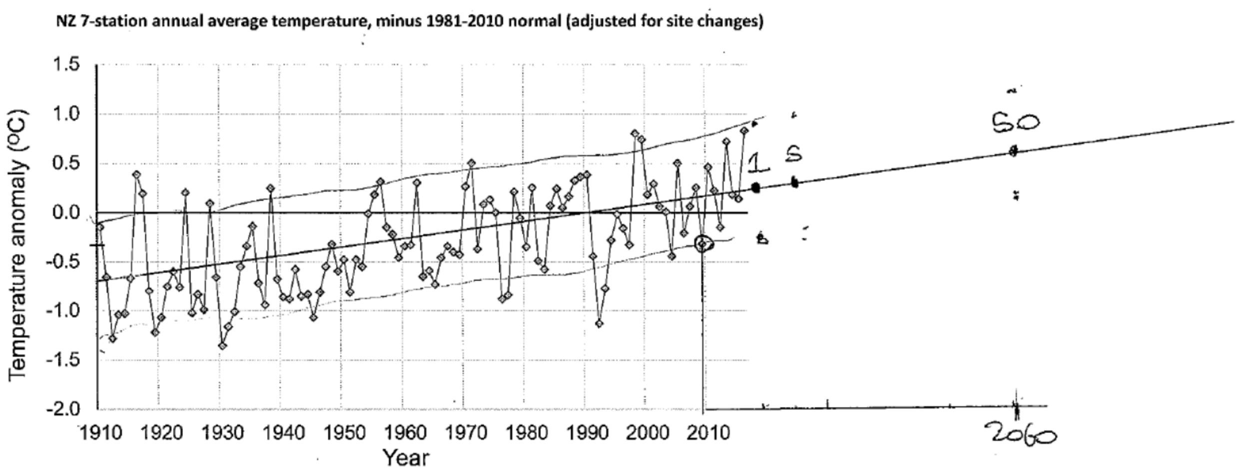


Figure 4.4 Esmerelda's Temperature graph

In this graph, Esmerelda sketched tick marks along the x-axis and used a ruler to superimpose a trendline over the displayed data. These actions reflect her attention to precision in her projections. In contrast to her projections for the Keeling graph, she sketched confidence intervals around each of her projections in this graph (indicated by the equidistant dots above and below her projections). Her rationale for the projections in this graph was:

Interviewer: …where do you think those [predictions] would fall on the graph? (pause)

Esmerelda: So, it looks like it's—has an upward slope. Kind of a shallow line.

Interviewer: Okay. (pause)

Esmerelda: Yeah. I think 2060 would be about there. And then, I'm guessing that the one-year prediction would be here. So, it would be slightly above the average. But I'm not really sure, because the points, they go above and below the average. So, I mean, it could be probably anywhere from up here to maybe down there.

Interviewer: Okay.

Esmerelda: And then—

Interviewer: So, is that range?

Esmerelda: Yeah. And—(pause)—five-year. That would be like—five-year would be about the same, but just slightly higher, with the similar kind of range. And the 50-year would be even higher, but still not that much higher. (pause) Probably with the similar range. Because I'm guessing that, since the temperature's influenced by a lot of different factors, it goes up and down from year to year.

Interviewer: Mm-hmm. Mm, can you say a little bit more about why you think the ranges—why you have the same range for each point?

Esmerelda: It's not strictly linear. It goes back and forth throughout the entire graph. So, I would assume that it would still keep going in kind of an erratic sort of—not random—path in the future. But it seems like it's generally going upward.

Aside from her brief comment that temperatures are influenced by different factors, Esmerelda did not use scientific models in her rationale for this graph; instead, she described the mathematical strategies she used (best-fit line, confidence intervals). For instance, she sketched the 50-year projection first, the 1-year projection next, and the 5-year projection last. This strategy is consistent with a focus on precision because a third point located on a line formed from two closely placed points has a greater chance of being skewed than if that line were formed by two distant points. She also indicated the pattern in the data would continue to go "in kind of an erratic sort of—not random—path in the future," which may be a reason she included confidence intervals around the projections in this graph and not in the Keeling graph.

Although Esmerelda indicated a lack of confidence in the accuracy of her projections due to the noise in the data, she explained how she could account for some of that noise in her sketch:

Interviewer: … So, how certain are you that these predictions will come true?

Esmerelda: I'm not very certain, especially since it's not tightly linear. And there's that range. It could be anywhere. It could be anywhere in there. I mean, it could be any point. But it's probably within that range. But the range is still pretty large. So, I'm not really that sure about any of them.

Interviewer: Are you more certain about, like, maybe one and five compared to fifty? Or—like, similar to the previous graph? Or are they all equally uncertain? Or is there something else?

Esmerelda: I think that the one and five are more certain, just like the previous graph. But I think they're also less certain than the previous graph, because it's not following a strict pattern. It's just generally going upward. So. I'm not really sure.

Interviewer: Mm-hmm. What about if I said, like—if I had asked you about this, the range you drew. How certain are you that they are going to fall within that range? Would it be higher or lower? The same?

Esmerelda: I think it would be higher, because it looks like most of the points, they stay within what looks like half a degree of the—I kind of—I drew the "best fit" line.

And most of the points seemed to stay about half a degree from that. So, if I make a range, that's about half a degree from the best-fit line, and that probably would mean that most of the points would fall in there as well.

Interviewer: Mm-hmm. So, you'd be more—you have a higher certainty that they'll fall within the range that will come true?

Esmerelda: Yeah.

Interviewer: That long. Okay. And then, within, like, the—you're more certain that the range will come true, like, but within the range, is the one, five, and fifty—are you more certain about one and five compared to fifty? Or are you still—are they equally high?

Esmerelda: Yeah. I still think that the one and the five are probably going to be more accurate, because it's a shorter amount of time, so less things can change between one year than fih—fifty years. Or five years.

Esmerelda's response to addressing the variation in the displayed data is similar to Bob's sketching of confidence intervals.

Generalization: Attempts at Global Connections

Across graphs, Esmerelda used scientific models to compare the outcomes of local factors to each other and to connect those outcomes to global systems in her generalizations. For instance, Esmerelda's concern regarding the generalizability of the pattern in the Keeling graph data to other locations used scientific models related to two local factors—geographical latitude and cattle farming:

Interviewer: … You mentioned the observatory, and this is in Hawai'i. Do you think that if they were to do CO_2 concentration during that same time period, but they did it in Michigan, how do you think the patterns would compare? (pause)

Esmerelda: I think, if I remember correctly, carbon dioxide tends to concentrate itself near the poles. So, I would assume that the farther north you go, the higher the general concentration would be. But I'm not really sure about that. I would also think that, maybe if you go somewhere that's a lot more industrially based, and has a lot more—or maybe has a lot more farming that releases carbon dioxide. Or has a, just a general lifestyle that results in more carbon dioxide release, then there would be a higher concentration. So, I would think that—I know that since Hawai'i has a lot of cattle farming, I would assume that in the immediate area, near that, there would be a lot of carbon dioxide. But there's some cattle farming in Michigan, too, and I know that since Michigan's farther north, that might also

	cause there to be more carbon dioxide. So, I’m not really sure, comp (ph)—if I compare the two, if it would really be that much of a difference.
Interviewer:	**Mm-hmm. So, probably like, maybe in the, relatively the same place?**
Esmerelda:	Yeah. I think so.

Esmerelda indicated the carbon dioxide concentration would be greater in Michigan due to its higher latitude, based on her earlier incorrect explanation that carbon dioxide concentrations tend to be greater at the poles. Her generalizations for the Temperature and Arctic graphs were similar to her generalizations for this graph, in that her generalizations were based on incorrect explanations (scientific model that is incorrectly paired with the description of an observed pattern in the real world). In contrast to Bob’s generalizations, Esmerelda’s generalizations only addressed the trends.

Annika as a Literal Graph Reader

Annika was a high school student who had received explicit instruction regarding the Keeling graph through her teacher's use of one of the units from the *Carbon TIME* curriculum. She treated the graphs as representations of local Earth systems data collected in specific places, often relying on information gathered from the text elements to make sense of the graphs. Her explanations of those systems were causal associations that foregrounded local factors and were dependent on the context of the graph. Her projections consistently included oscillations that were inconsistent with the displayed frequency and time scale. Most of her responses were accompanied by statements regarding a lack of confidence in her claims. Below, I show how Annika's responses reflect these descriptions of her engagement with the practices during her interview.

Interpretation and Analysis: Foregrounding of Text

When Annika talked about the graphs, she consistently foregrounded information from text elements, as in her responses regarding her initial interpretation and analysis of the Temperature graph:

Interviewer: **…All right, so taking a look at this graph, what do you think this graph is about?**
Annika: Annual average temperature. (laughs) (background noise) Yeah.
Interviewer: **Yeah?**
Annika: I mean, that's—I mean, that's what the title says. I'm just trying to make sure I can read it or something.
…
Interviewer: **…what do you think would be the most important thing to notice?**
Annika: (background noise) Well, I guess the—
Interviewer: **And it can be the same as the…**
Annika: —first thing I notice is I don't know what this word means, but I don't know if it—
Interviewer: **Oh, the anomaly?**

Annika: —has anything to do with that. I'm guessing that you should look for that stuff if you're trying to analyze the graph, yourself. But probably the title and what are the two elements that are being graphed, I guess, and then what the results are. Or, if you have to do it, then you can, kind of, get an idea from what you're supposed to be graphing.

Annika identified text elements (title and information from axis labels) as important to notice, which contrasts with Esmerelda, who addressed parts of the data analysis associated with the represented phenomenon. Many of Annika's responses are consistent with the *reading the data* level described by Curcio (1987), which involves literally reading the labels corresponding to certain graphical elements, and the *reading between the data* level also described by Curcio, which involves retrieving information from multiple elements (e.g., reading coordinates for a point). Her interpretation and analysis for the remaining two graphs were similar to her interpretation and analysis of this one.

Explanation: Causal Associations between Local Variables

Annika's explanations for the displayed patterns in the data were causal associations often addressing local variables; however, the types of causal associations she made differed by graph and according to whether she was explaining the trend or variability. Below, I share examples of her explanations for the Keeling and Arctic graphs to highlight these differences.

Annika provided different types of explanations for the periodic variability and trend in the Keeling graph. The following excerpt shows her explanation for the periodic variability:

Interviewer: … Are there other patterns that you see in this data?
Annika: I mean, it, kind of, has a little mountain-like shape, I guess. It just keeps, kind of, going up and down and up and down. I'm guessing that it's because of the seasons and stuff like that.
Interviewer: So part of – so can you say a little bit more about the seasons how it would make – cause that up-and-down pattern [periodic variability]?
Annika: Well, based on the temperature and stuff, then it would be based on the season, is the temperature that comes with the season. So I'm guessing, depending on how

cold or hot it is, the CO_2 will probably change, as well. It could be completely wrong, but…

Interviewer: But that's what you're thinking right now?

Annika: Mm-hmm.

…

Interviewer: Do you have ideas about what's causing the overall trend going up? Is that different from what's causing the squiggly up-and-downs?

Annika: Yes and no, kind of. I mean, I guess the weather does contribute to it, but, also like I said earlier, I think there are other things that are producing CO_2 that also cause, I guess, the – it to stay trapped in the heat, to keep – continue the temperature to keep going up.

When Annika said seasonal temperatures cause changes in the carbon dioxide concentration ("depending on how cold or hot it is, the CO_2 will probably change"), she identified the cause (temperature) and effect (changes in CO_2 concentrations) without specifying the nature of their relationship (i.e., *how* increasing/decreasing temperatures cause increasing/decreasing changes in CO_2 concentrations); this response is consistent with a covering law explanation (Braaten & Windschitl, 2011).

In contrast, Annika's explanation for the trend did address direction in the cause and effect relationship:

Interviewer: And then you mentioned about stuff that we do causing it [continued increase in trend]. Can you say a little bit more about what are some of those things that…?

Annika: Well, like our thermostats produce a lot of CO_2, like in our houses. And even just breathing produces CO_2. (chuckles) Think – I mean, also depending on factories, they can also use a lot of CO_2. But, yeah…

Interviewer: So you mentioned thermostats and breathing. The first two, the – do you have ideas about how the thermostat contributes to the CO_2?

Annika: Well, I'm guessing, based on – I'm not 100-percent sure but I know we talked about it a little bit, based on the air that it's producing, it can also cause CO_2, that it releases.

Interviewer: And then breathing, how does breathing contribute?

Annika: We can breathe in oxygen and breathe out carbon dioxide. (laughs)

Annika indicated that thermostats and (human) breathing produce carbon dioxide, which are causal associations that address the direction of the relationship between the causes and effect.

The causes she identified in this response were also examples of local causes, consistent with her foregrounding of local factors in her generalizations (which I address later when describing her engagement with the generalization practice).

In contrast to her explanations for the Keeling graph, Annika's explanations for the Arctic and Temperature graphs only addressed the trends and did not address (random) variability. In her explanation for the Arctic graph, she linked the trends from all three graphs:

Annika: Feel like they're [all three graphs] all related. They're looking at, well, the ice, specifically, because the higher the temperature, then there – there's going to be melting ice, which probably heightens sea levels, so they're probably looking at a bigger picture. But I feel like they're connected just 'cause they have to do with each other. (chuckles)

Interviewer: So you feel like all three graphs are connected to each other?

Annika: I mean, yeah. Maybe. I could be wrong, but it's just like they're, you know…

Interviewer: Well, when you said they're connected, what were you thinking? What was in your mind at the time?

Annika: (background noise) Well, I'm just thinking, I mean, they have to do with each other. CO_2 concentration contributes to higher temperatures, which contributes to ice melting, so, yeah, it was just a thought. Then I also get way ahead of myself, so (chuckles) that could be wrong. (chuckles)

Annika's description of the relationship between carbon dioxide and temperature is a covering law explanation (Braaten & Windschitl, 2011) because she did not address how carbon dioxide concentrations contributed to increasing temperatures. However, she did address the direction of the relationship between the temperature and area of sea ice. Overall, Annika did not use a consistent strategy in her explanations of the phenomena represented in the graphs.

Prediction: Single Strategy, Similar Rationales

Annika's projections for the three graphs consistently included oscillations that were not consistent with the displayed frequency or time scale; however, her projections did continue in the same direction as the trend for the displayed data. Annika was the only participant in my study whose horizontal distance between the 5-year and 50-year projections was closer than the horizontal distance between the 1-year and 5-year projections. Her expressed rationale for the lack of confidence in the accuracy of her projections was vagaries of human activities or noisy data. Below, I show how these characterizations are reflected in her responses to the Keeling and Temperature graphs.

For the Keeling graph, Annika's projections are shown in Figure 4.5:

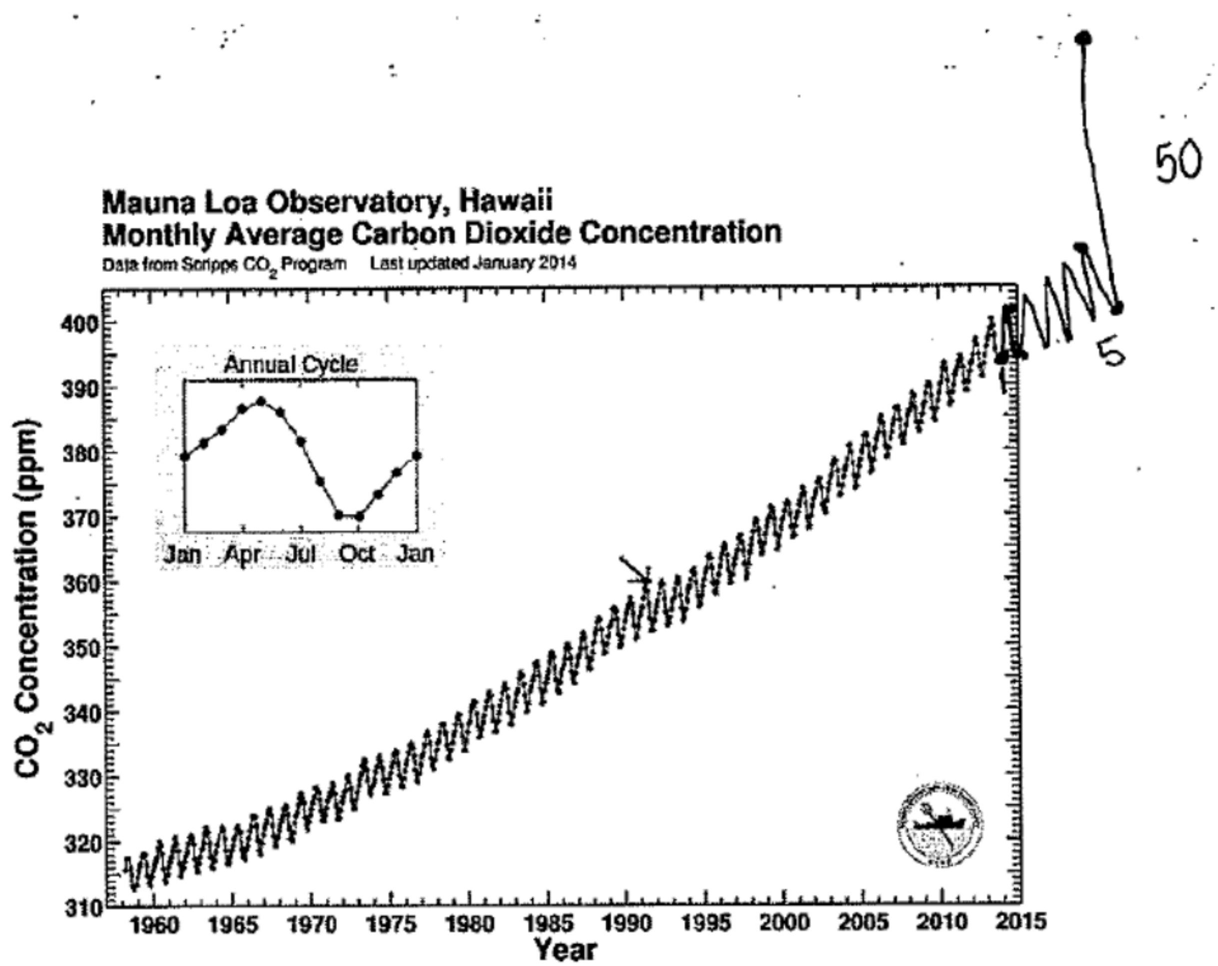


Figure 4.5 Annika's Keeling graph

Annika's projections followed the pattern in the displayed data, but her oscillations were not consistent with the displayed frequency or time scale. As stated earlier, the horizontal distance between her 5-year and 50-year projections was closer than the distance between her 1-year and 5-year projections. Her rationale for these projections was as follows:

Annika: And I feel like it was just going to keep going [up] like that, based on the pattern. So this is one. And then, five, I'm guessing - I mean, just going straight up to five?

Interviewer: Mm-hmm. Like, five years. Well, I mean, you can – like, you can do the in-between years, but where do you think the "five" would be? Like, where's it's going to…

Annika: Well, I just feel like it's going to keep going up like the pattern that it's going right now. So this is probably five years. It could be wrong; I don't know. (chuckles) And then 50 years?

Interviewer: Yeah, 50.

Annika: (laughs) I don't – I don't think I'm going to have enough room. Let me see how I'd do this. I'm just going to go pretty wild. Like, 50 years would be up here, pretty high unless we do something to change it up…

Annika indicated that she did not accurately represent the spacing between the 5-year and 50-year projections because the graph did not "have enough room." In contrast, Esmerelda attached a second piece of paper to ensure that she would have room for her 50-year projections.

With respect to her confidence in these projections, Annika responded as follows:

Interviewer: So the prediction that you made for one year, how certain are you that's probably going to happen?

Annika: I think it [1-year] already happened, so… (laughs) Like, it could be higher, but I know that it was going to keep going up because we keep using more things that have CO_2 and – or produce CO_2. And then, five years, it might be higher, but I know that it was also going to keep going up. And then, 50 years, I'm not sure. I'm – if we don't really do anything to change how much CO_2 we're producing, then it'll probably be – go up really high, but, if not, maybe not. It just hasn't happened yet, so I'm not 100-percent sure. …

Annika's note that the 1-year projection already occurred is consistent with her attention to text elements. Her 50-year projection is the first time she indicated a lack of confidence in the accuracy of her projections, which she attributed to the vagaries in human activities. Her responses regarding her confidence in these projections is consistent with her practice of *reading the data* (Curcio, 1987).

For the Temperature graph, Annika's projections were similar to the ones she sketched for the Keeling graph, as shown in Figure 4.6:

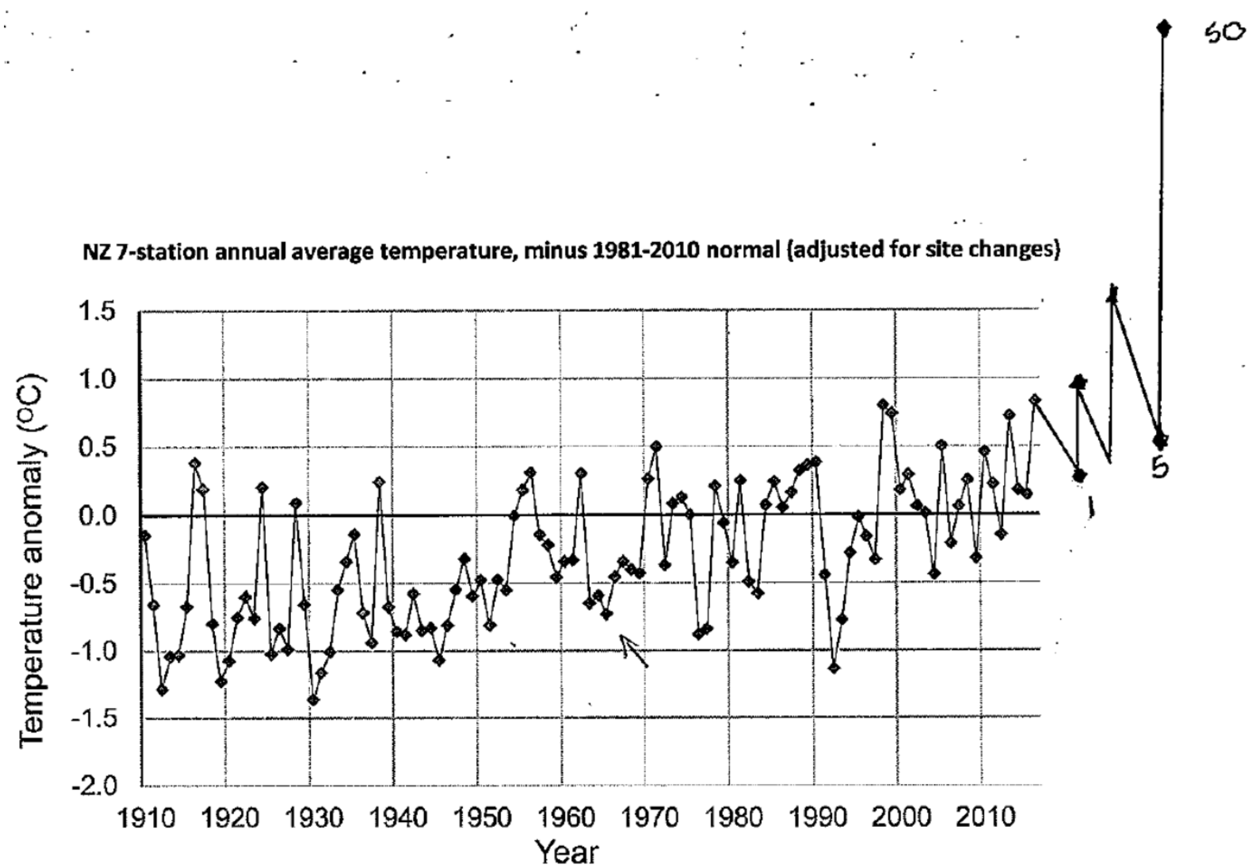


Figure 4.6 Annika's Temperature graph

Annika's projections for this graph followed the pattern in the displayed data, but the oscillations she sketched were not consistent with the displayed frequency or time scale; additionally, the horizontal distance between her 5-year and 50-year projections was closer than the horizontal distance between her 1-year and 5-year projections. Her rationale for these projections was as follows:

Interviewer: **… So can you say it – say a little bit behind your thinking about why you picked those points for one, five, and 50?**
Annika: Well, I don't really – I don't have the entire data; I just have, kind of, have what they wrote down on here. But, at the beginning, it's not very consistent, but the past few years were, kind of, based off what I'm seeing. They were, kind of – they went up. I mean, they fluctuated within that but they, kind of – the overall trend is going up, so that's, kind of, just what I tried to mimic on one five, and 50.

Annika indicated she attempted to "mimic" the pattern in the data despite acknowledging that the displayed variability was "not very consistent." Even though the Temperature graph displays random variability, whereas the Keeling graph displays periodic variability, she used a single strategy to sketch her projections. In contrast, Esmerelda and Bob used different strategies to sketch their projections depending on the graph.

With respect to Annika's confidence about her projections in the Temperature graph:

Interviewer: **…how confident are you about your prediction for that one [1-year]?**
Annika: 80 (ph) percent, maybe.
Interviewer: **80 percent?**
Annika: The other ones are four. (chuckles)
Interviewer: **So both of them would be 4 percent for the five and 4 percent for the 50?**
Annika: No, not 4 percent for 50. Two percent for 50. Right, (laughs) right.
Interviewer: **Two percent for 50? (laughs) All right, you're very unsure about that one?**
Annika: I'm not very – I don't, I don't really know 'cause, at first, it wasn't like that. I'm just thinking maybe it was a trend that it just, kind of, went up a little bit, and then it'll go back to being super-crazy.

Instead of referencing the vagaries of human activities like she did for the Keeling graph, Annika responded with percentages and commentary about how the pattern in the data was "super-crazy." Her responses to these graphs suggest she may be responding to the contrasting signal-to-noise ratios between the Keeling and Temperature graphs. The nature of her projections for both of these graphs is reflective of the intermediate level described by Covitt and Anderson (2018) in their learning progression for predictions, extending the data at varying degrees of precision in their sketches without invoking models.

Generalization: "Different Places are Different"

Annika's treatment of the three graphs as representations of local data was most reflected in her generalizations of the Temperature and Arctic graphs, and less so in her generalizations of the Keeling graph. In the following paragraphs, I present examples from all three graphs to support this argument.

In the Temperature graph, Annika emphasized the significance of local factors:

Interviewer: **…So do you think this pattern that you see here [in Temperature graph] would also be similar to in other places, kind of like what I asked earlier?**

Annika: Well, if it's specifically about temperature, probably not. Well, I don't—probab-—I'm just going to go with probably not because the temperature in different places are different; some places are going to be hotter or colder. So yeah. (chuckles)

Interviewer: **So the – so other places are going to be hotter, hotter or colder. But what about the shape of the graph? Do you think that would be similar?**

Annika: Oh, in other places? Yeah, probably, because they're also going to experience changes in the weather and stuff, so it's probably going to be a lot of movement in the graph. But I think it'll look a little different because the temperatures won't be the same. But, yeah.

Annika indicated that the displayed pattern in the data would not be generalizable for the Temperature graph even though each location would experience the same weather changes. Her foregrounding of the local factors to generalize for the Temperature graph happens to be reflective of actual real-world conditions.

Similar to the Temperature graph, Annika emphasized the significance of local factors for the Arctic graph:

Interviewer: **… if we were going to other places, say, the Ant-, Antarctica, do you think the pattern would be the same, similar, different?**

Annika: I think it would be similar but, obviously, wouldn't be the same 'cause they're not the exact same places. But I feel like, if the heat – if there's heat all around, I guess, they'll go over (ph). Don't really know what other way to say it, but then everything would be suffering; all the ice would be melting like that idea. But I feel like they would be similar 'cause they're both places with lots of ice, and they would go – be melting, is what I'm guessing.

Annika stated that because the two locations have “lots of ice,” the patterns in their data would probably be similar to each other. Although her conclusion for this graph differs from her conclusion for the Temperature graph, she still emphasized the role of local factors in her generalization of this graph.

In contrast to the Temperature and Arctic graphs, Annika’s generalization for the Keeling graph seemed to emphasize similarities across locations:

Interviewer: **…So this pattern that you see here, this is in Hawai’i. Do you think this pattern would be the same, similar, different if we were to compare it to other places like, say, Michigan or Texas, or Maine?**

Annika: Well, the weather’s a little bit different in the different places, but I feel like the overall trend would be the same, like it would still fluctuate with the weather. Maybe the numbers aren’t exact, but we’re all experiencing—if it was—I’m—I guess I’m biased or something towards global warming, but if it was for the same reason for everybody, then I feel like the trend would, kind of, still be the same. It’d be like a pattern.

Interviewer: **(background noise) So you keep saying “biased towards global warming.” What makes you think you’re biased towards global warming?**

Annika: I don’t know. ‘Cause we’re learning about it in class, and this is really similar to what we’re learning in class. (laughs)

Annika’s first statement was that “weather’s a little bit different in the different places” is a statement about a local factor. Although she indicated the trend in the Keeling graph would be similar for data collected in another location due to global warming, which is the “same for everybody,” this response seemed to be informed her self-acknowledged “bias” towards global warming that she learned in class.

Susan as a Storyteller of the World

Susan, who was in the same class as Annika, was a high school student who had also received explicit instruction regarding the Keeling graph through her teacher's use of one of the units from the *Carbon TIME* curriculum. Susan treated the three graphs as records of human activities, which she frequently used to explain the represented phenomena. Her projections consistently included oscillations that were inconsistent with the displayed frequency and time scale. Consistent with her explanation and projections, she did not explicitly address trend or variability when talking about the relationship between the graph and the world. Below, I show how Susan's responses reflect these descriptions of her engagement with the practices.

Interpretation and Analysis: No Reference to Trend or Variability

Susan generally provided force-dynamic explanations (Pinker, 2007; Talmy, 1988) that did not distinguish between patterns in data and explanations, or between trend and variability. She was the only participant in my study to not explicitly address trends and variabilities, even though she indicated that the patterns formed by the points were the most important features to notice in the Keeling and Temperature graphs. For instance, the excerpt below is an example of her response regarding the Keeling graph:

Interviewer: **…looking at this [Keeling] graph, what do you think are the most important features that people should notice about it?**

Susan: I think they should notice how it is increasing throughout the years but at the same rate within because it seems like they're figuring out slowly. But they're using the same technique.

Interviewer: **Mm-hm. Can you say a little bit more about like the increasing between the years?**

Susan: So it looks like it's increasing just a little, seeing as it looks like a straight line with both of them. But it's still going up in a way.

Susan identified the organization of the points as important to notice without referring to the trend or variability, even though the Keeling graph displayed a clear trend and periodic variability. For the Temperature graph, which was noisier than the Keeling graph, Susan used similar language to talk about the pattern in the displayed data:

Interviewer: … What do you think that point tells you?
Susan: There are kind of…like over here [points on the left side of graph], there are a lot that are equal to that point. But over here [points on the right side of graph], not so much. So maybe you could say there was a change here [point selected by interviewer] because over here [points to left of graph], these are all low, and up here [points on the right side of graph], it's really high.
Interviewer: And on the right, they're high.
Susan: Yeah. So maybe that could like mark a change.

Susan said because the points on the right side of the graph were not in the same place as the points surrounding the selected point, a change must have occurred. She described the location of an element with respect to the other elements without referring to the trend or variability, which was consistent throughout her responses for the remaining practices and/or graphs.

Explanation: Actions Done by People

Susan consistently attributed patterns in the data to stories she told of activities done by people, which is best exemplified in her explanations of the graphs. Below is an excerpt from her explanation of the pattern in the displayed data for the Keeling graph:

Interviewer: … So the in-betweens that you were talking about and how it increases, can you say a little bit about like what you think might be causing it?
Susan: Since CO_2 is gas, right, maybe there're more cars or something going around or like more traffic because I guess during certain months, it could go up. Like if there're seasonal things like sports, people have to use more CO_2 and stuff. But the decreases could be when it's kind of just more…I guess not so much going around. So like maybe it's a season change amongst cars or something.
Interviewer: Mm-hm. When you mentioned sports people use CO_2 more, like can you say a little bit more about like what you mean by that?
Susan: Oh, I guess there's more buses and like people changing and like going around from place to place since there are a lot of competitions.
Interviewer: Mm-hm. Okay. Cool. And then you also mentioned something about seasons. I was wondering if you could say a little bit more about that?

Susan: Yeah, like each season… like there're certain things for the season, that season. Like one day, there's football for this one. And then the other one, like it's winter. And maybe not a lot of people are into winter stuff, so they just stay home. And those would be the decreases. But summer, everyone goes out.

Susan indicated that the cause of the pattern was the seasonal use of cars during sports seasons, which portrays human activities as the agentic factor causing the pattern, consistent with force-dynamic reasoning (Pinker, 2007; Talmy, 1988). For the remaining two graphs, she also used force-dynamic reasoning to explain the causes of those phenomena. Susan's explanations for the displayed pattern in the data focused on the variability, suggesting she may not be familiar with the represented phenomenon; her response is consistent with the findings by Shah and colleagues (Shah, 2002; Shah & Hoeffner, 2002). In contrast, the other exemplar participants explained the causes of the represented phenomena by using covering law (Annika), scientific models and principles (Esmerelda and Bob), and evidence-based reasoning (Bob).

Prediction: Single Strategy, Contrasting Rationales

Susan's projections included oscillations that were inconsistent with the displayed frequency and time scale. For her 1-year and 5-year projections, she generally continued the pattern in the displayed data, with the rationale that people would continue to act in a similar manner during this time period. For her 50-year projections, she generally departed from the pattern, explaining that people would likely change their activities. Below, I show how these characterizations are reflected in her responses to the Keeling and Arctic graphs.

For the Keeling graph, Susan's projections are show below in Figure 4.7:

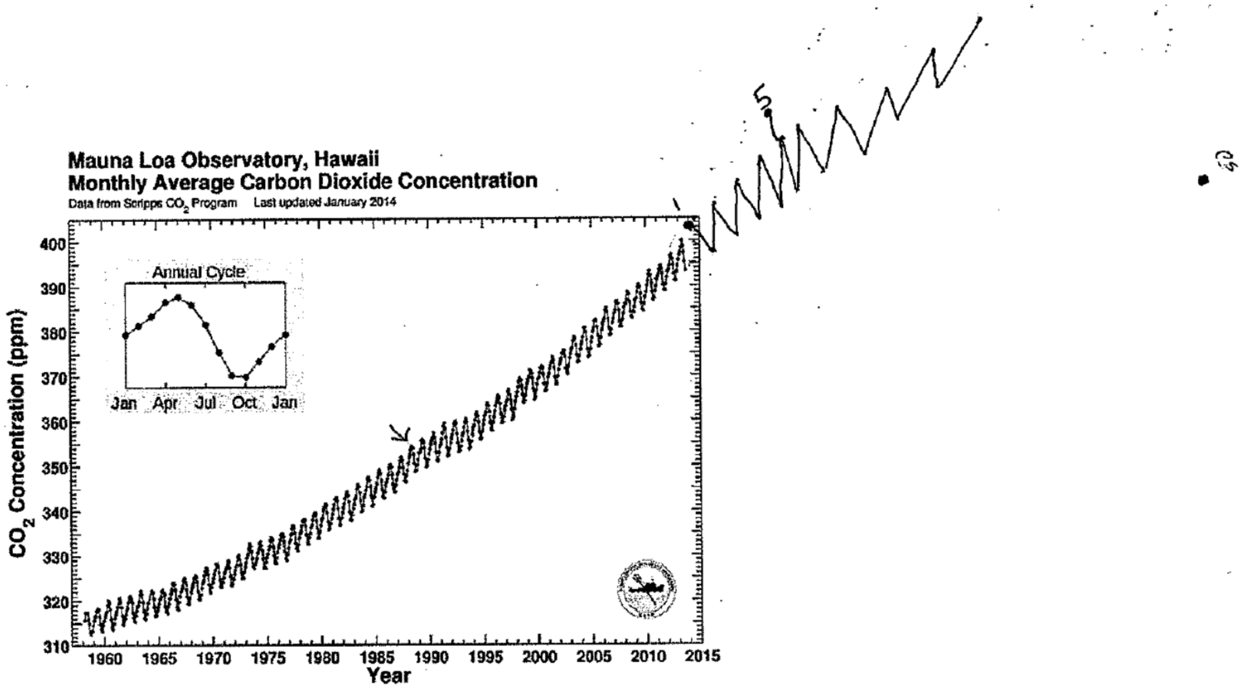


Figure 4.7 Susan's Keeling graph

Susan's 1-year and 5-year predictions followed the pattern in the displayed data, while her 50-year prediction deviated from that pattern; additionally, her oscillations were inconsistent with the displayed frequency and time scale. Her rationale for these projections was as follows:

Susan: Okay. I think it [1-year/5-year projections] would kind of like…it would stay the same. But I feel like nowadays, it might be like going higher. So kind of not shoot up exactly but like increase more so. So the line wouldn't be exactly like that which is soon.

Interviewer: Well, go ahead and sketch it…if you want to use a ruler, feel free.

Susan: Maybe like that. And then here're the bottom lines. (pause). So I think we have more like technology and things using CO_2 nowadays. So it would kind of boost a lot.

…

Interviewer: All right. And then where do you think 50 would be?

Susan: I think it would still like increase, but somewhere, I feel like there would be a dramatic drop maybe.

Interviewer: A dramatic drop?

Susan: Yeah.

Interviewer: What makes you think there would be a dramatic drop?

Susan: I feel like usually we have like a downfall. So kind of like things were going well, and then the (Great) Depression came. And then after that time, it started increasing slowly again. So I think somewhere, we're bound to have like a little drop coming soon.

Similar to her explanations, Susan attributed the projections of this graph to human activities (e.g., "technology and things using CO_2 nowadays," "then the [Great] Depression came"). With respect to her confidence for these projections, her response was as follows:

Interviewer: **…how sure are you of the first one, like Year 1, that that's where the data point would be?**
Susan: It just seems like maybe that's an easy guess because if you're starting here, then you could see it's just going up little by little. So it would soon go up there. Like maybe not that high, but somewhere around there.
Interviewer: **But you're pretty sure like, yeah, it's going to follow the pattern?**
Susan: Yeah. I feel like –
Interviewer: **Okay. And how sure are you about like Year 5?**
Susan: I think the lines would be smaller and like shorter but still maybe around right there.
Interviewer: **Okay. So relatively. And then like for 50?**
Susan: I do feel like it's not going to be that high. It's going to drop a little. But not like dramatically. Just through the years. But then I feel like it would start going back up.
Interviewer: **Mm-hm. Okay. And it would go back up because…?**
Susan: People would start figuring out ways and like working together to figure out what they can do to bring it all back up.

Susan expressed confidence for her 1-year projection but repeated her rationale for her 5-year and 50-year projections without explicitly addressing her confidence about them. Similar to her rationale for the 50-year projection in the Keeling graph, her rationale for the 50-year projection in this graph ("People would start figuring out ways and like working together to figure out what they can do to bring it all back up") suggests people are agents of change for the future; this response is consistent with her treatment of graphs as records of human activities.

For the Arctic graph, Susan's projections were similar to the ones she sketched in the Keeling graph, as shown in Figure 4.8:

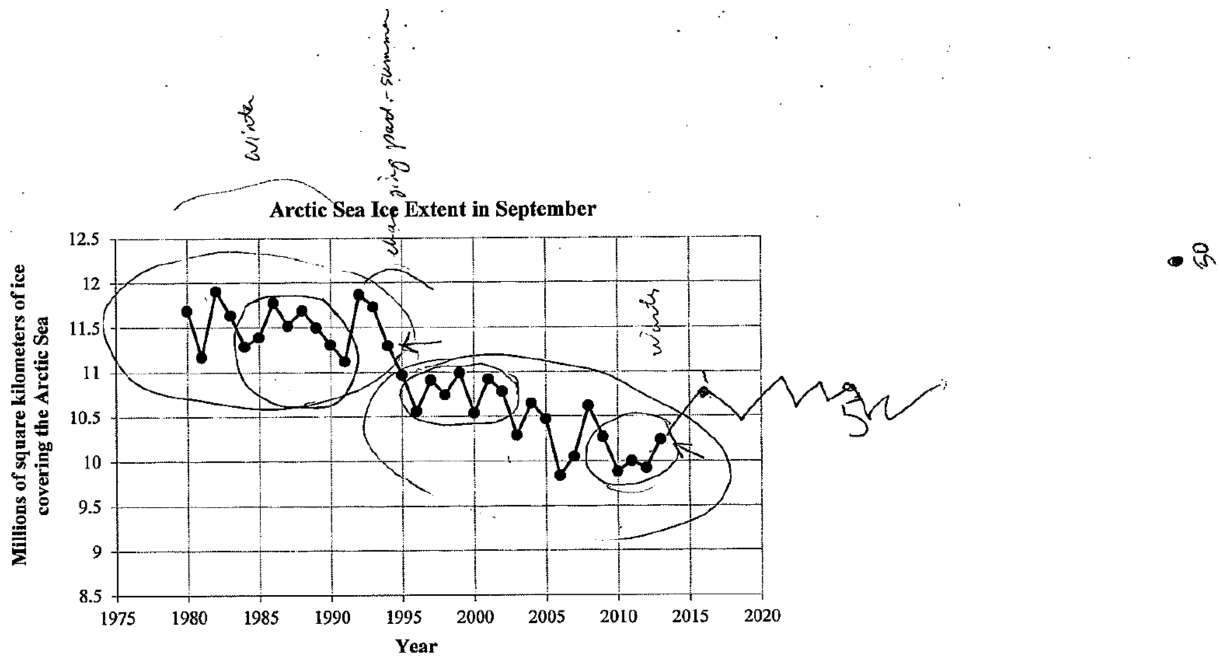


Figure 4.8 Susan's Arctic graph

Susan's 1-year and 5-year projections had about the same y-axis values while her 50-year projection was higher. She used a different rationale for her predictions in the Arctic graph than the human activities that she identified as her rationale for predictions in the Keeling graph:

Interviewer: **…if you had to make predictions for 1 year, 5 years, 50 years, where do you think they would be?**

Susan: It seems like they're more so shaped in W's than M's. So I want to say it's going to go up a little bit. So that would be one year. And then five years, it would be another. So this would be an M. And then, W. So it would kind of be like this part of the W which they seem to be kind of equal if you look over here in the same general groups. So this, again, would probably be another circle, I think.

Interviewer: **Yeah, go ahead. And if you want to draw a circle like… or you can dotted-line it if you're just sort of like – (pause)**

Susan: So this would be a W because here's your M, somehow. That would be right here.

Interviewer: **Okay. Cool. And then 50 years?**

Susan: I think in 50 years, there will be more dots in one group. They're like more little W's and M's, I guess I can call them.

Interviewer: **Mm-hm. What do you think it would be like on the graph?**

Susan: Well, right here, it seems like it's going down. So I'm not exactly sure if these are correct because maybe it could be like an up and then down and then back, like on repeat. So I'm going to guess it would be maybe like a middle medium. So kind of along with those, but not–

Interviewer: **Okay. So the 50… like this point that you have for 50, is it like higher or about the same height as that first group?**
Susan: I would say it's about the same height but not too much higher. But not too much lower. So somewhere around that general area.
Interviewer: **And then you're making that prediction based on like…?**
Susan: I'm just guessing, really, because I'm not exactly sure like what's the pattern.

Susan used the shapes of letters she observed ("W" and "M") to locate her predictions; she was the only participant whose rationale for any graph was based on letter shapes. With respect to her confidence in these projections, her response was:

Interviewer: **…How confident do you feel about these predictions?**
Susan: With the one [1-year prediction], I kind of feel like I think it's going to go higher after a while. So it's just going to be this on repeat. So I think I am positive with this one. And then this one [5-year prediction] would be maybe like not full positivity about it, but I still think it's kind of similar rate. This one [50-year prediction], I have no clue. (laughter)

Susan expressed confidence for her 1-year and 5-year projections and indicated she guessed for her 50-year projection, similar to her levels of certainty for the Keeling graph. Her projections from both graphs are reflective of the lower anchor described by Covitt and Anderson (2018) in their learning progression for predictions (identification of inappropriate trends, does not perceive uncertainty, qualitative sketches that did not attend to a model).

Generalization: Lack of References to Location

Although Susan was not asked to generalize the graphs to other locations during the interview, she also did not mention the location of the data collection in any of her responses for the Keeling and Temperature graphs. Instead, she typically referred to human activities that were not dependent on location. The Arctic graph was the only time she mentioned location (she said "Arctic Sea"), but they were in reference to the graph itself and not its represented phenomenon.

Summary of the Narratives

This section compares the narratives of the four exemplar participants (Bob, Esmerelda, Annika, and Susan) with respect to their graphical sense-making of the Keeling, Temperature, and Arctic graphs, as shown in Table 4.1. Each student's narrative is summarized after the table.

Table 4.1 Summary of exemplar participants' engagement in graphical sense-making

crosscutting strategies	
Bob	▪ Treated the graphs as social artifacts of global Earth systems. ▪ Speculated about purposes for selecting/representing data; made connections across systems and scales. ▪ Used multiple strategies to minimize inaccuracies when making claims.
Esmerelda	▪ Treated the graphs as social artifacts of local Earth systems. ▪ Systematically analyzed graphs, addressing data collection and analysis. ▪ Had a strategy to address constraints (outcomes involving multiple causes or locations) in making accurate claims.
Annika	▪ Treated the graphs as representations of local Earth systems. ▪ Primarily cited information from text elements and made causal associations. ▪ Attributed lack of confidence in accuracy of claims to vagaries of human activities or noisy data.
Susan	▪ Treated the graphs as records of human activities. ▪ Talked about the graphs without addressing trend or variability. ▪ Did not express a lack of confidence with respect to accuracy of claims.
interpret and analyze	
Bob	▪ Indicated the graphs represent data selected by research groups to communicate certain messages about changes in Earth systems. ▪ Speculated about purposes for data selection and/or representation, consistent with reading beyond the data (Curcio, 1987).
Esmerelda	▪ Indicated the graphs represent local data that show changes in Earth systems. ▪ Described data collection and analysis activities associated with graphical elements, consistent with reading beyond the data (Curcio, 1987).
Annika	▪ Indicated the graphs represent local data collected in particular places. ▪ Foregrounded information from text elements, consistent with reading the data (Curcio, 1987).
Susan	▪ Indicated the graphs represent human activities. ▪ Talked about the graphs without addressing trend or variability.

Table 4.1 (cont'd)

explain	
Bob	▪ Used evidence-based reasoning (Brown et al., 2010) to suggest explanations for trends and periodic variability, using scientific models and principles. ▪ Attributed random variability to statistical noise.
Esmerelda	▪ Used scientific models and principles to explain trends and periodic variability. ▪ Attributed random variability in Temperature graph to multiple causes.
Annika	▪ Made causal associations to explain trends and periodic variability. ▪ Did not explain random variability.
Susan	▪ Explained patterns in data by describing human activities, consistent with force-dynamic reasoning (Pinker, 2007; Talmy, 1988).
predict	
Bob	▪ Used different strategies to sketch projections, based on variability. ▪ Used multiple strategies for projections; consistent with displayed time scales. ▪ Identified systemic randomness and lack of information as constraints for sketching accurate projections. ▪ Accounted for constraints by sketching increasing confidence intervals.
Esmerelda	▪ Used different strategies to sketch projections, based on variability. ▪ Projections precisely consistent with displayed frequencies and time scales. ▪ Identified lack of information as constraint for sketching accurate projections. ▪ Accounted for constraints in Temperature and Arctic graphs by sketching confidence intervals.
Annika	▪ Used single strategy to sketch projections, often using similar rationales. ▪ Projections inconsistent with displayed frequencies and time scales. ▪ Indicated that accuracy of projections was constrained by vagaries of human activities (Keeling graph) and noisy data (Temperature and Arctic graphs).
Susan	▪ Used single strategy to sketch projections but used different rationales. ▪ Projections inconsistent with displayed frequencies and time scales. ▪ Suggested human activities would counter current trends in Keeling graph. ▪ Did not mention uncertainties from limited data or variability in Earth systems.
generalize	
Bob	▪ Used scientific models and principles to address how local data were reflective of global systems. ▪ Explicitly addressed extent of generalizability for trends and variabilities.
Esmerelda	▪ Connected local factors to global systems with scientific models and principles that were used inappropriately. ▪ Concluded trends were generalizable despite uncertain outcomes from multiple causes.
Annika	▪ Foregrounded the influence of local factors. ▪ Concluded generalizability of trends depended on represented phenomenon.
Susan	▪ Did not mention, or peripherally addressed, location of the data collection.

Bob approached the graphs as a competent scientist. He indicated that graphs are representations of data selected by research groups to make certain points about patterns of change in Earth systems. Similar to most scientists, Bob strongly relied on evidence (or its lack thereof) presented before him when making claims about the graphs. He had the broadest arsenal of strategies to draw from when making sense of the graphs, as indicated by his triangulation of perspectives when explaining the represented phenomena, making predictions, or generalizing the graphs. These resources may partly account for Bob's confidence in his claims.

Esmerelda approached the graphs as a capable citizen. She indicated the graphs were representations of local data showing patterns of change in Earth systems, systematically mapping graphical elements to the world. Statements describing how scientists collected or analyzed the data accompanied most of her responses. When relevant, she used (sometimes inappropriate) scientific models or principles in her explanations of the patterns in the data. Her projections were precisely sketched, reflective of a small arsenal of strategies she used when confronted with a lack of evidence or ambiguities in the graphs. Although she foregrounded the role of scientific models and principles when generalizing graphs to other locations, the models she used were not consistent with the contexts.

Annika approached the graphs as a literal graph reader. Her responses, which heavily foregrounded information from text elements, indicated that graphs were representations of local Earth systems that could be explained through causal associations, such as the covering law explanations (Braaten & Windschitl, 2011). Her responses were almost always accompanied by disclaimers as to their accuracy, especially when making projections. She foregrounded the role of local factors when generalizing the graphs to other locations.

Susan approached the graphs as a storyteller of the world. She indicated the graphs were representations of human activities, which she explained through force-dynamic reasoning (Pinker, 2007; Talmy, 1988) without addressing trend or variability. Her sketched projections were consistent across graphs but were based on contrasting rationales. She generally did not express a lack confidence with respect to the accuracy of claims made about the graphs, which did not address the trends or variabilities.

General Framework for Graphical Sense-Making

The general framework, shown in Table 4.2, summarizes my characterizations of the responses from all the participants. As noted earlier, the exemplar participants' names (Bob, Esmerelda, Annika, Susan) from Table 4.1 were replaced with general descriptors representing different levels of sophistication (analytic+, analytic, literal, figurative).

Table 4.2 General framework of approaches for the graphical sense-making of the Keeling, Temperature, and/or Arctic graphs

crosscutting strategies	
analytic+	▪ Treated graph as a socially constructed representation of global Earth systems. ▪ Used relations between systems and scales to make connections between local and global systems.
analytic	▪ Treated graph as a socially constructed representation of local Earth systems. ▪ Used sophisticated strategies to analyze nature and limits of random variation.
literal	▪ Treated graph as a representation of local Earth systems. ▪ Relied on the elements explicitly displayed in the graphs, which emphasize local Earth systems, to make sense of them.
figurative	▪ Treated graph as a general record of human analyze. ▪ Compared patterns in data to commonplace analyze.

Table 4.2 (cont'd)

interpret and analyze	
analytic+	Speculated about graph construction decisions with respect to data selection and/or representation.
analytic	Systematically analyzed graphical elements; may have associated mappings with data analysis.
literal	Constructed mappings that primarily referred to information from text elements.
figurative	Associated graph with human activities; did not address trend or variability.
explain	
analytic+	Used scientific models and principles to explain trend and periodic variability; linked random variability with systemic randomness.
analytic	Used scientific models and principles, sometimes with mistakes, to explain trend; may have identified causes for, or not have explained the variability.
literal	Used causal associations to explain trend; may have identified causes for, or not have explained the variability.
figurative	Attributed patterns in data to human activities or may indicate they have no explanation for the patterns in the data.
predict	
analytic+	Used different strategies across graphs, along with confidence intervals, to sketch projections consistent with time scale and displayed variability.
analytic	Used different strategies across graphs to sketch projections consistent with time scale and displayed variability.
literal	Used different strategies across graphs to sketch projections inconsistent with time scale and/or displayed variability.
figurative	Used one strategy across graphs to sketch projections that may be inconsistent with time scale and displayed variability.
generalize	
analytic+	Considered local vs. local and local vs. global factors to determine the generalizability of trend; addressed generalizability of variability.
analytic	Compared local factors, and mentioned global factors, to determine generalizability of trend (and possibly variability).
literal	Compared local factors to determine the generalizability of trend without mentioning global factors.
figurative	Mentioned local/global factors and/or location of data collection for the graph peripherally, or not at all.

Descriptions of Changes in the Crosscutting Strategies and Individual Practices

The general framework shows how my characterizations of the participants' use of the crosscutting strategies and individual practices increased in sophistication with respect to the approaches they used. The crosscutting strategies partly addressed the intended audience (treatment of the graphs) and purposes (main uses of the graphs) of the graphs. Interpretation and analysis addressed how graphical elements were mapped onto aspects of the real world. Explanations focused on the type of stories told to explain the causes of the represented phenomena. Predictions addressed the nature of the forecasted data points, focusing on the number and types of strategies used when sketching projections for graphs with high and low signal-to-noise ratios. Generalizations focused on determining the representativeness of the local systems represented in the graphs with respect to other local and/or global systems. These sets of crosscutting strategies and individual practices characterize the level of sophistication with respect to the approaches that participants used to make sense of the graphs presented to them.

Characterizations of the Approaches

The approaches described in the general framework address how all the participants in my study engaged in graphical sense-making, which are the answers to my research questions. In this section, I describe the nature of each set of crosscutting strategies and individual practices that characterize an approach to graphical sense-making and the relevance of that approach to making informed decisions with respect to the three graphs used in this study.

With an analytic+ approach, graphs are treated as representations of data that may be used to persuade people in taking particular actions. Questions regarding the source of data represented in the graph, in addition to the intents and purposes of the graph creators, may arise.

Key scientific models and principles are used to explain the represented phenomena. Additionally, relatively sophisticated mathematical strategies are used to analyze the nature and limits of random variation. Connections made between systems and scales produce reasonably accurate predictions and generalizations from information displayed in the graphs. Using an analytic+ approach to graphical sense-making suggests people are likely to understand the social and long-term consequences of decisions related to climate change.

With an analytic approach, graphs are treated as representations of data that reflect the data collection methods and analyses used by the scientists who constructed them without questions arising about their sources of data or intended use(s). While scientific models and principles are used to explain the represented phenomena, they are sometimes applied incorrectly. Mathematical strategies are primarily used to account for random variation. Although attempts to make connections across systems and scales may produce slightly inaccurate explanations of predictions and generalizations, using an analytic approach to graphical sense-making suggests people would still understand the social and long-term consequences of decisions related to climate change.

With a literal approach, graphs are treated as representations of local data. Scientific models and principles are not used, so the explanations of the represented phenomena involve associating causes with effects without explaining the associations. Because simple mathematical strategies that do not address the nature and limits of random variation are used, predictions may be partially accurate. Since scientific models or principles are needed to make connections between local and global systems, a literal approach to generalizations compares outcomes from common local factors without addressing global systems. Using a literal approach to graphical sense-making suggests people may not fully understand the long-term consequences of decisions related to climate change, which impact people beyond the local systems.

With a figurative approach, graphs are treated as records of human activities rather than representations of data. Explanations of the represented phenomena do not use scientific models or principles and often do not explicitly address the trend or variability. Although simple mathematical strategies are used to make predictions, the sketched projections are primarily determined by the stories of human activities. Since scientific models or principles are not used, a figurative approach to generalizations does not explicitly address global systems. While local factors may be addressed without centering on the activities of individual people, a figurative approach to graphical sense-making suggests people would not fully understand the long-term consequences of decisions they make with respect to climate change.

Characterizations of All Participants

I found that most participants used different approaches across practices and graphs with few exceptions, as shown in Table 4.3. Most of the participants also used a literal approach for the crosscutting strategies and individual practices—except for explanation, and more participants used a figurative approach for prediction than any other practice, as shown in Table 4.4. Both tables represent the same information but focus on different aspects of the participants' engagement with graphical sense-making.

Table 4.3 Characterizations of all participants' practices

	crosscutting strategies	interpret and analyze	explain	predict	generalize
Ally	literal	literal	literal	figurative	literal
Anne	literal	literal	literal	literal	literal
Annika	literal	literal	literal	figurative	literal
Bob	analytic+	analytic+	analytic+	analytic+	analytic+
Courtney	literal	literal	literal	literal	analytic
Erica	literal	analytic	analytic	literal	literal (KT) analytic (A)
Esmerelda	analytic	analytic	analytic	analytic+	analytic
Everest	literal	analytic	analytic (K) literal (TA)	literal	literal
Greg	literal	literal (KA) figurative (T)	literal	literal	literal (KT)
Macy	literal	analytic (K)	analytic (K) literal (TA)	figurative	analytic
Mindy	literal	literal (TA)	analytic (K) literal (T)	literal	analytic (K) literal (T)
Nick	literal	literal	analytic (K) literal (T)	figurative	literal (K)
Ozzy	literal	literal	literal	literal	literal (K)
Shane	literal	analytic	analytic	literal	analytic
Sherry	literal	literal	literal	figurative	literal
Susan	figurative	figurative	figurative	figurative	figurative
Tara	literal	analytic	analytic	literal	literal
Walter	analytic	analytic	analytic	analytic	analytic
not available	—	—	Everest (A)	—	Greg (A) *Nick* (T) *Ozzy* (T)

Note: If different approaches were used across graphs, the graph was indicated (K=Keeling, T=Temperature, and A=Arctic). If only two graphs were addressed, students' names were italicized; else, they addressed three graphs. Students who did not address a given practice for a graph were listed in the last row.

Table 4.4 Characterizations of all participants' responses

	APPROACHES to GRAPHS	
	participants	**approach**
crosscutting strategies	**Bob**	analytic+
	Esmerelda, *Walter*	analytic
	Ally, Anne, **Annika,** Courtney, Erica, Everest, Greg, Macy, *Mindy, Nick, Ozzy,* Shane, *Sherry, Tara*	literal
	Susan	figurative
interpret and analyze	**Bob**	analytic+
	Erica, **Esmerelda**, Everest, Macy (K), Shane, *Tara*, *Walter*	analytic
	Ally, Anne, **Annika,** Courtney, Greg (KA), Macy (TA), *Mindy*, *Ozzy*, *Nick*, *Sherry*	literal
	Susan, Greg (T)	figurative
explain **not available:** Everest – A	**Bob**	analytic+
	Erica, **Esmerelda**, Everest (K), Macy (K), *Mindy* (K), *Nick* (K), Shane, *Tara*, *Walter*	analytic
	Ally, Anne, **Annika**, Courtney, Everest (TA), Greg, Macy (TA), *Mindy* (T), *Nick* (T), *Ozzy*, *Sherry*	literal
	Susan	figurative
predict	**Bob**, **Esmerelda**	analytic+
	Walter	analytic
	Anne, Courtney, Erica, Everest, Greg, *Mindy*, *Ozzy*, Shane, *Tara*	literal
	Annika, *Ally*, Macy, *Nick*, *Sherry*, **Susan**	figurative
generalize **not available:** Greg – A *Nick – T* *Ozzy – T*	**Bob**	analytic+
	Courtney, Erica (A), **Esmerelda**, Macy, *Mindy* (K), Shane, *Walter*	analytic
	Ally, Anne, **Annika**, Erica (KT), Everest, Greg (KT), *Nick* (K), *Mindy* (T), *Ozzy* (K), *Sherry*, *Tara*	literal
	Susan	figurative

Note: If different approaches were used across graphs, the graph was indicated (K=Keeling, T=Temperature, and A=Arctic). If only two graphs were addressed, students' names were italicized; else, they addressed three graphs. Exemplar participants' names were in bold. If a practice for a graph was not addressed, it was indicated in the first column.

Two questions that arose from the findings in Table 4.3 and Table 4.4 were whether the participants would use a single approach: (1) across practices within a graph, and (2) for the same practice across graphs. In the following sections, I respond to these two questions.

Across Practices

The participants varied with respect to the approaches they used across the crosscutting strategies and individual practices, as shown in Tables 4.3 and 4.4. Five participants were relatively consistent in using the same approach across practices for the graphs presented to them during their interviews: Susan (figurative), Anne (literal), Ozzy[1] (literal), Walter (analytic), and Bob (analytic+). Of the remaining thirteen students, four used a mix of figurative and literal approaches (Ally, Annika, Greg, Sherry), six of used a mix of literal and analytic approaches (Courtney, Erica, Everest, Mindy, Shane, Tara), one used analytic and analytic+ approaches (Esmerelda), and the two remaining students used three different approaches (Macy, Nick). None of the students used all four approaches. In the following sections, I talk about patterns observed within the students who took two or three approaches across the crosscutting strategies and individual practices.

Two Approaches. Eleven participants used two adjacent approaches (e.g., literal and analytic) across the crosscutting strategies and individual practices (Ally, Annika, Courtney, Erica, Esmerelda, Everest, Greg, Mindy, Shane, Sherry, Tara). These students either used the same approach for each of the individual practices with the exception of one practice or used two approaches for more than one of the individual practices.

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[1] Ozzy did not address the generalize practice for the Temperature graph.

Six participants (Ally, Annika, Courtney, Esmerelda, Greg, Sherry) used the same approach across practices with the exception of one practice. For Ally, Annika, Esmerelda, and Sherry, the practice with a different approach was prediction; for Courtney, it was the generalize practice while for Greg, it was the interpret and analyze practice (only for the Temperature graph). For five of these students, the practice that differed related to the Temperature and/or Arctic graphs, whether it was in regards to making predictions (Ally, Annika, Esmerelda, Sherry) or interpretation and analysis (Greg). The common theme across the differing practice relates to the students' responses to random variation. For Ally, Annika, Greg, and Sherry, the differing approach was less sophisticated than their approach to the remaining practices, while for Courtney and Esmerelda, the differing approach was more sophisticated.

The remaining five participants (Erica, Everest, Mindy, Shane, Tara) used two approaches for more than one practice. They each used a combination of literal and analytic approaches. Each student was characterized as taking a literal approach to making predictions and for their crosscutting strategies. Their approaches to prediction were the least sophisticated, or one of their least sophisticated approaches, compared to their approaches to the remaining practices.

Three Approaches. Two participants used three approaches in their graphical sense-making (Macy, Nick) of the graphs presented to them during the interview. For both students, prediction was the only practice for which they took a figurative approach. Consistent with most of the students who took two approaches across practices, these students' approach to prediction was their least sophisticated approach, or one of their least sophisticated approaches, as compared to the approach(es) they took for the remaining practices.

Of the participants who used two or three approaches, the least sophisticated approach, or one of their least sophisticated approaches, related to graphs displaying random variation. This pattern in their performances suggests that uncertainty due to random variation is influential with respect to students' overall approach(es) to graphical sense-making.

Across Graphs

My participants generally used the same approach with respect to an individual practice across the graphs with few exceptions, as shown in Tables 4.3 and 4.4. Of the eighteen participants, six used different approaches across graphs (Erica, Everest, Greg, Macy, Mindy, Nick). For four of these students, the multiple approaches for a practice across graphs happened with the explain practice (Everest, Macy, Mindy, Nick). For Greg, it was the interpret and analyze practice; for Erica and Mindy, it was the generalize practice. Mindy was the only student who used different approaches across graphs for more than one practice (explain and generalize).

The use of multiple approaches by these students (Everest, Macy, Mindy, Nick) for the explanation practice across the graphs suggests that graph content may affect their approach; this finding is reasonable because explanations of phenomena are necessarily content dependent. Additionally, their explanations of the Keeling graph were consistently more sophisticated than their explanations of the Temperature and/or Arctic graphs, which builds on the earlier observation that participants tended to produce less sophisticated responses when random variation was involved.

The use of multiple approaches by Erica and Mindy for the generalization practice across the graphs also suggests that graph content may influence their approaches for generalizing the graphs. Since generalization involves addressing the outcomes of local and global factors, which utilizes scientific models and principles that are necessarily content dependent, Mindy's use of multiple approaches to generalize the graphs is consistent with her use of multiple approaches to explaining the graphs. However, Erica consistently used one approach (literal) in her explanations of the graphs while using two approaches in her generalizations of the graphs (literal for the Artic graph, analytic for the Keeling and Temperature graphs). In Erica's case, it is possible the context of the location she was generalizing the graphs *to* played a role in her use of different approaches to generalizations.

Summary

The general framework illustrated the different approaches taken by my participants with respect to the crosscutting strategies/individual practices and the graphs presented to them during the interviews. Of the eighteen participants who were interviewed, thirteen used multiple approaches to the crosscutting strategies, individual practices, and/or graphs. Only two participants (Susan and Bob) used approaches at the extreme ends of the framework. However, my findings do not discount the importance of constructing these approaches, especially considering that all but two students who used multiple approaches only used two adjacent approaches. The presence of adjacent approaches highlights potential relationships between practices (e.g., explain and generalize) in addition to relationships with the nature of the displayed data (e.g., uncertainty due to random variation) and/or content (e.g., explanation).

CHAPTER 5: What Do My Findings Mean for Researchers, Educators, and Me?

This findings from this dissertation captured different levels of approaches used by my participants when they talked about their comprehension of the Keeling, Temperature, and/or Arctic graphs. In this chapter, I used my findings and findings from previous studies to define the criteria for being an informed citizen with respect to the crosscutting strategies and individual graphical sense-making practices. These criteria, and their associated crosscutting strategies and individual graphical sense-making practices, have implications for curriculum development, classroom instruction, and assessment design. At the end of this chapter, I reflect on the limitations in my study and describe potential avenues for future research.

Overview

The narratives highlighted contrasts in my exemplar participants' approaches to graphical sense-making for the three graphs presented to them. Bob used many strategies to support claims he made about the graphs, often speculating about the purposes for the scientists' selection and representation of data. Esmerelda approached the graphs analytically, using different strategies for different graphs. Annika used the text in the graphs literally, expressing hesitance when making claims beyond the displayed text. Susan used the graphs to talk about peoples' activities. The contrasts in these participants' engagement with graphical sense-making for the three graphs correspond to different levels of periphery with respect to a community of practice for an informed citizenry, which I address in the next sections.

Being an Informed Citizen with Respect to Graphical Sense-Making

My definition of informed citizen was mainly informed by my findings and Duncan et al.'s (2018) concept of *laypeople's evidentiary practices*. In my study, the participants used different approaches to make sense of the graphs presented to them, even though they were presented with the same graphs; these approaches could be organized into four levels of sophistication. Duncan et al.'s concept of *laypeople's evidentiary practices* addressed how laypeople employ norms and practices different from those of scientists when reasoning about evidence. They suggested that laypeople should be able to examine secondary indicators of evidence (e.g., credibility of authors, general agreement from scientific community at large) to evaluate the trustworthiness of evidence; in other words, laypeople should rely "on the judgment of expert communities" (p. 910).

Based on my findings and the work by Duncan et al., I define an informed citizen as a person who: (1) considers a graph to be a socially constructed representation of data; (2) applies scientific models and principles, appropriately addressing different systems across scales, when constructing explanations, predictions, and generalizations; (3) uses strategies to address uncertainties related to random variation; and (4) shows concern about the graph's source/purpose/audience and data selection and/or representation. These criteria define the actions of an informed citizen, a *competent insider* within a community of practice for an informed citizenry or Feinstein's (2011) *competent outsider* with respect to the scientific community. The participants in my study met all, some, or none of these criteria, which locate them from most to least central with respect to a community of practice for an informed citizenry; their location with respect to that community of practice approximately corresponds to the approaches in the general framework, from most sophisticated (analytic+) to least sophisticated (figurative).

Explaining the Criteria

The first two criteria relate to a participant's treatment of the graph and the types of stories they told about how the represented phenomena occur, respectively. Meeting the first criterion, which is to treat the graph as a representation of data, is essential to being an informed citizen because if participants do not treat graphs as representations of data collected to measure changes in phenomena, decisions they make regarding their interpretation and analysis of the graph would not address the phenomena represented in the graph. The second criterion addresses the participants' expressed applications of scientific models and principles to explain the phenomena represented in graphs; this criterion differs from their *recollection* and application of scientific models and principles, which is what I asked participants to do during their interviews. The significance of the difference is addressed below when I describe the characterizations of the approaches. Meeting this criterion, appropriately applying scientific models and principles, is necessary to address the scientific content knowledge associated with the subject of the decisions made by informed citizens.

The last two criteria relate to a participant's response to random variation and expressed ideas about the source/purpose/audience of a graph and data selection and/or representation. The third criterion, which is to use strategies that address uncertainties related to random variation, is important because most empirical graphs have low signal-to-noise ratios. To make informed decisions, citizens need to be able to differentiate the signal from the noise, and/or determine if there is a signal within the noise. The last criterion, which is to show concern about the graph's source/purpose/audience and data selection and/or representation, is also important to being an informed citizen because citizens need to be able to ascertain if the information presented in a graph is trustworthy.

Applying the Criteria to the Approaches

Of the four approaches in the general framework for the Keeling, Temperature, and/or Arctic graphs, two were consistent with the criteria for being an informed citizen while the other two were not. While my general framework presents a progression from being the most to least central with respect to membership in a community of practice for an informed citizenry, it is not the only sequence. In the following paragraphs, I first address the two approaches that were consistent with my criteria for being an informed citizen before addressing the two approaches that were not consistent with my criteria.

The two approaches consistent with the criteria for being an informed citizen were the analytic+ and analytic approaches. Participants who used these approaches treated graphs as representations of data, which meets the first criterion.

In the analytic+ approach, the graphs were treated as representations of global data. Scientific models or principles were explicitly used to inform predictions and generalizations across systems and scales, thus meeting the second criterion. Because multiple strategies were used to sketch projections, and questions were posed about the source/purpose/audience and data selection and/or representation, the remaining two criteria were also met; thus, the analytic+ approach describes participants who are competently informed citizens.

In the analytic approach, the graphs were treated as representations of local data. Scientific models or principles were also explicitly addressed used to inform predictions and generalization across systems and scales; although the scientific models and principles may be incorrectly applied at times, this approach still meets the second criterion. Since multiple strategies were used to make predictions, this approach also meets the third criterion. Although participants did not *pose* questions about the source/purpose/audience and data selection and/or representation, they did comment on related aspects, such as how scale may affect the interpretation of a graph, which meets the last criterion. Thus, the analytic approach also describes participants who are capably informed citizens.

The two approaches not consistent with the criteria for being an informed citizen were the literal and figurative approaches. In the literal approach, the graphs were treated as representations of data, which meets the first criterion. Because scientific models or principles were not explicitly addressed, not enough evidence is available to determine whether the participants would have been able to apply scientific models or principles to inform their predictions and generalizations. Since participants also did not explicitly address the source/purpose/audience and data selection and/or representation for the graphs, the last criterion is not met. Thus, a literal approach describes participants who are peripherally informed citizens. With a figurative approach, participants do not treat the graphs as representations of data; because the first criterion is not met, the figurative approach describe participants who are not informed citizens, or outsiders to a community of practice for an informed citizenry.

Contributions to the Literature

My dissertation adds to the growing body of work that addresses how students make sense of graphs. I built on findings from previous studies by addressing the ideas and sense-making of students during their engagement with the Keeling, Temperature, and Arctic graphs and by identifying potential connections between the individual graphical sense-making practices. In this section, I focus on these two contributions.

Many studies addressing graph comprehension have shown that students' interpretations of graphs were not consistent with the canonical interpretations, such as their perception of line graphs as literal pictures (Kerslake, 1981; Leinhardt et al., 1990; McDermott et al., 1987; Preece, 1983; Stein & Leinhardt, 1989), without addressing how the students' ideas and sense-making were not consistent with the canonical interpretations. In my findings, the general framework represents the range of ideas and engagement in the graphical sense-making practices that were expressed by my participants during their interviews, which addresses how students' graphical sense-making compares to canonical interpretations. Similar to many learning progressions (Alonzo & Steedle, 2009; Mohan et al., 2009), I included students' alternate conceptions as part of the less sophisticated levels to capture their ideas and graphical sense-making.

Previous studies have also addressed factors influencing students' comprehension of graphs related to specific single practices, such as their prior content knowledge about the represented phenomena (Friel et al., 2001; Glazer, 2011; Postigo & Pozo, 2004; Roth & Bowen, 1999; Wavering, 1989), prior experiences related to graph comprehension (Chinn & Brewer, 2001; Friel et al., 2001; Janvier, 1981; Pozzer-Ardenghi & Roth, 2010; Shah, 2002; Shah & Hoeffner, 2002; Trickett et al., 2009), and consideration of purpose (Friel et al., 2001; Glazer, 2011) and audience (Glazer, 2011). In my findings, the crosscutting strategies from the general framework describe aspects of the participants' graphical sense-making that were present in their engagement with multiple individual practices. Because the participants' engagement with the individual practices share common aspects of the crosscutting strategies, their engagement with the individual practices may be connected to each other.

Practical Implications

One of the main themes in my introduction was that schools have an important role in helping students learn how to make sense of graphs. While my findings show that predictions and generalizations were more challenging for many of the participants in my study, especially if the graph displayed noisy data, my findings also showed that there may be connections between the crosscutting strategies and individual practices (e.g., explanations and generalizations) for the Keeling, Temperature, and/or Arctic graphs. These findings have practical implications for curriculum development, classroom instruction, and assessment design.

Curriculum Development

Curricula are designed for multiple, sometimes overlapping, purposes (American Association for the Advancement of Science, 2001; Pinar, 2011) and often with the ultimate goal of improving student learning. To achieve this goal, curriculum designers need to consider the needs of the students, appropriate performance expectations (i.e., learning goals or outcomes), in addition to constraints and other considerations (e.g., standards, assessments) that teachers may face when implementing curriculum.

Curriculum developers may use the approaches from my findings to refine the upper and lower bounds of learning goals and outcomes, with respect to the Keeling, Temperature, and Arctic graphs, that they set for students. Since the approaches from the general framework describe different levels of sophistication that students may use when making sense of the graphs, curriculum developers can use the general framework to construct learning objectives that are reasonably attainable by their students. For instance, some of the participants in my study used a figurative approach to making predictions because they did not use strategies that addressed uncertainty with respect to random variation. If curriculum developers want to help figurative students develop more sophisticated approaches to making predictions, they could design an activity, or a series of activities, to introduce those students to strategies that help them respond to uncertainties due to random variation. With repeated guided practice in these strategies over time, figurative students may learn to make more sophisticated predictions.

Classroom Instruction

Teachers, especially those who are teaching new content for the first time, are often unsure of what is reasonable to expect from their students' performances with respect to learning objectives. Helping teachers recognize the different approaches students may use to make sense of the graphs, and the ways the practices are connected to each other, can help teachers select instructional strategies that can help develop their students' graphical sense-making. In the following paragraphs, I describe how teachers may use the lower level and upper level approaches from my general framework to inform instruction in their classrooms.

Teachers can use the descriptions of the lower level approaches (figurative and literal) to understand some of the resources their students may bring to the classroom, in addition to challenges their students may face, to plan instruction that adapts to those conditions. For instance, a teacher may have students who treat graphs as recordings of human activities, reflective of the figurative approach described in the general framework. In this situation, a possible course of action for the teacher could be to have students collect data for a phenomenon and then construct and analyze the representations for that data. The acts of collecting data, and constructing and analyzing representations for those data, can help students move beyond treating the graph as records of human activities, similar to the modeling activities described in the studies by Lehrer and Schauble (2004, 2005, 2012).

Teachers can also use the descriptions of the upper level approaches (analytic and analytic+) to select instructional strategies that may help their mid-level students reach those upper level performances. Consider students who present their generalizations of graphs to other locations. A teacher could formatively assess the students' explanations for the phenomenon being generalized, using the general framework to diagnose their levels of sophistication from their responses. Using this information, the teacher could then scaffold students' engagement in generalizing graphs to other locations, similar to the idea of scaffolding described by many other researchers (e.g., Vygotsky, 1978; Wertsch & Toma, 1995).

Assessment Design

Assessments are central to the design of curriculum and instruction. They may be comprised of items (e.g., questions, tasks) that teachers, curriculum designers, or others use to monitor and evaluate students' growth with respect to performance expectations. Similar to its use for curriculum design and classroom instruction, the general framework may be used to inform assessment designers of an expected range of performance with respect to the graphical sense-making practices. For large-scale assessments, the approaches can inform the development of items to create assessments that bridge multiple grade levels (i.e., figurative approach with respect to middle school students). For classroom assessments, teachers can use the general framework to tentatively diagnose the nature of students' challenges when making sense of graphs—which informs their in-the-moment pedagogical responses to their students.

Reflections about My Study

My main motivation for doing this work is to contribute to the development of a more informed citizenry. Becoming a critical consumer of information represented in graphs requires the use of the graphical sense-making practices described in this study. However, my use of interviews to elicit my participants' graphical sense-making was not exactly representative of situations that members of the general public would find themselves in when making sense of graphs. During the interviews, I asked the participants to explain the causes of the represented phenomena based on what they could recall from memory. In real life, members of the general public would not need to recall scientific models and principles from memory; instead, they could access that information from other resources (i.e., reliable websites, trustworthy experts). For instance, if Esmerelda had access to the Internet (or another reliable source of information) and could use that information to inform her graphical sense-making, her explanations and generalizations of the phenomena represented in the graphs may have been reflective of an analytic+ approach to those practices.

Another limitation is that my conduct of the interviews, which were dialogues with my participants, tended to make assumptions consistent with participants whose approach to graphical sense-making was analytic or analytic+. My dialogue with Bob was coordinated because I found it easy to follow his responses and could ask appropriate questions to elicit his sense-making. In contrast, my dialogue with Susan was less coordinated because I found it difficult to follow her responses; I sometimes made presumptions about her responses that should have been followed up with additional questions. Asking follow-up questions, such as questions regarding her ideas about trend and variability in graphs displaying high and low signal-to-noise ratios, would have provided concrete evidence to support my claims of her use of the crosscutting strategies and engagement in the individual graphical sense-making practices. Although Susan was one of the initial students I interviewed, pilot-testing my interview protocol with younger students may have better prepared me in responding to figurative responses. Over time, I became more aware of my bias with each additional interview and through my analysis and coding of the data.

While my coding of the excerpts revealed key differences between the approaches to graphical sense-making, I did not have the opportunity to formally develop reliability evidence for my coding of the responses with respect to the different levels of sophistication because it took time for me to learn how to accurately describe the diverse perspectives of my participants' graphical sense-making, especially if the they took a figurative or literal approach. Ellis (2007) also referred to this process as part of the motivation for her work on developing a taxonomy to categorize generalizations. My use of an expert frame to analyze the participants' responses may also explain my less coordinated dialogues with participants who took a figurative or literal approach to graphical sense-making during the interviews.

However, I did have numerous conversations with my dissertation co-directors about my characterizations of the exemplar participants throughout the writing of my dissertation; our weekly conversations provided opportunities for me to check and recheck my characterizations of the participants' responses with respect to their sense-making of the graphs presented to them. Members from the science education writing group also helped to informally code some of the excerpts with respect to my framework. While I did not have a chance to formally develop reliability evidence for coding the responses with respect to the different levels, I felt the time I spent learning to attend to the students' voices was invaluable towards my development as a researcher and educator because I always want to honor and accurately reflect the perspectives of others. In future work, I will strive to be more attentive to the students' voices and address concerns related to reliability and validity.

Future Directions

Despite some of these limitations, my findings still suggest avenues for future research. At the forefront, my curiosity was piqued by how the high school students in my study dealt with uncertainty, especially with respect to predictions and generalizations. Investigating approaches to uncertainties is important because informed citizens will often be asked to make decisions regarding ambiguously displayed data. Thus, my current and future work could inform a larger study investigating the different approaches to graphical sense-making across graphs and practices, zooming in on a few key areas—namely with respect to uncertainty due to random variation and connections across practices.

Future research questions could focus on: (1) the extent that practices are connected with each other across graphs (e.g., explain and generalize), and (2) how engagement in data collection and analysis may affect students' approaches to practices relating to systematic randomness that are inherent in measurements of phenomena, building on the findings from Lehrer and Schauble (2004, 2005, 2012) with respect to their work on helping elementary and middle school students understand natural variation through distribution. The answers to these questions build upon the work completed in this dissertation and can lead to further implications for teacher education and professional development and further the goals of preparing students in becoming members of a community of practice for an informed citizenry.

APPENDICES

APPENDIX A: Teacher Recruitment Script E-Mail Template

Dear Teacher Network [or teacher name],

My name is May Lee and I am a doctoral candidate on the *Data Nuggets* project at Michigan State University, which focuses on how students' quantitative reasoning develops over time through the use of activities based on the work of scientists. In my research, I am interested in investigating how high school students interpret graphs of ecological phenomena. For my dissertation, I need to interview high school students who have already taken a life science class (e.g., Introduction to Biology, Biology 1). If you are a parent of a high school student or know of educators working with high school students (e.g., summer school), and the students are interested in participating in a 30-45 minute interview on interpret graphs, please contact me at leemay1@msu.edu by next Monday, June 18. Also, please contact me if you have any questions about this study.

Sincerely,

May Lee

APPENDIX B: Student Recruitment Script

Hi, class. My name is May Lee and I'm a researcher at Michigan State University. I'm here today to talk a little bit about my research and to see if you'd be interested in participating in it. To help me do this, I will first hand out this form. [Hand out the consent form to students.] As I go through this form, please feel free to ask questions you may have.

I am interested in learning about how students make sense of graphs in science. To do this, I need to talk to students about their ideas. Your responses will help me understand how students like you make sense of graphs used in science and help me and other researchers develop better science instructional materials for future students and teachers.

If you choose to participate, I would set up a time to interview you that is convenient for both you and your teacher. During the interview, I would show you three graphs and ask questions about things you notice in the graph and what you think the graph represents. The interview would take no longer than 45 minutes. I would collect two types of information: an audio-recording of the interview and any written work you might produce while you are working with the graphs.

During the interview, you can choose to not answer specific questions or change your mind about participating at any time. Your participation in this research will have no effect on your grade or standing in your science class.

If you, or your parent or guardian, have questions about this study later on, you can contact me through the information provided on the form here [point to contact information section]. If anyone has questions about this research now, I can answer them. [Answer any questions.]

Great! Thank you for taking time to hear about my research. If you are under 18 and would like to participate, I would need you, and your parent/guardian, to complete the bottom of this form. If you are 18 or over, you do not need a signature from your parent/guardian. I hope you consider participating in this research!

APPENDIX C: Study Information/Consent Form

CONSENT FORM for RESEARCH STUDY on GRAPH COMPREHENSION

1. **PURPOSE of RESEARCH STUDY**
   You are being asked to participate in a research study investigating how students analyze and interpret data displayed in graphs. Please feel free to ask the researcher any questions you may have about this study.

2. **WHAT YOU WILL DO**
   If you agree to participate, I will show you a series of four graphs and audio-record your responses to questions asked about those graphs. For each graph, I will ask questions about what you notice in the graph and what you think they represent. Feel free to say whatever comes to mind – your ideas do not have to be completely thought out because I am interested in how you make sense of the graphs. The interview will take no longer than 45 minutes.

3. **YOUR RIGHTS**
   Since participation is voluntary, you may choose not to answer specific questions or stop participating at any time. Whether you choose to participate or not, there will be no effect on your grades or standing in your school. If you are under 18 years old, we will need permission from your parent or guardian for you to participate in this study.

4. **POTENTIAL RISKS, COMPENSATION, and BENEFITS**
   The risk to your participation in this study is minimal, in that you may feel uncomfortable about being audio-recorded during the interview. There is no compensation for participating in this study. One possible benefit to participating in this study is that you have an opportunity to talk about how you make sense of phenomena represented in graphs. A potential broader societal benefit may be improved science curriculum and instruction for future students.

5. **PRIVACY and CONFIDENTIALITY**
   To protect your privacy, all identifying information (e.g., your name, teacher's name, school name, city where you live) will be kept confidential—to the maximum extent allowable by law—in a secure location accessible only to the project research staff and the Institutional Review Board (IRB). An ID code or pseudonym will be used to label all data associated with you. The key, linking your name with your ID code or pseudonym, will be maintained separately from your data and stored on password protected computers. We will use these ID codes or pseudonyms in the analyses of data, presentations, and publications.

6. **CONTACT INFORMATION**
   Questions or concerns about this study should be directed to the researcher, May Lee, by email (leemay1@msu.edu) or phone (219-794-4559). If you have questions or concerns about your role and rights as a research participant, or would like to obtain information, offer input, or register a complaint about this study, you may contact, anonymously if you wish, Michigan State University's Human Research Protection Program by phone (517-355-2180),

fax (517-432-4503), email (irb@msu.edu), or regular mail (4000 Collins Road, Suite 136, Lansing, MI 48910).

7. **DOCUMENTATION of INFORMED CONSENT**
Your signature below means that you voluntarily agree to participate in this research study. Signing this paper means that you have read this information, or have had it read to you, and that you would like to participate in this study.

Your Name (*printed*): ______________________________

Your Signature: ______________________________

Parent/Guardian Signature: ______________________________

Date: ______________________________

You will be given a copy of this form to keep.

APPENDIX D: Graphs Used in the Interviews

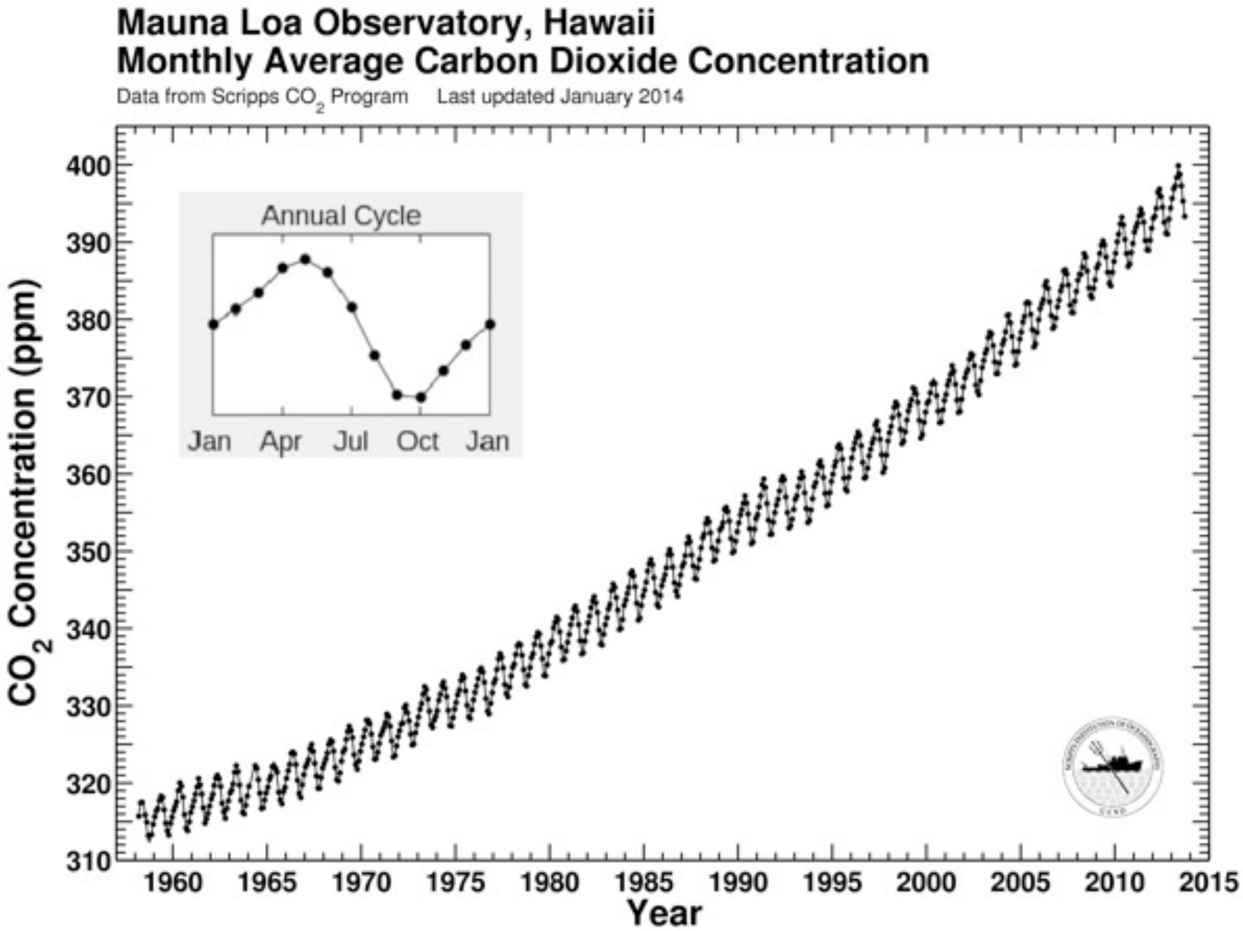

Figure D.1 Keeling graph: Changes in the concentration of atmospheric carbon dioxide over Mauna Loa, Hawaii (adapted from *Carbon TIME* project)

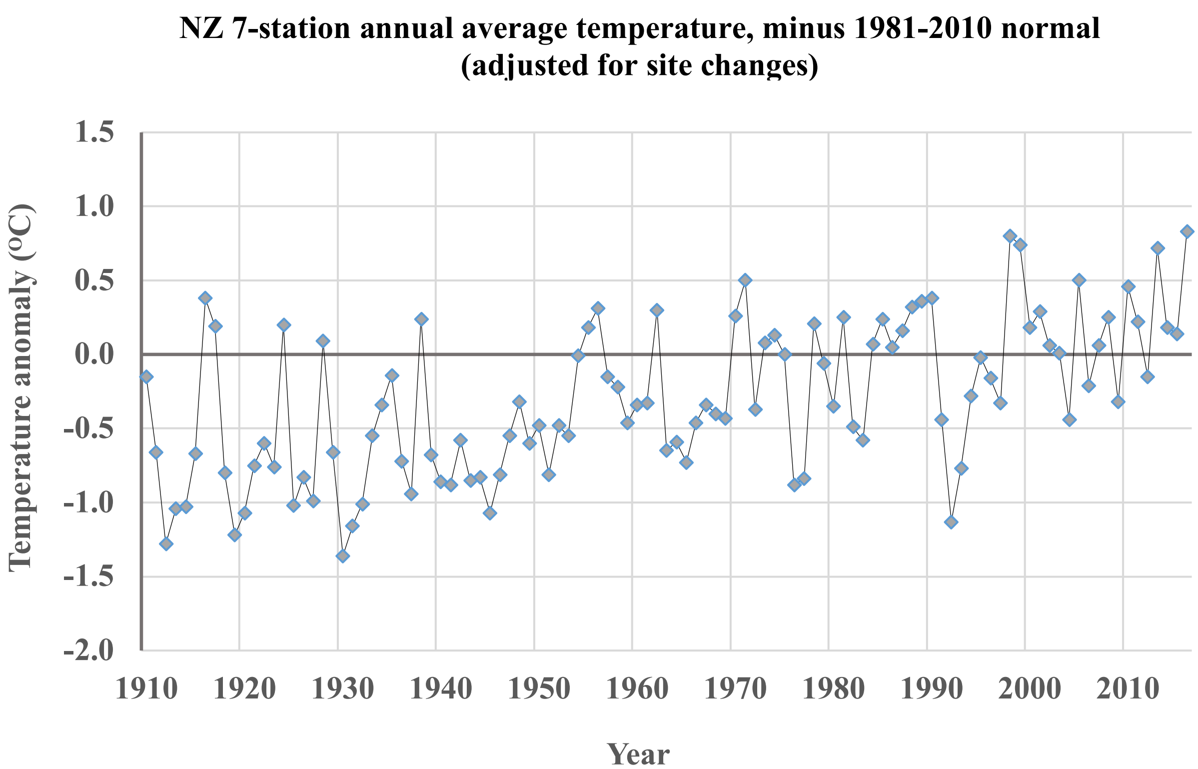

Figure D.2 Temperature graph: Changes in temperature anomalies in New Zealand (adapted from *Data Nuggets* activity: When a Species Can't Stand the Heat)

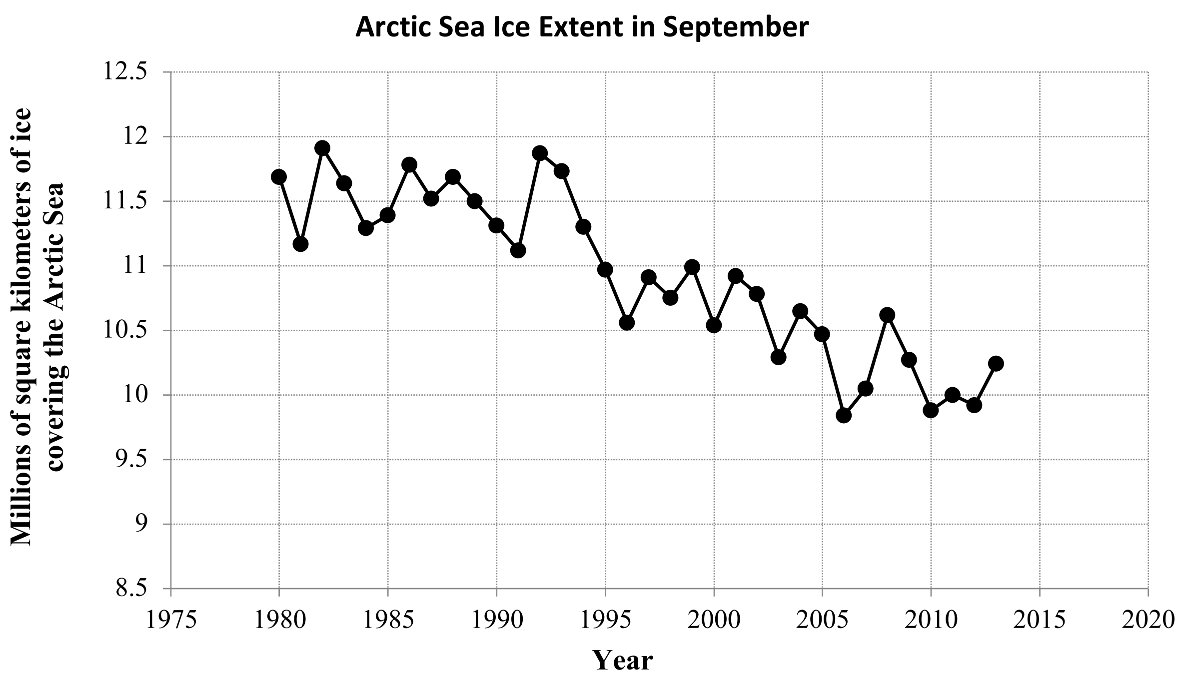

Figure D.3 Arctic graph: Changes in the area of ice covering Arctic Sea (adapted from *Carbon TIME* project)

APPENDIX E: Scientific Models and Principles Associated with Graphs

Climate change is conceptually challenging to understand, in part because learning about climate change requires analyses and interpretations of data that span physical and temporal scales (Shepardson et al., 2009, 2012). Climate is defined as the average weather for an area for at least 30 years, and may be thought of as the "statistics for weather" (Barwell, 2013, p. 32). Earth's climate is caused by atmospheric circulations, with air masses rising from the tropics and descending towards the poles, with storms that transfer moisture and energy in the middle latitudes (Weart, 2010). The atmosphere, oceans, cryosphere, geosphere, and biosphere are realms that influence those atmospheric circulations. Because those realms are highly interconnected, changes to the cycling of matter and flows of energy within one realm will lead to changes in the climate.

One significant change in our climate is the increase in average surface temperatures on Earth due to anthropogenic additions of greenhouse gases to our atmosphere; this change is also known as global warming. Because Earth's climate is a complex system, scientists use climate models that focus on particular aspects of the system in order to study those aspects independently. While three of the most commonly used models include *pools-and-fluxes of carbon*, *heat transfer by radiation*, and *global circulation*, my dissertation will focus on the first two models, which are the less complex than the *global circulation* model.

The *pools-and-fluxes of carbon* model is based on the idea that carbon is mainly stored in the Earth's atmosphere, oceans, terrestrial ecosystems, and crust. These places are called carbon *pools* because they act as large reservoirs of carbon. The movement of carbon between pools is called *flux*. Fluxes are processes that connect pools through cycles and feedback loops. Examples of carbon fluxes include photosynthesis, cellular respiration, gas diffusion (between ocean and atmosphere), decomposition, fossil fuel combustion, and geological processes (e.g., weathering or erosion of ancient marine sediments). Each carbon pool can give carbon to the atmosphere (acting as a *source*) or remove carbon from the atmosphere (acting as a *sink*). If the sizes of the sources and sinks are equal to each other, the carbon pools will be in equilibrium and will not change over time.

Certain human activities (e.g., deforestation, burning of fossil fuels) increase the numbers and sizes of sources on Earth (e.g., atmospheric carbon pool) without a corresponding increase in the numbers and sizes of sinks (e.g., photosynthesis, gas diffusion exchange between ocean and atmosphere). This imbalance results in a net increase in the size of the atmospheric carbon pool, which is the main reason atmospheric carbon dioxide levels have increased over time.

Figure D.1 (Keeling graph) illustrates an example of changes in the mean monthly concentration of atmospheric carbon dioxide over Hawaii from 1957 to 2015; the data for this time-series graph were collected by the Scripps CO_2 Program at the Mauna Loa Observatory in Hawaii. The shape of this graph shows the atmospheric carbon dioxide concentration with a long-term trend with an increasing rate of change and a short-term variability that is periodic, with regularly increasing and decreasing annual cycles. The *pool-and-flux* model attributes the long-term trend primarily to anthropogenic activities and attributes the periodic variability to photosynthesis and cellular respiration.

The *heat transfer by radiation model* is based on the idea that the cycling of carbon (as atmospheric carbon dioxide) in the Earth's atmosphere plays a central role in regulating Earth's climate. Carbon dioxide contributes to the greenhouse effect, which is the exchange of radiation into and out of the Earth's atmosphere such that it warms up the Earth. Of the solar energy, or shortwave radiation (e.g., visible, UV), entering the Earth's atmosphere, about 30 percent of that energy is reflected back into outer space while the remaining 70 percent is absorbed by the land, oceans, atmosphere on Earth, and released into the Earth's atmosphere as longwave radiation (i.e., infrared).

The greenhouse gases (e.g., carbon dioxide, water) in the Earth's atmosphere trap the longwave radiation, which prevents them from escaping into outer space. Increasing concentrations of atmospheric carbon dioxide produce a net temperature increase near Earth's surface, or global warming (Houghton & Woodwell, 1989; Intergovernmental Panel on Climate Change, 2007). Figure D.2 (Temperature graph) shows changes in temperature anomalies in New Zealand from 1909 to 2015; a temperature anomaly is the difference between the annual mean temperature for a year and the reference temperature (which is the average of the annual mean temperatures between 1981 and 2010).

Data for this time-series graph were adapted from the National Institute of Water and Atmospheric Research in New Zealand. This shape of this graph shows the temperature anomalies with a long-term trend that increases at a constant rate over time and a short-term variability that is random, with the temperature anomalies varying in magnitude and direction each year. The *heat transfer by radiation* model attributes the long-term trend to increasing concentrations of atmospheric carbon dioxide (greenhouse gas) and attributes the periodic variability to various anthropogenic and natural factors.

Consequences of global warming due to climate change.

While the increase in the mean global temperature on Earth over the past century is less than two degrees Fahrenheit (one degree Celsius), the effects of this change has noticeable consequences in various ecological (Maclean & Wilson, 2011) and biological (Hughes, 2000) systems. An ecological consequence of global warming is the melting of glacial ice, which causes more heat to be absorbed, rather than reflected, by the Earth. This consequence contributes to the rise in sea levels, release of more carbon dioxide and methane into the atmosphere (thawing of permafrost in the Arctic Sea), changes in major ocean circulation systems that affect regional climates across the world, and changes in the large-scale temperature and pressure gradients the northern hemisphere, causing the jet stream—which carries cold Arctic air—to wander further south than it has in the past. These events are due to the physical properties of water.

The simple atomic structure of water (two hydrogen atoms bonded to one oxygen atom) allows water to have a high specific heat capacity, which means it can absorb large amounts of heat before it gets hot itself; this property indicates that water can maintain temperatures in organisms and environments. Water also has distinct molecular arrangements for each of its physical states (i.e., solid, liquid, gas), and is the only substance that exists on Earth in all three states. For instance, the molecular arrangement of ice causes it to have a greater volume and lower density than liquid water; this property means that when the polar ice caps melt, it will take up more volume as a liquid than it took up as solid ice—causing sea levels to rise. Because water from the melted ice is initially colder than the surrounding body of water, its addition causes change to ocean circulation systems that affect regional climates. Its molecular arrangement also makes water a polar molecule—in that it is slightly positive on the hydrogen side and slightly negative on the opposite side; this polarity allows water to be a solvent, which means that it can dissolve many different compounds (e.g., carbon dioxide). When ice at the polar caps melt, it starts to thaw the permafrost (ground—which contains water—that has been frozen for more than two years) underneath it, which causes the carbon dioxide trapped within the permafrost to be released into the atmosphere; this release of carbon dioxide increases the size of the carbon pool, which perpetuates global warming.

One ecological impact of climate change is the melting glacial ice in the Arctic Sea (Andry et al., 2017). Figure D.3 (Arctic graph) shows changes in area of glacial ice covering the Arctic Sea from 1980 to 2013. The data for this time-series graph were collected from satellites pictures taken from the area each November. This graph shows the area of ice decreasing over time, indicating a negative long-term trend (due to increasing temperatures). While the magnitude and direction of the area of ice varies each year, displaying random variation, it is unlikely the area of ice will increase to an extent that the long-term trend would become positive. During the displayed time period, the area of ice that increased from a previous year occurred 13 times and the area of ice that decreased from a previous year occurred 20 times, both with changes in area that were roughly the same magnitude; this pattern indicates the overall trend is negative. The changes in magnitude of the area in adjacent years were similar and there is no indication as to whether the area of ice would increase or decrease each year.

APPENDIX F: Interview Protocol

Before the Interview

- **Materials:** charged audio recorder, pen
- **Each participant**: consent form, paper copy of *Keeling, Temperature,* and *Arctic* graphs, pen/pencil, clear transparent ruler
- Briefly go over consent form with student, especially purpose of project and assurances that participation in this study will not affect academic standing in science class.

Start of Interview

Thank you for participating! I am interested in how students make sense of graphs, so it would be helpful for me if you could talk through what you notice in the graphs and how you are making sense of what you notice. There's no "wrong" response, and you can also always change your response later on if you think differently about it. Do you have any questions before we get started? [Start audio-recorder.]

Here is the first graph. [Show *Keeling* graph.]

1. **Have you seen this graph before?**
   a. If so: Where did you see it? What do you remember about it?
   b. If not: **What do you think this graph is about?** Who do you think created the graph? How do you think they created it? Where do you think you might see a graph like this being used? Who do you think this graph would be useful for? What did you think was the most important thing to notice about this graph?

   - [If a graph component is addressed, follow up with corresponding graph component prompts (#2). If a graph component is not addressed, say, "I noticed you haven't mentioned this part of the graph…do you have a name for it?" and then follow up with prompts for that part].
   - [If a pattern is addressed, follow up with corresponding pattern prompts (#3).].

2. **ASPECTS**
   a. **Title**: What information do you think the title tells you about the graph? Do you have ideas about why this location was chosen?
   b. **Y-axis:** What information do you think this axis tells you? Do you have ideas about why the people who created the graph chose to measure that?
   c. **X-axis:** What information do you think this axis tells you? Do you have ideas about why the people who created the graph used that time period/scale?
   d. **Point:** What information do you think this point tells you? Do you think it represents a single measurement or multiple measurements? [follow up with predictions prompts]
   e. **Set of points:** What information do you think all these points, as a whole, tell you? Do

you think all these measurements came from the same place?

f. **Line:** What information do you think this line tells you about the data in the graph?

g. **Describe one pattern you see in this graph.** What makes you describe the pattern that way? Are there other patterns or anything interesting in this graph that you noticed? [If pattern is a long-term trend, have student draw the line for that pattern on the graph.]

3. **APPLICATIONS**
   a. **What do you think caused this pattern?** How do you think that [cause] relates to the pattern?
   b. On the graph, make predictions for where you think a data point would be one year later,
   c. 5 years later, and 50 years later. What made you choose to put your predictions in those places?
   d. How certain are you of each prediction that it will come true?
   e. Do you think this pattern would be the same, similar, or different in other locations?
   f. Do the relationships represented by this pattern connect with things you've seen or done in school or at home? Do you think there are things you do that might cause this pattern?

Here is the second graph. [Show *Temperature* graph.]

4. **Have you seen this graph before?**
   a. If so: Where did you see it? What do you remember about it?
   b. If not: **What do you think this graph is about?** Who do you think created the graph? How do you think they created it? Where do you think you might see a graph like this being used? Who do you think this graph would be useful for? What did you think was the most important thing to notice about this graph?

   - [If a graph component is addressed, follow up with corresponding graph component prompts (#6). If a graph component is not addressed, say, "I noticed you haven't mentioned this part of the graph…do you have a name for it?" and then follow up with prompts for that part].
   - [If a pattern is addressed, follow up with corresponding pattern prompts (#7).].

5. **ASPECTS**
   a. **Title**: What information do you think the title tells you about the graph? Do you have ideas about why this location was chosen?
   b. **Y-axis:** What information do you think this axis tells you? Do you have ideas about why the people who created the graph chose to measure that?
   c. **X-axis:** What information do you think this axis tells you? Do you have ideas about why the people who created the graph used that time period/scale?
   d. **Point:** What information do you think this point tells you? Do you think it represents a single measurement or multiple measurements? [follow up with predictions prompts]
   e. **Set of points:** What information do you think all these points, as a whole, tell you? Do you think all these measurements came from the same place?
   f. **Line:** What information do you think this line tells you about the data in the graph?
   g. **Describe one pattern you see in this graph.** What makes you describe the pattern that

way? Are there other patterns or anything interesting in this graph that you noticed? [If pattern is a long-term trend, have student draw the line for that pattern on the graph.]

6. **APPLICATIONS**
   a. **What do you think caused this pattern?** How do you think that [cause] relates to the pattern?
   b. On the graph, make predictions for where you think a data point would be one year later,
   c. 5 years later, and 50 years later. What made you choose to put your predictions in those places?
   d. How certain are you of each prediction that it will come true?
   e. Do you think this pattern would be the same, similar, or different in other locations?
   f. Do the relationships represented by this pattern connect with things you've seen or done in school or at home? Do you think there are things you do that might cause this pattern?
   g. **What about connections to this graph?** [show *Keeling* graph]

Here is the last graph. [Show *Arctic* graph.]

7. **Have you seen this graph before?**
   a. If so: Where did you see it? What do you remember about it?
   b. If not: **What do you think this graph is about?** Who do you think created the graph? How do you think they created it? Where do you think you might see a graph like this being used? Who do you think this graph would be useful for? What did you think was the most important thing to notice about this graph?

   - [If a graph component is addressed, follow up with corresponding graph component prompts (#10). If a graph component is not addressed, say, "I noticed you haven't mentioned this part of the graph…do you have a name for it?" and then follow up with prompts for that part].
   - [If a pattern is addressed, follow up with corresponding pattern prompts (#11).].

8. **ASPECTS**
   a. **Title**: What information do you think the title tells you about the graph? Do you have ideas about why this location was chosen?
   b. **Y-axis:** What information do you think this axis tells you? Do you have ideas about why the people who created the graph chose to measure that?
   c. **X-axis:** What information do you think this axis tells you? Do you have ideas about why the people who created the graph used that time period/scale?
   d. **Point:** What information do you think this point tells you? Do you think it represents a single measurement or multiple measurements? [follow up with predictions prompts]
   e. **Set of points:** What information do you think all these points, as a whole, tell you? Do you think all these measurements came from the same place?
   f. **Line:** What information do you think this line tells you about the data in the graph?
   g. **Describe one pattern you see in this graph.** What makes you describe the pattern that way? Are there other patterns or anything interesting in this graph that you noticed? [If pattern is a long-term trend, have student draw the line for that pattern on the graph.]

9. **APPLICATIONS**
   a. **What do you think caused this pattern?** How do you think that [cause] relates to the pattern?
   b. On the graph, make predictions for where you think a data point would be one year later,
   c. 5 years later, and 50 years later. What made you choose to put your predictions in those places?
   d. How certain are you of each prediction that it will come true?
   e. Do you think this pattern would be the same, similar, or different in other locations?
   f. Do the relationships represented by this pattern connect with things you've seen or done in school or at home? Do you think there are things you do that might cause this pattern?
   g. **What about connections to this graph?** [show *Keeling* and *Temperature* graphs]

Great, that is all the questions I have for you. [Collect materials and graphs from student.] Thank you for taking time to share your ideas with me!

APPENDIX G: Interview Transcripts for the Exemplar Participants

G-1: Bob’s interview transcript and sketched predictions for the Arctic graph

G-2: Esmerelda’s interview transcript and sketched predictions for the Arctic graph

G-3: Annika’s interview transcript and sketched predictions for the Arctic graph

G-4: Susan’s interview transcript and sketched predictions for the Temperature graph

G-1: Bob's interview transcript and sketched predictions for the Arctic graph

KEELING	
Interviewer:	**This is the first graph. Have you seen this graph before?**
Bob:	I've never seen this graph before.
Interviewer:	**Okay, great. So, taking a look at this graph, can you tell me what you think it's about? (pause)**
Bob:	It looks like we're plotting how much CO_2 is probably in the atmosphere versus time and it's taken in Hawaii. It's what it looks like to me.
Interviewer:	**Okay. Do you have ideas about who might have created this graph?**
Bob:	I would guess the Mauna Loa Observatory. And then there's a seal here, but I can't quite…maybe it's the seal of that observatory.
Interviewer:	**Okay.**
Bob:	Oh, data from Scripps CO_2 Program.
Interviewer:	**Mm-hmm (affirmative). Where do you think a graph like this might be used?**
Bob:	Where?
Interviewer:	**Yes.**
Bob:	Climate change research, environmental research, maybe different government organizations or university students studying the atmosphere. Stuff like that.
Interviewer:	**What makes you think climate change research? Because I don't see the word climate change there.**
Bob:	Well, I know that CO_2 is important in that research, so I've heard, and it looks like it's going up. From what I think I remember; a lot of CO_2 traps the heat in the atmosphere and causes global warming.
Interviewer:	**Okay. Do you have ideas about who you think this graph could be useful for?**
Bob:	Environmental researchers, scientists or, again, government organizations.
Interviewer:	**So, basically the same people who created the graphs.**
Bob:	Yes.
Interviewer:	**Cool. So, when you're looking at this graph, what do you think would be the most important thing that people should pay attention to?**
Bob:	Well, the upward trend. It seems kind of linear, but slightly – I mean, it's not an exactly straight line. It's jagged as well but I'd imagine that's due to just the seasons. I'm guessing this annual cycle is kind of a zoomed-in version of one of these little jags here. Yes, the upward trend and it seems like the slope is greater. It's been accelerating since the 2000s.
Interviewer:	**So, compared to what the first part was like, you were pointing from 1960 to 19 –**
Bob:	Seventy-five, yes. That best fit line slope looks probably less than from, say, 1990 to 2015.
Interviewer:	**Okay, great. So, if you had to describe the pattern – I know you talked a little bit about the jags and the increase. How would you describe the pattern that you see in this graph?**
Bob:	Jagged, increasing, pretty much anatomically almost the whole time and I don't really have that much information about it, but it seems to me like it accelerates slightly.
Interviewer:	**Can you say a bit more about accelerating?**
Bob:	Yes. The slope is not quite constant. It seems to be increasing as a function of time positively.
Interviewer:	**Do you have ideas about what might be causing the increase?**

Bob: Well, the graph itself doesn't really have any information about that. I can tell you about things that I've heard such as human activity that could be causing this, but from the graph, I don't see any indication of any hypothesis about what's causing it.

Interviewer: Mm-hmm (affirmative). Yes, okay. What about the jagged lines you were talking about? Do you have ideas about what might be causing that?

Bob: Yes, well, if I'm right where this is kind of a blown up - Because the scale here is in years and it looks like these jags probably take place pretty much once a year. So, I'm guessing that there's something about the seasons or the temperature of the air that changes the readings. Or maybe it's a natural, cyclical phenomenon. I don't know enough about atmospheric science or CO_2 to really have a good hypothesis about why'd that be happening, but I'd guess it'd have to do with – let's see, it looks like it's higher in maybe the warmer months and a little lower in the colder months. So, I'd guess that it would have something to do with temperature.

Interviewer: Okay. You also noticed that the time went from 1960 to around 2015. Do your ideas about why the people who created this graph are displaying that time period?

Bob: It could be that 1960 is when they first started taking data and it could be that this graph was made – It says last updated January 2014, but it could be that they're still taking data. But they haven't compiled that yet or that this graph is from 2015, or they stopped taking data in 2015. It may have data earlier, but maybe they're just showing this snippet to emphasize something. Although, I would guess not because from it seems like it seems like the slope decreases as a function of time. So, if you really wanted to show it increasing more recently, you'd probably want to show more to the left. By left I mean earlier in time.

Interviewer: That makes sense. What about the CO_2 that they're measuring? Do you have ideas about why they might be measuring the CO_2 as opposed to, say, something else?

Bob: Just from my general knowledge of what I've heard that the climate scientists like to track CO_2 because I think it gives a good – I don't exactly remember why it's related to the warping of the climate, but as I mentioned earlier I think it has to do with the light rays come in instead of – Some of them always go all the way out of the atmosphere, but some of them are bounced back in and kept in the Earth's atmosphere. Maybe CO_2 is really good, kind of like a blanket either deflecting the light back in, or trapping it, or the light scatters so much that it doesn't get back out of the atmosphere leading to warmer. But I'd imagine carbon dioxide is a naturally abundant thing in our atmosphere. Used in our oxygen-CO_2 cycle for trees and us to breathe and live. So, it's probably fairly easy to detect because I'd imagine it makes quite a large percentage of the molecules in the atmosphere. So, it's probably easy to detect and maybe the CO_2 is one of the things that – We're probably putting a lot of CO_2 into the air maybe through our current energy creation methods. That'd be my hypothesis but I haven't looked at this in a while so I'm not exactly sure.

Interviewer: Yes. You mentioned O_2-CO_2 cycle with the trees. Can you say a little bit more about that like how you were thinking about it? (chuckles)

Bob: I'm thinking middle school. Well, I know us humans breathe oxygen and I think we breathe out carbon dioxide. I think the trees are opposite where they take in carbon dioxide and output CO – No, sorry, take in, yes, carbon dioxide and output the oxygen for us to breathe. But I don't think this is caused because people are breathing out a lot more than they're breathing in. That's what I remember from that cycle. I don't know if that's right.

Interviewer: I didn't know if the O_2-CO_2 cycle had anything to do with the jagged lines you were talking about.

Bob: Yes, it could be. Maybe – Well, then again, I was going to think if this were in a colder climate maybe the trees – Well, evergreens stay alive all the time and other trees die in

	the winter. So, that could be part of it. But this is also in Hawaii where I imagine trees don't really die in the winter, but that could be contributing to it yes.
Interviewer:	**So, you mentioned Hawaii, do you have ideas about why this measurement and this investigation was done in Hawaii as opposed to other places?**
Bob:	Well, it looks like they have an observatory there and I would imagine – the things I'm thinking of is that it's secluded; it's far away from the mainland of the United States. Maybe that helps with more accurate measurements. There are fewer pollutants out there. That would be my guess.
Interviewer:	**Okay. Cool. So, I'm going to circle a point on this graph. This one right here. Can you say what that point represents to you?**
Bob:	I would say that this point –
Interviewer:	**If you need a straight edge, here you go.**
Bob:	Sure. I'll just plot it. I would say at this point means that the Mauna Loa Observatory in Hawaii measured about 360 CO_2 parts per million in some month in 1997.
Interviewer:	**Okay. And then the dot that I circled, do you think that the people that created this graph used a single measurement or multiple measurements to represent that dot?**
Bob:	Well, I would think it would be good practice to take a lot of measurements, but I don't really see – If you take a lot of measurements, you should propagate your error and put error bars. I don't really see error bars, but that could also be because it's so small maybe the errors are so small that you can't see it or they took away the error bars because it would've confused the overall message of the graph. Or they didn't (chuckles) calculate the error or they only took one measurement. But I'd imagine they're, maybe – I don't know if they're constantly taking measurements or in a periodic fashion and then they average it over – I don't know it looks like they take one maybe once a month. One, two, three, four, five, six, seven, eight, nine, ten, 11, 12. Yes. Maybe average it once for the month or they could just take one measurement a month, but I would imagine they take more and do some type of averaging.
Interviewer:	**So, is the dot on this part of the graph that I circled, is that the same as the dot that's inside that inset or is it different?**
Bob:	My theory is that this is a blowup of one of these sections here. I don't know if it's specifically the one where this dot is. I would've liked if they had labeled what year this was. Maybe it could be a specific year or it could be an average of all of the years normalized in some fashion just to show you these jagged lines more look like this.
Interviewer:	**Okay. Cool. So, then if I ask you one year later for the next one, where do you think that point would land on the graph?**
Bob:	From this dot?
Interviewer:	**Not from that dot, from the end of this graph. One year later, where do you think the next -**
Bob:	In 2016?
Interviewer:	**Mm-hmm (affirmative).**
Bob:	2016 will be just a little bit past – probably go with that. I'd be in probably a lower part of its cycle if you're talking about winter of 2016. The start of 2016. I would say higher than the last point, but not as high as the greatest peak thus far.
Interviewer:	**Okay. So, can you put a dot there and put a one next to it?**
Bob:	Right here?
Interviewer:	**Yes, and then what about five years later? Where do you think that point would fall?**
Bob:	Well, that's tough because my idea is that maybe this is some type of exponential function. I would guess –
Interviewer:	**And if you need more paper, let me know.**
Bob:	Probably somewhere around here.

Interviewer: **Okay. And then could you put a five there? Can I ask you to make one more?**
Bob: Mm-hmm (affirmative).
Interviewer: **Fifty years later?**
Bob: Fifty –
Interviewer: **Yes. Where do you think that's going to land?**
Bob: So, 65 to 15. So, another one of these two over to here. Probably somewhere up here, 50.
Interviewer: **Great. Super. All right. So, my next question is going to be, can you talk a little bit about how you made the decisions to put down the one, five, and 50 where you did?**
Bob: Mm-hmm (affirmative). I made the assumption that this could be fitted loosely as an exponential function. Tried to sketch that best I could and then put a dot at the corresponding time.
Interviewer: **I know you talked about the jagged edges and you mentioned it for the one-year predictions, your one-year mark. Between the one and five years and five and 50, do you imagine that the jagged edges would continue?**
Bob: Yes, it's because of an annual cycle. I would imagine that they would continue. It seems, though, it's been jagged the whole time and I think the phenomenon we're seeing is there's kind of a smaller cycle of the CO_2 concentration due to the seasons. And then a more global trend that the jagged lines are going up. So, if you were just looking at a very small sample, blowing that up it would look like this and I would say, "Oh, well, this is just cyclic. Nothing's happening. It's not really going up." But only when you step back and look at a large half a century period do you see it increasing.
Interviewer: **Cool. And then when you made these, one, five, and 50, how certain are you that these values are going to come true?**
Bob: Within what?
Interviewer: **Tolerance or range.**
Bob: Yes. Generally?
Interviewer: **Yes, generally.**
Bob: If I said maybe gave myself these margins of error probably – Well, it depends on what we do to curve this, but I would imagine we might do a little bit but probably not enough. Maybe 70 percent chance that it lands within here. But I don't really have any statistics to back that up.
Interviewer: **I noticed your margin of error, the circle that you drew around the one point, is smaller than the one for your 50 (chuckles).**
Bob: Yes, well, it's tougher to extrapolate further and further into the future.
Interviewer: **Why is that? Or why do you think it is?**
Bob: Yes. Well, two reasons. One is that if we start doing something to curb this, today it will take some time for that to ripple through the environment and change it. So, even if we did something now, it would still maybe take five or ten years to start to reverse the trend. But I imagine we're not going to curb it enough tomorrow. Maybe when it gets direr, we'll curb it. So, it's really hard to tell how dire it's going to get. How many people's minds are going to change. What the world governments are going to look like. As the future goes on, the divergent possibilities just grow exponentially. The second reason is that there could be some not human effect, but some physical effect. Or maybe when the Earth reaches certain CO_2 parts per million that a new function would better fit it. So, maybe it becomes a cubic function or maybe it caps off somehow for some other physical reason and not a human reason then that wouldn't be seen at this low of a PPM respectively.
Interviewer: **So, the low PPM goes from 310 to 400?**
Bob: Yes.

Interviewer: **I know this is not your background. I totally understand, but do you have ideas about when it might become dire? At what numbers approximately? Do you have a sense of that?**

Bob: Yes, one thing I'd heard in terms of temperature I kept hearing the figure of two percent or two degrees Celsius increase. It was either two degree or two percent. I think it's degree because that's a lot smaller. In terms of this, I'm thinking that I mean, parts per million. A million is ten to the sixth and these are of order 100 squared. So, we're looking at about 1/10,000th as a fraction of the atmosphere that CO_2 makes up. I don't really recall what I'd imagine if you get, maybe, to the next order of magnitude 1 in 100 that seems quite high for the variety of things that are in the atmosphere. But I don't know what the dire zone is.

Interviewer: **Good. I was just curious. So, then in this graph, it was taken in Hawaii, right? So, if you could imagine the people who created the graph wanted to do this in Michigan, do you think the graph would be similar, different? What would that data look like?**

Bob: I would imagine it would probably have the same overall global trend and it would also have jagged lines because – It might even be more jagged because we have more pronounced seasons. Greater variance in our temperature but maybe the global trend wouldn't be as clear. There might be more noise, if you will, from other pollutants that are put in the air.

Interviewer: **Do you think that the range for the CO_2 and PPM – Do you think that would be similar? Do you think it would be higher or lower?**

Bob: I would say maybe slightly higher because going off of my theory that there might be more pollution in a place that's surrounded by land with more people that are producing more things as opposed to an island that's surrounded by water.

Interviewer: **Okay. Do you think there are things – I know I'm going back to Hawaii again or just that graph – that people do that might impact in the shape of that graph?**

Bob: (crosstalk) Do you mean the researcher?

Interviewer: **The human activities.**

Bob: That's causing this?

Interviewer: **Yes.**

Bob: Yes, I don't get that from this graph alone because this doesn't have – if there was a separate graph that showed maybe human energy consumption or something like that. People have done that so that would give me the hypothesis that there's a connection, but then the second thing is that the correlation doesn't necessarily mean the causation. But there's also the physics and the theory behind it to explain why there would be a causation. So, in this graph alone no I couldn't, but I've seen similar graphs and also ones side-by-side that show the increase in human activity that they think might cause this. So, from that, that's why I think that it is caused, at least in part, by human activity.

Interviewer: **Mm-hmm (affirmative). Do you see this graph – I know you said you hadn't seen it before, but graphs like these do you see it outside in other places like outside of school?**

Bob: Well, in the 2000s culturally there was the Al Gore movie. I don't remember the name of it.

Interviewer: **Inconvenient Truth.**

Bob: Yes, Inconvenient Truth. So, I think the graph he was showing, the one that got really steep, was temperature. But I'm sure there were things like this in here. I've never really looked, honestly, that in-depth into them. Yes, I've seen these things in passing.

Interviewer: **Cool. That's all the questions I have for that graph right now.**

Bob: Great.

TEMPERATURE

Interviewer: **I'm going to show you a second graph. So, have you seen this graph before?**

Bob: I have not seen this graph.

Interviewer: **No? All right. I'm going to ask you very similar questions. Taking a look at the graph, what do you think it's about? (pause)**

Bob: I don't know what NZ is. Maybe that's the name of this station where this was conducted. But it looks like it's a graph of temperature versus time. It says temperature anomaly. Maybe they're only plotting temperatures that seem to be outliers. I'm not exactly sure. It also says, "Minus 1981 to 2010," but yet there are points between 1981 and 2010. But in very general terms, it looks like a temperature versus time plot taken at this NZ7 station. Average temperature.

Interviewer: **The NZ stands for New Zealand. (chuckles)**

Bob: Okay, New Zealand.

Interviewer: **Yes, that's not something I would expect people to know. So, this graph, temperature over time, do you have ideas about who might've created this graph?**

Bob: There's no indication here besides the New Zealand and seven station, which again I think might be the name of the site, the laboratory, where they're taking this. But beyond that, they probably, again, either a government lab or it could be a private company. But some researchers that were interested in this question.

Interviewer: **Do you know how they might use this graph? Do you have ideas?**

Bob: Probably similar to the last graph. Governments will use it to inform policy.

Interviewer: **Mm-hmm (affirmative). What about who the graph might be useful for?**

Bob: Yes, again, policymakers, and research scientists.

Interviewer: **Okay. So, looking at this graph, what do you think would be the most important things people should notice about it if they're trying to understand it?**

Bob: Well, one note is at first, I thought maybe this is some temperature difference because it is centered at zero. But then I remembered that zero Celsius isn't as cold as I think it is, right? Because I'm used to Fahrenheit and zero is very cold, but I think zero Celsius is warmer than zero Fahrenheit.

Interviewer: **Yes.**

Bob: Yes, okay. I think this might just be some regular temperature not a difference. Well, actually this is a much larger range than the last graph.

Interviewer: **Than the previous graph?**

Bob: Yes, that's twice a century. It seems more noisy or noisier. It's not as fine. They didn't seem like they took – here it looks like they took multiple measurements per year. Here they probably just took one per year. Hopefully around the same time of the year. So, this jagged pattern probably isn't due to seasons. It could be due to some other natural phenomenon. But in general, it's not as pronounced as the other, but there is I would say an upward tending slope to my naked eye. You'd probably have to do some computer fitting. It especially looks more pronounced right after 2000 going upwards. Now, this could just be a little spike that comes back down and that could have a bias. It's definitely not as clear as the earlier one. But then, again, I remember that the temperature I don't think had to increase that much to hit a dire zone as opposed to maybe the CO_2.

Interviewer: **So, I know you talked about a bunch of different things. If you had to summarize what you thought the most important parts to notice were—**

Bob: A slight upward trend and very noisy.

Interviewer: **Mm-hmm (affirmative). Okay. I know you said that it's noisy. It's going up and down. Do you have ideas about what might be causing it as opposed to what's not?**

Bob: Yes, I was trying to think about that. It seems like the wavelength, the period, is over the – Well, it's not even really a regular period, but maybe it seems to be three or four years or something. Three or four years. I don't really know what happened cyclically there in

New Zealand. I would guess that because I can't really think of anything that's cyclic with that time period. It could just be statistical noise or it could just be that they're so many factors that go into the temperature that it's tough to – yes, that could be causing this. Also, it's quite a small scale.

Interviewer: **For the Y-axis range?**

Bob: Yes. On the order of ones as opposed to the order of 10s.

Interviewer: **Okay. What about that upward trend that you saw? Do you have ideas on what might be causing that?**

Bob: Well, again, I think these from the theory that I learned that these are linked. The more CO_2 you have traps more heat and increases the temperature. It seems like the accelerating of the slope in the CO_2 correspond to a sharper increase in the temperature as well. But it's tough to really say that conclusively.

Interviewer: **You mentioned that the timescales were different, right? This one was over a longer period.**

Bob: Yes, I mean, I feel like temperature's a very natural thing for humans to record. So, they probably have been doing that for a while and didn't start looking at CO_2. Because they had to think of different theories of, "Why would the temperature be going up?"

Interviewer: **Okay. So, do you think the displayed range of time that's on the temperature graph – What do you think why the graph creators chose to display that time period?**

Bob: Again, either this graph is made around 2015 or they haven't compiled the data yet for more. But going back this far, probably to show before we had too much industrial explosion or cars running on gasoline. What the world kind of looked like.

Interviewer: **When do you think the cars?**

Bob: I'm trying to remember.

Interviewer: **Yes, I'm so poor with history, I don't know anything (chuckles).**

Bob: I'd have to say cars are invented probably somewhere around here, right? Okay, well, Great Gatsby's in the 1920s. They had cars then.

Interviewer: **Okay (chuckles).**

Bob: Because I remember from the book and the movie.

Interviewer: **The movie? The book? Yes.**

Bob: Probably around the turn of the 20^{th} century. Turn to the 20^{th} century. But it was more of a luxury, you know?

Interviewer: **Mm-hmm (affirmative). Not many people had it.**

Bob: Yes, I think the 1950s is when it really became a –

Interviewer: **Necessity, maybe?**

Bob: Yes. There where the middle class it started to become a commonplace thing. I would say just so that you can see pre-fossil fuel explosion and post.

Interviewer: **So, the 1960s is when you're making that border, that mark?**

Bob: Yes, I'd probably say 1960 and then there's maybe another type of border around 1990 when we've probably increased our energy consumption worldwide to an even greater extent than this period between 1960 and 1990.

Interviewer: **What kinds of stuff were you thinking that people did to increase that energy consumption?**

Bob: Burning more fossil fuels. Because I recall – I have to look at a graph of things over time – that the human population has kind of exploded. In 1900, it was still maybe around three or four billion and now it's really increasing quite rapidly now. So, more people need more energy and we haven't switched over to more renewable sources to keep up with that. So, we're burning more fossil fuels, which I think the theory goes—these release more CO_2, which traps more heat and increases the temperature.

Interviewer: **Cool. Can you circle that point right there?**

Bob: Yes.

Interviewer: **Great. So, again, what do you think that point represents?**
Bob: I'd say that point is the annual average temperature. Yes, New Zealand Seven station 1971-ish in Celsius.
Interviewer: **And do you think that point represents a single measurement or multiple measurements?**
Bob: It says average temperature, so I'd say they probably took multiple temperatures over the year and averaged it to that point. Yes, now that I think about it, that could be another reason for the great jaggedness is that it's averaging over a whole year.
Interviewer: **So, there's lots of variability in it?**
Bob: Yes.
Interviewer: **Okay, cool. So, if you had to say one year later, where do you think the next point would fall?**
Bob: From here?
Interviewer: **From the end. (crosstalk) Always from the end, (chuckles) sorry.**
Bob: Yes. Well, it's tough because it could be due for a down or slight up. But I would say, in this range and maybe on average right around there.
Interviewer: **Okay. Can you put a line next to that one? And then what about five years later?**
Bob: Is this ten, five? Five's like here. Probably here in this range.
Interviewer: **Okay, and then 50? (pause)**
Bob: Something like that.
Interviewer: **Okay. Awesome. Can you say a little bit about how you decided where to put the ranges, and the points, and all of that?**
Bob: Yes. I drew a line that best fits starting at 2000 and extended that line and put points at the various times were asked. Again, here this range is based off how high or the size of these jumps here.
Interviewer: **So, your one-year range is based on the ranges of previous?**
Bob: Yes. And five's extended a little bit. Not that I'm thinking that the jags are going to get bigger but that's just my error. Again, because it's tougher to extrapolate further into the future.
Interviewer: **So, I'm kind of curious. You used it from 2000 on and then previously you had a best fit line that went from 1910, the beginning. What was your thinking on choosing to base it off of that more recent line?**
Bob: Yes. I think they showed such a long period to suggest that this steeper trend is not part of some overall more global thing that's going like that. So, if this is the world we live in now, physics doesn't really care about what happened earlier. So, I would imagine that this sharp increase isn't part of some cyclic nature before. So, this part doesn't really play. The part before 2000 doesn't really play that much of an influence. Maybe this line is a little too steep, but yes, the current physical state doesn't really care about what's happened earlier. I would imagine whatever's causing this increase if it is human activity, is likely to continue as our population grows.
Interviewer: **Okay, cool. So, this is taken in New Zealand. Do you have ideas about why they're measuring temperature in New Zealand?**
Bob: Probably for a similar reason to Hawaii, it's also an island. A bit bigger. So, for similar reasons probably less – I guess we're not doing CO_2, we're doing temperature. But there could be less statistical noise when you're more isolated like that.
Interviewer: **Can you give us some examples of statistical noise?**
Bob: Well, for the CO_2 I was thinking about all the pollutants that we just put in the air via city. But with temperature, maybe there aren't as many pollutants. I don't think that the moving around of people really changes the local temperature. Maybe ever so slightly. So, maybe it's not as important that it was in New Zealand. I'm also thinking New Zealand is in the southern hemisphere and I would think it's closer to the South Pole than

it is. I'll bet the distance from New Zealand to the South Pole is probably similar to the distance from us in Michigan to the North Pole.

Interviewer: **I don't know the answer to that.**

Bob: Yes, me neither.

Interviewer: **(chuckles)**

Bob: But the fact that it's not at the equator where the temperature doesn't – well see, I would think maybe you'd want to do it there where you don't have so much variability with the seasons. But it's not in the equator where it's very hot all year round and it's not too far to the poles where it's very very cold all year round.

Interviewer: **So, it's somewhere in between?**

Bob: Yes, maybe to talk about that that's more natural where a lot of humans live. Although, a lot of humans do live near the equator as well.

Interviewer: **Okay (chuckles). So, talking about humans. Are there things that people do that might affect the shape of this graph, do you think?**

Bob: I would imagine that this increase is…a direct cause of that is because of the CO_2 and one of the causes of that is due the human activities mentioned earlier such as accelerating our fossil fuel consumption. So, the humans aren't directly causing it, but I think it's indirect from the CO_2, which is in part directly caused by human activity.

Interviewer: **Does it matter that this graph is in Hawaii and this one's in New Zealand?**

Bob: Well, yeah. But I'd imagine that these types of graphs, this type of data's been taken in a lot of different places on Earth and that people have compared these things. But if you're trying to make a direct correlation from here to here, yes, it definitely matters that they're not in the same place. It'd be better if they were. But if what I suspect is true where people are seeing similar trends all over the Earth, then it wouldn't matter as much as you see. It's more of a global phenomenon than a local one.

Interviewer: **Okay, cool. Do you have time to do one more graph?**

Bob: Yes, that's fine.

Interviewer: **Cool. Thank you. So, that's all the questions I have for this one. And this is the last graph. All right. I forgot one more question. You talked about how the temperature and the CO_2 because it's a global phenomenon, you think that they might be related. Are there other connections between the two graphs that you see, or differences, or what do you notice? Because I know you were doing a lot of comparing throughout the whole entire time, but I didn't know if there was anything else that you wanted to add.**

Bob: Besides the general upward trend and then an increase in the slope at the turn to the 21st century, and the jagged nature of them. That's what I would say would be the similarities.

ARCTIC

Interviewer: **Cool. Great. All right. So, now the third graph. Have you seen this graph before?**

Bob: I have not.

Interviewer: **No? Okay. So, again, what do you think this graph's about? (pause)**

Bob: This looks like a plot of the amount of ice that is currently – well, not currently – covers the Arctic Sea at a given point in time in September of that given year.

Interviewer: **Okay. Do you have ideas of who might create a graph like this?**

Bob: Similar to the last two. Government organizations or climate researchers.

Interviewer: **Who would use these kinds of graphs?**

Bob: I think it'd be used probably by the same people that it's been created by but also for public knowledge as well. The people making them are probably trying to disseminate it to the public realm as well.

Interviewer: **Mm-hmm (affirmative). Can you say a little bit more about disseminate?**

Bob: Yeah. It can be tough to get people to pay attention to scientific findings that don't seem to actively affect their day-to-day lives. I mean, you see…people say, "Science says two cups of coffee a day is—you know…" Because that's what people think really affects them. Yes, I'm sure there's a large push and campaign to share this knowledge because it is knowledge for all of humanity. So, I'm sure that's part of their, if not the main, reason that they take the knowledge to share it.

Interviewer: What do you think are the most important parts to notice about this graph?

Bob: Well, it looks like it had a somewhat flat slope and now, again, starting close to the turn of the 21st century a decrease in slope. I think the main point is that the amount of ice covering the Arctic Sea is decreasing, presumably, because it's melting.

Interviewer: So if you had to describe the pattern, I know you said it was flat and then it's decreasing, how would you describe the pattern to someone who's not seen this graph before?

Bob: I would say it looks like a plateau where it's flat for a certain period of time and then a downward slope starting at about the year I was born, 1995.

Interviewer: (chuckles) Do you have ideas about what might be causing the up and down that we see in the graph?

Bob: Yes, first I was thinking seasons but it says that these were all taken in September. So, it could be statistical – you know, human error. The period seems to be, maybe, a couple of years.

Interviewer: Do you have ideas about how the people who collected this data, how they did it?

Bob: Yes. I was thinking about that because how do you measure how much ice there is? Maybe they take aerial pictures and they can use geometry to make a scale between what they see in the picture and what the actual distance is. Maybe they put down markers and so they say, "That's a mile," and then they take the picture and they see the two markers. Then, from there, they take the shape of what they see. Either have a computer look at the area of what that is or break it up into – you could do some type of numerical integration to estimate the area and then I would imagine they have some idea of how deep it is as well…given that we know the percentage of ice that floats and how much is below it. But here it's just square kilometers so they're just concerned with the area. Yes, maybe probably an aerial photo is what I would say and that could be why it only starts in 1980. Well, then again, we start putting stuff into space in the '70s I think. So, that's probably when we started having that technology to do that.

Interviewer: So, the question I was asking before was the –

Bob: Why it's so jagged?

Interviewer: Yeah. Like what was causing it? (chuckles)

Bob: Yeah, I can't think of anything besides just statistical error.

Interviewer: Okay. And then you've already talked about the other two points. So, if you could circle this point right there. Can you say what that point represents to you?

Bob: This point says that there were about 10.5 million square kilometers of ice covering the Arctic Sea in September of 1996.

Interviewer: Okay, and then do you think that dot represents a single measurement or multiple measurements?

Bob: It says in September. I would imagine though that they probably took multiple measurements in each September and averaged them, but it doesn't explicitly say that.

Interviewer: Do you think they're still collecting data on this?

Bob: Yeah, probably. I don't know why they wouldn't be. It seems as though they've extended it to 2020 and they also have a little gap here, 1975/1980, where they don't have any points. I don't know why. Maybe this is an older graph. But I would imagine that they're still collecting data, yes. Maybe it's tougher too. Maybe it's more broken up, but I'm not really sure.

Interviewer: **Okay. So, then one year later –**
Bob: The ice that is. One year later.

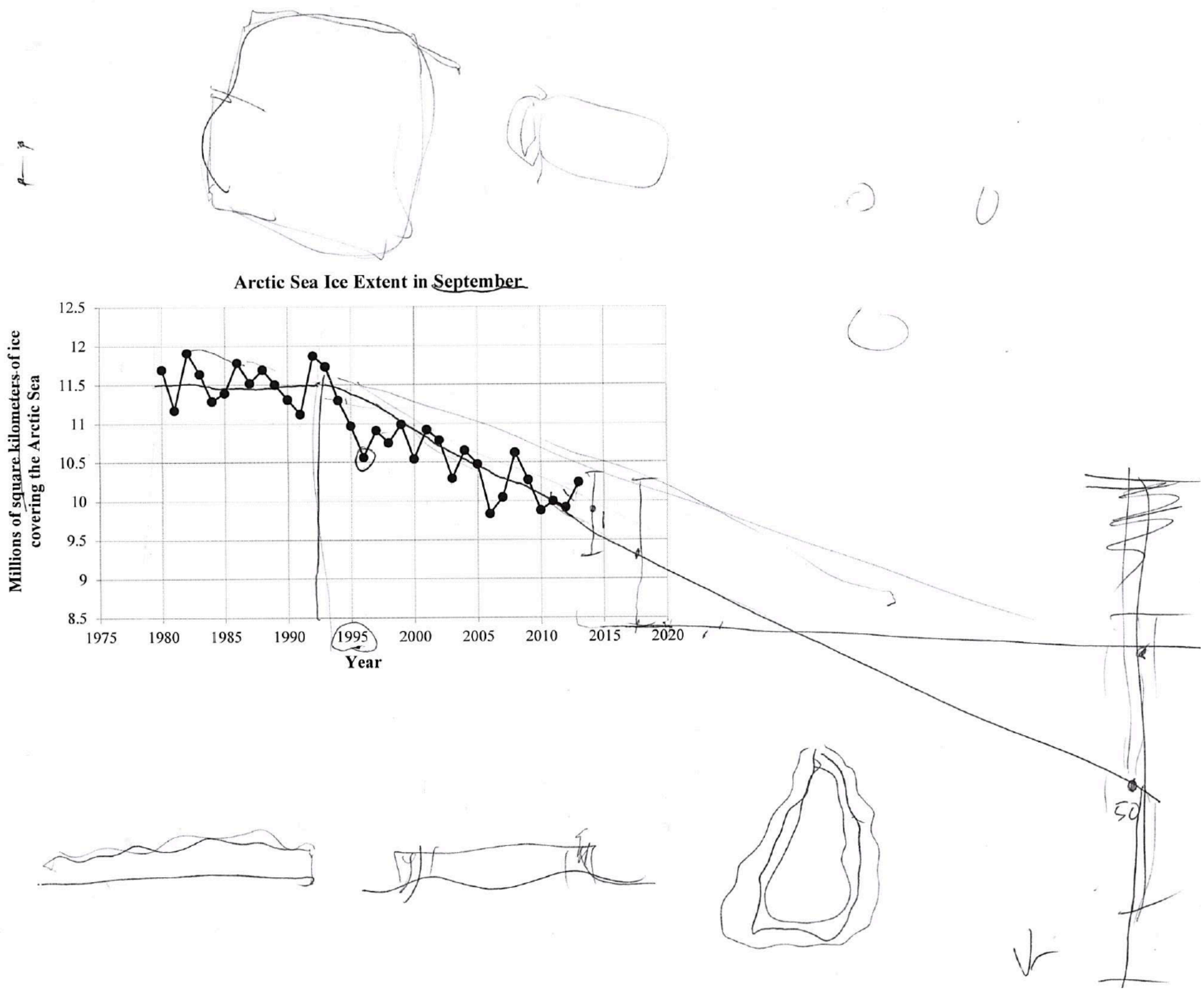

Figure G.1 Bob's Arctic graph

Interviewer: **Yes.**
Bob: Probably here … some error like this. Five years…here. And 50, was it? Well, this whole thing so…25.
Interviewer: **Do you need more space?**
Bob: I think it just fits, but I would imagine that it's going to not be that big.
Interviewer: **Great. So, the rationale for how to locate these points?**
Bob: Yes, I'm going to draw in a best-fit line extending that. Not really taking into account the plateau before.
Interviewer: **Uh-huh. I have a question. These points for one year and five-year look like they're sort of in the center [of error range], but 50 years it looks like it's a little bit not in the center of the range. Is it because you ran out of paper?**
Bob: Yes, that's just because I ran out of that. It should probably be more in the center of the error range. I'm just trying to show that this one goes up. It's a bigger error so this one extends down further, yes.

Interviewer: **Okay. So, yes, you definitely wanted to go. Okay, great. The rationale, it's pretty much similar to what you were saying for the previous graph?**
Bob: Yes, similar to these graphs here.
Interviewer: **Okay. Cool. Do you think there are things that people do that might affect the shape of this graph?**
Bob: Yes, I think the…humans do things that cause an increase in CO_2 concentration, which causes an increase in temperature, which would melt the ice, which would decrease the area of ice in the Arctic Sea.
Interviewer: **So, the same activities that you talked about sort of just trickles down to this one?**
Bob: Yeah.
Interviewer: **Okay. Got you.**
Bob: Exactly.
Interviewer: **Are there other connections that you see between the three graphs?**
Bob: The time that each one of them starts to have its slope increase more greater than previous seem to be all around the turn to the 21st century, around 2000. These two increasing at a greater rate—previously this one's decreasing at a greater rate than previously.
Interviewer: **And then the location? So, this one's in the Arctic Sea, right?**
Bob: Mm (affirmative).
Interviewer: **If we were to plot this in, say, Antarctica as opposed to the Arctic Sea, do you think the graph would be similar?**
Bob: Well, I know that Antarctica is an actual continent. So, there's land there with a sheet of ice on it. Whereas the Arctic Sea is just ice on top of the water. So, I'd imagine that…it…well, so if you're on land in Antarctica and the ice melts, it would probably just decrease its height but still be the same area because it's fixed by the land. But if you're on the water, then whole chunks could melt or fall off into the sea so that would decrease the area. So, you'd probably wouldn't see as much of a decrease. I know Antarctica, maybe, here's the land and the ice sticks out. So, some of it is on the water. So, that part is probably receding to look more like that. It's probably not as drastic as in the Arctic.
Interviewer: **Okay. So, you think the slope would be less.**
Bob: Yeah.
Interviewer: **I think that is all the questions I have you.**
Bob: All right.
Interviewer: **Thank you.**
Bob: Sounds good.

END TRANSCRIPT

G-2: Esmerelda's interview transcript and sketched predictions for the Arctic graph

KEELING

Interviewer:	**Great. So, here is the first graph. Have you seen this graph before?**
Esmerelda:	No.
Interviewer:	**No? Okay. So, taking a look at it, what do you think this graph is about? (pause)**
Esmerelda:	Sl (ph)—looking at the concentration of carbon dioxide throughout different years. And it keeps it going. I noticed it keeps it going back and forth. Parts per million. (pause) And it's the average carbon dioxide concentration. So, I'm guessing in ph (ph)—in the atmosphere, but I'm not sure.
Interviewer:	**Mm-hmm. Okay. What makes you think "atmosphere"? Just out of curiosity.**
Esmerelda:	Because I know carbon dioxide is a thoroughly major gas component of the atmosphere, besides oxygen and nitrogen. That's kind of what I think where it belongs. I also know it plays a role in photosynthesis, so I might—it be dealing with that.
Interviewer:	**Mm-hmm. Mm 'kay. I'll ask you a little bit more about your responses in a bit. But first, I was wondering: do you have ideas about who might've created this graph?**
Esmerelda:	I mean, I'm guessing some kind of, like, research biologist. Or, like—I'm thinking maybe biology, because carbon dioxide plays a role in photosynthesis. But this isn't Mauna Loa Observatory, Hawaii, from a CO_2 program. Maybe they're dealing with global warming.
Interviewer:	**Mm-hmm. Mm 'kay. Where do you think a graph like this might be used? (pause)**
Esmerelda:	We can use it to monitor the carbon dioxide level, and use it as a gauge to see maybe where we think we might be going in the future. And it could be used to try and identify what might be causing it. Because I'm guessing—I mean, this one says it's from Hawaii. If we have ones from different places, then we can compare them to see which ones have the highest carbon dioxide rate, and highest rate of increase.
Interviewer:	**Mm-hmm. You mentioned that it's like, "These are things that we can do to see."**
Esmerelda:	Mm-hmm.
Interviewer:	**So, I was wondering who you thought the "we" would—**
Esmerelda:	Oh.
Interviewer:	**—count. Who counts as the "we"?**
Esmerelda:	The sci (ph)—the research scientists that are working on it.
Interviewer:	**Uh-huh.**
Esmerelda:	Yeah.
Interviewer:	**Okay. So, basically, in their work. Like, the—**
Esmerelda:	Yeah.

Interviewer: **—stuff that they're doing? Do you think this graph would be useful to other people? Or primarily the research?**

Esmerelda: Yeah, I think. I think primarily the scientists that are working on it. But it's probably also—if they find out that it has any kind of correlation to things that ordinary citizens are doing, maybe, then it could also influence ordinary people, I guess.

Interviewer: **Mm-hmm. Like (chuckling)—so, can you say a little bit more about how that might influence ordinary people? Like, what would they do?**

Esmerelda: Well, if it's about—if it real—if it's about global warming, and they're trying to find ways to prevent the carbon dioxide increase—because it looks like it's increasing from the graph—then they could—then the—there might be a way for, just like any person to influence that by what they're doing. Like, electricity usage, for example.

Interviewer: **Mm-hmm.**

Esmerelda: But if it's not about that, and it's more about how plants maybe react to increased carbon dioxide, or something like that—assuming that it is carbon dioxide in the atmosphere—then it could maybe be more about in what areas plants maybe grow the best, or in what conditions.

Interviewer: **Mm-hmm. Mm 'kay. Great. So, the people who are using these graphs: if they had to pay attention to a certain part, they—what part do you think is the most important part they should be paying attention to?**

Esmerelda: I think it's definitely important to make sure that you're looking at this scale and what each—I guess, what the input and output of the graph represents.

Interviewer: **Mm-hmm. Can you say a little bit more about input and output?**

Esmerelda: The year is the input, and output is the carbon dioxide concentration. And that helps you realize that the higher the graph is, then the higher the carbon dioxide concentration is in that year. It's also helpful to notice that it's measured in parts per million. So, it doesn't really start at zero, because that would be zero parts per million. I'm guessing that's not really found in whatever they're testing, because they started at 310 pow—parts per million. And the year doesn't start at zero, either, because they start collecting the data at what looks like around 1960.

Interviewer: **Mm-hmm.**

Esmerelda: Yeah.

Interviewer: **Do you have ideas about why they started in 1960, for this data collection? Or why they—like, the data displays from 1960 to 2015?**

Esmerelda: I'm guessing it's probably when people began to have interest in carbon dioxide concentration, and began to really collect reliable data versus just estimating or maybe not collecting data at all.

Interviewer: **Mm-hmm. So, you mentioned reliable data. Can you say a little bit more about what makes it reliable?**

Esmerelda: I'm not really sure how they measure the carbon dioxide concentration. But I would assume that, when you're measuring pretty much anything, there can be different tools that you use to measure, and some are more accurate or precise than others.

Interviewer: **Mm-hmm. Mm 'kay. So, maybe the tools—**

Esmerelda: Maybe the technology was less advanced, and so scientists today aren't sure, maybe, about what—about whether the data back then was reliable or not. Or maybe they just didn't start collecting it until around 1960.

Interviewer: Okay. So, there are a couple of possibilities. Okay.

Esmerelda: Yeah.

Interviewer: You also mentioned the carbon dioxide concentration in PPM.

Esmerelda: Mm-hmm.

Interviewer: Do you have ideas about why the researchers chose to measure CO_2 concentrations, as opposed to something else, like nitrogen or oxygen?

Esmerelda: Well, I know nitrogen doesn't really have that much of an im—well, I mean, it has an impact on plants and animals, because it's definitely needed for life. But since it's a lot more common than some of the other gases, and only a very few organisms can actually use it when it's in the atmosphere, it doesn't really play as much of a role. And I think maybe, also, humans aren't—maybe—it's not—as of m—it's not of much interest right now, because scientists are discussing a lot about global warming right now, and that tends to have a lot to do with carbon dioxide. Because that seems to be the—one of the main greenhouse gases that we're releasing. So, I'm thinking that might be why they chose carbon dioxide concentration, versus nitrogen or oxygen.

Interviewer: Okay. Great. And then, you—earlier, you said that the pattern was increasing. Do you have ideas about what might be causing this pattern to go up?

Esmerelda: I'm thinking it probably has a correlation with the technology increase. It—I mean, it increases at kind of a shallow curve from 1960 to 2015. But I know that people have definitely been using more technology that uses electricity, which is basically harnessed through fossil fuels. And there's also a lot of—I know there's a lot of—like, a lot of cattle farming on Hawaii, and I'm wondering if that has something to do with the carbon dioxide release. Because cattle farming tends to produce a lot of carbon dioxide. So, I'm thinking that might—those might be some of the major causes.

Interviewer: Mm-hmm. Okay. Great. And then you also mentioned this pattern within the shallow curve. Do you have ideas about what might be causing that pattern?

Esmerelda: Well, there's a smaller graph within that says—that goes between January—well, that goes throughout a year, and it shows how it curves up and down. And it looks like it—the—I mean, assuming that the scale on the side is similar to the carbon dioxide concentrations scale that, up higher, is a lot more carbon dioxide than—it shows that, throughout the spring and summer, there's an increase in carbon dioxide, and then, around late summer and fall, it decreases. And I think that might be due to, maybe, the season cycles on Hawaii. Like, maybe—I don't really know how their, how the seasons work in more tropical regions. But I know that if there's, like, maybe a more rainy season, then plant growth will be more vigorous and probably use up more of the carbon dioxide. So, I'm guessing that might have something to do with it throughout every year, when plant growth is most active. That causes the carbon dioxide to increase or decrease.

Interviewer: **Mm-hmm. Okay. Earlier, you had mentioned that you possibly thought that photosynthesis might have something to do with this. Can you say a little bit more about that now? Like, how you were thinking?**

Esmerelda: Well, I know that plants use carbon dioxide for their metabolism. So, the fact that the, within the curve, the graph goes up and down, kind of like a sine wave. It probably has to do with the plants. And also, I know that there's a certain range in which plants prefer their carbon dioxide to be for their optimal growth. Because if they don't have enough carbon dioxide, then they can't really control their metabolism, and they can't grow very much. But if there's too much carbon dioxide, I know that plants don't really grow that well, either. And I'm not really sure why. But they might—scientists might also be looking at this using this graph to figure out in what range plants grow the best, and maybe why plant growth has changed, possibly.

Interviewer: **Mm-hmm. Okay. Great. So, I'm going to circle a point right here. Can you tell me what you think that point represents?**

Esmerelda: Can I use the rulers for this?

Interviewer: **Yes. Definitely. (pause)**

Esmerelda: Looks like it's at a little bit less than 360 parts per million. Three hundred fifty-eight, maybe. And it's a point in time a little bit less than halfway through – 1991.

Interviewer: **Okay. So, at that point in time, and at that concentration, do you think it represents a single measurement that was taken, or multiple measurements?**

Esmerelda: Since it's the monthly average, then it represents, like, the—that they probably took a lot of samples throughout the entire year, and they created an average for what each month—for the carbon dioxide concentration for each month. So, it probably—I'm not sure how many, but it represents definitely more than one.

Interviewer: **Okay. And then, when you're looking at this whole data set, right? Do you think they took the measurements in one location, or in multiple locations?**

Esmerelda: I would think that they take it in the same location, because then, that ensures the data isn't affected by the location. Because if they take it in multiple locations, then that could be another variable that is being manipulated that they would probably, I would assume, want to keep constant.

Interviewer: **Mm-hmm. Okay. And, see, this one location, right? You mentioned the Observatory, and this is in Hawaii. Do you think that if they were to do CO_2 concentration during that same time period, but they did it in Michigan, how do you think the patterns would compare? (pause)**

Esmerelda: I think, if I remember correctly, carbon dioxide tends to concentrate itself near the poles. So, I would assume that the farther north you go, the higher the general concentration would be. But I'm not really sure about that. I would also think that, maybe if you go somewhere that's a lot more industrially based, and has a lot more—or maybe has a lot more farming that releases carbon dioxide. Or has a, just a general lifestyle that results in more carbon dioxide release, then there would be a higher concentration. So, I would think that—I know that since Hawaii has a lot of cattle farming, I would assume that in the immediate area, near that, there would be a lot of carbon dioxide. But there's some cattle farming in Michigan, too, and I know that since Michigan's farther north, that might also cause there to be more carbon dioxide. So, I'm not really sure, comp (ph)—if I compare the two, if it would really be that much of a difference.

Interviewer: Mm-hmm. So, probably like, maybe in the, relatively the same place?

Esmerelda: Yeah. I think so.

Interviewer: Okay. You mentioned cattle farming now, a couple times. I was—

Esmerelda: Yeah.

Interviewer: —wondering, like, have you been to Hawaii before? Or—

Esmerelda: No, but I know that my dad went there as a business trip.

Interviewer: Uh-huh.

Esmerelda: He talked about there being a lot of cattle there.

Interviewer: Got you.

Esmerelda: It seems like it's a big thing there.

Interviewer: Okay. All right. Great. All right, so, you said—like, so, this graph is, ends right here. If you had to make a prediction for one year later, five years later, fifty years later, where do you think those dots would be? And go ahead and mark them, like, a dot with the one, five, and the fifty next to it. (pause)

Esmerelda: So—

Interviewer: Feel free to use the ruler, too—

Esmerelda: —it looks like it.

Interviewer: —if you'd like. Okay.

Esmerelda: It looks like it ends at 2013. No. 2014. So, 2015, I would assume it has a—since it—kind of, it oscillates for, throughout the year—

Interviewer: Mm-hmm. (pause)

Esmerelda: During January, it seems to be about in the middle. So, I would assume maybe it would look something like that.

Interviewer: Mm-hmm. And that's your one-year prediction?

Esmerelda: Yeah. And then, for—what was the other one? Fifty years?

Interviewer: Five and fifty.

Esmerelda: Five and fifty?

Interviewer: Yep. (pause)

Esmerelda: So, a five-year increment would be about there. (pause) There would have to be five of these oscillations between, around—

Interviewer: Okay.

Esmerelda: —here. Maybe looking somewhat like that.

Interviewer: Okay.

Esmerelda: And it seems like it keeps increasing faster and faster.

Interviewer: Mm-hmm. So, could you put, like, a one next to your one-year, and a five next—

Esmerelda: Mm-hmm.

Interviewer: —to your five-year? Yeah. Make a dot. Yeah. Great.

Esmerelda: Yeah. (pause) So, 50 would be here. And based on all the curves going, it would be significantly higher.

Interviewer: Okay. So, if you need—

Esmerelda: Yeah.

Interviewer: —here's extra pigment. (Pause from 00:19:23 to 00:19:45)

Esmerelda: So, maybe around there. But I don't—I'm not really sure.

Interviewer: **Okay. Great. Could you—would you mind putting a 50—**
Esmerelda: Oh.
Interviewer: **—next to it?**
Esmerelda: Yeah.
Interviewer: **Yep. Great. Awesome. So, now, I'm going to ask you, like—sort of like, what were your thought processes when you put down the one, five, and fifty? Like, how did you decide? Like, you knew there was five oscillations, but that was, like, the top of the oscillation versus the bottom. Like, so, you were thinking—like, when you made these predictions. (pause)**
Esmerelda: I kind of generalized it based on the, what seemed like an exponential curve. And I know exponential curves: they keep increasing faster. So, I knew the five would be a little bit higher than the one, and the fifty would be a lot higher than the five. (pause) And as far as the year, I wasn't really sure. I'm assuming that when they—that the new—the beginning of each year's—since the beginning of the year each year's in January—and it looks like at this part of the graph, it's kind of in the middle. So, I tried to kind of start it in the middle, and end it in this one. It looks like it's kind of at the top. But—
Interviewer: **But you meant for it to be in the middle.**
Esmerelda: Yeah. I meant for it to be in the middle.
Interviewer: **Okay. Yep; that's fine. How certain are you that these predictions will come true?**
Esmerelda: I'm not really that certain, because for one thing, I don't really have any number-based math to back it up. But also because I'm guessing that the carbon dioxide concentration, when it gets too high, it could cause other things to happen, such as, like, decreased plant growth. Or maybe people—a change in, like, the technology used could also cause a change in maybe the carbon dioxide concentration, or a change in lifestyle. And there are so many factors that'd influence it. It's likely that it's going to follow the same pattern that it has, but I can't really be sure.
Interviewer: **Mm-hmm. Yeah. So, you say you're uncertain about the—that these predictions will come true. Are—like, are you more certain about, like, maybe certain predictions over others? Or—**
Esmerelda: I'm definitely more certain about the one than I am about the fifty, and more certain about the five than I ah (ph)—or, more certain about the—yeah. More certain about the five than I am about the fifty.
Interviewer: **Mm-hmm.**
Esmerelda: Fifty years is a much larger increment of time, so it's a lot harder to predict than, say, one year or five years.
Interviewer: **Okay. And then, compared to one or five, are you equally certain about both? Or more certain?**
Esmerelda: I'm more certain about the one, because it's a smaller increment of time than the five.
Interviewer: **Okay. Got you. So, but you said that you've not seen this graph before. But have you seen graphs like this outside of school? Like, in the news? Media? Stuff like that?**

Esmerelda: I've seen, definitely, a lot of exponential graphs. And a few times, I've seen graphs that—like I mentioned earlier, the sine waves that oscillate up and down: I remember seeing some—the—they weren't really represented the same way as this graph, but they had a graph similar to this that showed the average carbon dioxide emissions, not concentrations. And it was average throughout the year. Or, not throughout the year, but an average for each year. And it was also increasing.

Interviewer: Mm-hmm. Where did you see these kinds of graphs? You mentioned the sine waves. Like, where do you—where do you see—or do you remember where you've seen them?

Esmerelda: Or the tangent wave, I think, was what I meant. But I remember, I—in Geometry, I saw—we talked about oscillating waves. And I—in Science Olympiad, we also talk about oscillating waves, because it has to do with sound production and—and Chemistry, also. Because an oscillating wave is also—a light wave is an oscillating wave.

Interviewer: Mm-hmm. Okay. Great. And then—so, these different places, do you th (ph)—earlier, you mentioned that people might influence the graphs. So, do you think that there are things that people do in their daily activities that might affect the shape of the graph?

Esmerelda: Yeah. I think that since most of our electricity comes from fossil fuels, and that the burning of fuels releases carbon dioxide, that an increased use in electricity will cause an increase in carbon dioxide. But I'm not really sure what percentage of the carbon dioxide that's in the atmosphere at any given moment, really, is affected by people. It seems like it's—the amount—the lifestyles of humans has affected the carbon dioxide significantly, because it seems to be increasing. But I'm not exactly sure to what degree.

Interviewer: Okay. Great. So, that's all the questions I have for this graph.

Esmerelda: Okay.

TEMPERATURE

Interviewer: I'm going to show you a second graph. This—and I'm going to ask you very similar questions. Have you seen this graph before? No?

Esmerelda: No.

Interviewer: Okay. So, what do you think this graph is about? (pause)

Esmerelda: It looks like it's about temperatures from year to year. It's the average temperature for each year, and it looks like it's kind of—it's looking at the difference, I guess, in average temperatures, from the 1981 to 2010 normal, which I'm guessing is, like, the determined average temperature from that point in time. And I'm guessing that's what the dark line in the middle represents. What the normal temperature is. And then, points that are above it had an average temperature for that year that were a little bit higher, and points that were below it had an average temperature that were a little bit lower, I think, is what it represents.

Interviewer: Okay. Do you have ideas about who might have created this graph? (pause)

Esmerelda: Meteorologists, I'm guessing, that recorded the temperature. (pause) Yeah. I'm not sure where it is, but, yeah.

Interviewer: Mm-hmm. Okay. So, who do you think would find this graph useful?

Esmerelda: I think meteorologists would find it useful, because they can use it to maybe figure out why some temperatures are different from the average. But also, climate change scientists can also use it, because climate change affects the global temperature.

Interviewer: Mm-hmm. Hm. You mentioned climate change. What made you think of that?

Esmerelda: It looked like the temperature—it seemed like it was increasing a little bit, in this graph also, because most of the points at the beginning are below the average, and most of the points at the end are above the average. So, that also made me think of climate change. Because that—because the temperature's increasing, and that's what climate change is.

Interviewer: Okay. Sounds good. So, I was wondering: like, for a meteorologist who'd use this graph, and other people—do you think there are other people who might use this graph? Or primarily meteorologists?

Esmerelda: I think—

Interviewer: Yeah.

Esmerelda: —yeah.

Interviewer: Okay. What do you think is the most important thing they should notice about the graphs?

Esmerelda: I think it's important to notice that the zero was in the middle. That's a little bit unusual. And that the dots on the graph—the points on the graph, they don't necessarily represent—they don't represent the teh (ph)—the actual temperature. They represent the difference from the, of that temperature for the, for that year from the normal temperature.

Interviewer: Mm-hmm.

Esmerelda: So, that's—that kind of shows why it makes sense that the temperature scale should be only a few degrees Celsius, instead of a much wider range.

Interviewer: Mm-hmm. So, you were talking about these dots, and how they're reh (ph)—compared to the zero line. If you had to describe the pattern that you see, how would you describe it?

Esmerelda: The points definitely kind—they go up and down from year to year at a s (ph)—what seems like to be fairly random. But it looks like they generally over (ph)—there's an overall increase, but it's very gradual. (pause) At the beginning, there's most of the—most of the points are below the zero. And there are only a few that are above. And at the end. And in the middle, there's—it's roughly equal. And then at the end, there are some that are above, and some that are below, but it still—it still goes back and forth through year to year.

Interviewer: Mm-hmm. Mm 'kay. You mentioned that there was a few-degree range in the temperature. Do you—s and I know you said you didn't know where the location was. But for what purposes do you think that people might be measuring temperature for? Do you have ideas about that?

Esmerelda: I'm thinking that a lot of times, people pay attention to temperature as kind of an evidence for global climate change. But also definitely to see if the—they want to see if there are any tempet (ph)—patterns to temperature, because then, that could help them predict what the temperature's going to be like in the future.

Interviewer: Mm-hmm. Mm 'kay. Then, here, they also have a particular time period. It goes from 1910 to a little bit over 2010. Do you have ideas about why they might have displayed that particular time range?

Esmerelda: Because it's probably when they were recording the data. I'm guessing similar to the last one that we did. I think they probably weren't really—they weren't recording data at this—this is, like, NZ Seven-Station. So, I guess the—they're probably recording the temperature from a weather station, and they probably weren't recording the temperature before then.

Interviewer: Mm-hmm. Okay. Great. And then, if I picked, like, for instance, this point right here, could you tell me what that represents to you? (pause)

Esmerelda: It represents the year—well, it looks like 2009. And it was a year when the average temperature was—it's slightly below, then—slightly below the normal temperature.

Interviewer: Mm. Okay. And then, do you think that point represents a single measurement, or multiple measurements?

Esmerelda: Since this is the average temperature, it probably represents multiple. And I would assume that it's a lot of measurements, because it's over a year. So, they probably took lots of different measurements throughout—I would assume the temperature put, would probably fluctuate from yeeh (ph)—throughout the year. Like, it would colder in winter, and warmer in summer, so they take the average temperature from all times of the year so that it's not just from one time of year.

Interviewer: Okay. And then, again, the whole data set. Do you think this was taken in one location, or in multiple locations?

Esmerelda: I noticed that, in the title, it said, "adjusted for site changes." So, it seems like they didn't take it all in the same location. But they say "adjusted for site changes," so, I'm guessing that they might have changed the, what the normal temperature was like, based on where they were recording the temperature at the time.

Interviewer: Mm-hmm. Can you say a little bit more about changing the—how you were imagining they were changing the normal temperature?

Esmerelda: So, the normal temperatures, like, is represented by the zero that's the zero line. That's the least amount that the average temperature could be, different from the normal temperature. If the average temperature for a year was exactly the same as the normal temperature, then they would be on the zero line. And the normal temperature for 1981 through 2010? That's, like, the average temperature for all of those years, I'm guessing, based on the location. So, if they took a lot of data samples from one location throughout that, between 1981 and 2010, then that would be their normal average. And then, the—if they had a different site that had a slightly different climate, then they would take the normal from that. So, what they—it says what they do is they take the—this is minus the 1981 to 2010 normal temperature. So, what I'm imagining they do, is they take the average temperature for a single year, and then they subtract the normal or the average temperature for the location that it was taken. And then that's the deviation from the normal location.

Interviewer: **Mm-hmm. Do you have ideas about, like, why they are plotting it against a zero line as opposed to just plotting against the actual temperatures?**

Esmerelda: I think that the plotting it against the zero line, it also—it helps adjust for the—what'd they say, "adjust for site changes"? If you're plotting the actual temperature, then the temperature is just the raw data, and it would definitely—I'm guessing it would change based on where they were taking the data. And it looks like that's not the variable that they're trying to look at here. They're not trying to see what the different temperature—checked temperatures are in different places. They're trying to see how the temperature, in general, changed over a time period.

Interviewer: **Okay. Great. Again, I'm going to ask you to make one-year, five-year, and fifty-year predictions. And so, where do you think those would fall on the graph? (pause)**

Esmerelda: So, it looks like it's—has an upward slope. Kind of a shallow line.

Interviewer: **Okay. (pause)**

Esmerelda: Yeah. I think 2060 (ph) would be about there. And then, I'm guessing that the one-year prediction would be here. So, it would be slightly above the average. But I'm not really sure, because the points, they go above and below the average. So, I mean, it could be probably anywhere from up here to maybe down there.

Interviewer: **Okay.**

Esmerelda: And then—

Interviewer: **So, is that range?**

Esmerelda: Yeah. And—(pause)—five-year. That would be like—five-year would be about the same, but just slightly higher, with the similar kind of range. And the 50-year would be even higher, but still not that much higher. (pause) Probably with the similar range. Because I'm guessing that, since the temperature's influenced by a lot of different factors, it goes up and down from year to year.

Interviewer: **Mm-hmm. Mm, can you say a little bit more about why you think the ranges—why you have the same range for each point?**

Esmerelda: It's not strictly linear. It goes back and forth throughout the entire graph. So, I would assume that it would still keep going in kind of an erratic sort of—not random—path in the future. But it seems like it's generally going upward.

Interviewer: **Mm-hmm. So, how certain are you that these predictions will come true?**

Esmerelda: I'm not very certain, especially since it's not tightly linear. And there's that range. It could be anywhere. It could be anywhere in there. I mean, it could be any point. But it's probably within that range. But the range is still pretty large. So, I'm not really that sure about any of them.

Interviewer: **Are you more certain about, like, maybe one and five compared to fifty? Or—like, similar to the previous graph? Or are they all equally uncertain? Or is there something else?**

Esmerelda: I think that the one and five are more certain, just like the previous graph. But I think they're also less certain than the previous graph, because it's not following a strict pattern. It's just generally going upward. So. I'm not really sure.

Interviewer: **Mm-hmm. What about if I said, like—if I had asked you about this, the range you drew. How certain are you that they are going to fall within that range? Would it be higher or lower? The same?**

Esmerelda: I think it would be higher, because it looks like most of the points, they stay within what looks like half a degree of the—I kind of—I drew the "best fit" line. And most of the points seemed to stay about half a degree from that. So, if I make a range, that's about half a degree from the best-fit line, and that probably would mean that most of the points would fall in there as well.

Interviewer: Mm-hmm. So, you'd be more—you have a higher certainty that they'll fall within the range that will come true?

Esmerelda: Yeah.

Interviewer: That long. Okay. And then, within, like, the—you're more certain that the range will come true, like, but within the range, is the one, five, and fifty—are you more certain about one and five compared to fifty? Or are you still—are they equally high?

Esmerelda: Yeah. I still think that the one and the five are probably going to be more accurate, because it's a shorter amount of time, so less things can change between one year than fih (ph)—fifty years. Or five years.

Interviewer: Okay. So, you mentioned you didn't know where this was. This is in New Zealand: "NZ." That's what that stands for.

Esmerelda: Oh, okay.

Interviewer: So, if we were to do this temperature graph in Michigan, as opposed to New Zealand, how do you think—with the same time range—how do you think the patterns would compare?

Esmerelda: Well, I think—I'm not really sure what the climate is like in New Zealand, but I know that it seems like—I would guess that it's—since it's surrounded by water—surrounded by ocean water, I mean, compared to Michigan—it probably has a wider range in temperature, depending on the ocean currents around it. So, I'm guessing that the temperatures in Michigan might be a little bit more closely linear than the New Zealand temperatures. But I'm not really sure if it would be hotter or colder, or about the same. But as far as the temperature being close to an average, it would probably be a little bit closer in Michigan, but probably not by much.

Interviewer: Mm-hmm. Do you think the normal that they have—the 1981 to 2010 that you were talking about, to form the zero line—do you think it would be similar in Michigan, compared to New Zealand? Or would it be—like, how would it be different, if it's not similar?

Esmerelda: I'm not really sure what the—about what the average temperature would be, compared to New Zealand. I don't really know.

Interviewer: Okay. And then, do you see—well, before I ask that question: do you—have you—like, I know you said you have not seen this graph before, but have you seen it in other places, outside of school? Like, in the news media?

Esmerelda: I've seen graphs similar to this, but for graphs for Michigan temperature. I've seen some of those, and I just—what I—the only thing I really remember from those is that it has kind of a similar, erratic, random pattern where it goes up and down, but it also increases gradually, but I don't really remember by how much.

Interviewer: Mm-hmm. For the Michigan graphs: were they about this—above the zero line? Or were they about, like, actual temperatures?

Esmerelda: I think they were about actual temperatures. So, it was different than this graph where they're based on the deviation from the normal temperature.

Interviewer: Mm-hmm. And then, do you think there are things that people do on, in their daily activities, that might influence this graph? The shape of the graph?

Esmerelda: I think maybe similar to the first graph. Things like energy consumption. It seems like there's a, definitely a correlation between greenhouse gas emissions and temperature increase. So, I think that may be a reduction. Greenhouse gas emissions would cause the temperature to increase more slowly.

Interviewer: Mm-hmm. Okay. Do you see connections between these two graphs?

Esmerelda: They're both increasing, but this one seems to be more linear than this one, where the, that one would be an exponential curve. But they also seem to go back and forth where they're not strictly on a curve or a line.

Interviewer: Mm-hmm. Are there things that you think might connect the two graphs?

Esmerelda: Since they're both going up, it looks like they have kind of a direct relationship with each other. Because when one of them goes up, the other one goes up, and it's kind of around a similar timeframe. Like, this. This graph is only for the second half, I guess, of the temperature graph. But it looks like when it—the—it increases—the temperature increases when the carbon dioxide increases. So, that would suggest that there's a connection between them.

Interviewer: Mm-hmm. Do you have ideas about what that connection might be? Or what might be—yeah like.

Esmerelda: I think that the carbon dioxide concentration probably help (ph)—probably, from what I've learned at school, has to do with the—it can trap heat on the Earth. So, that would cause the temperature to increase.

Interviewer: Mm-hmm. Does it matter that this one, the measurements are taken in Hawaii, and the measurements here are taken in New Zealand? If, like, when you were saying, like, CO_2 concentration traps heat, so it would increase temperature, does the difference in location matter, do you think?

Esmerelda: I think maybe it matters a little bit, but I remember seeing a graph, once, with, like, global temperature increase. And it seems like the carbon dioxide, since gas travels around the Earth, and I think it—the greenhouse gases tend to concentrate around the poles. And they, the gases, travel around. They're not static. They're not going to stay in the same place. They—it probably affects places all around the world, but it would probably have more of a connection if they were in the same place, I would guess.

Interviewer: Mm-hmm. Okay. Great. So, I know it's almost—like, do you have time to do one more graph, or are you—

Esmerelda: I have time to do one more. Yeah.

ARCTIC

Interviewer: One more? Okay. Great. So then, this is the third graph. Have you seen this graph before?

Esmerelda: No.

Interviewer: No. Okay. So, taking a look at this graph, what do you think it's about?

Esmerelda: So, the title says, "Arctic Sea Ice System in September," and I think that's probably about how far the—I guess how big the ice mass is in the Arctic. How far it extends from the land, I guess. And it's measured in square kilometers, covering the Arctic Sea. And it says in September, so, I'm guessing they measure it in September every year.

Interviewer: Mm-hmm. Do you have ideas of who they might be? (Chuckling)

Esmerelda: I'm not sure what kind of scientist would do that, but I'm guessing a scientist of some sort recording this data.

Interviewer: Do you have ideas about how those scientists might have gotten this data? Like, how they—

Esmerelda: I think maybe they use maps, or maybe satellite images, to look at images of the Arctic, and use that to measure the area of the ice.

Interviewer: Mm-hmm. So, who do you think would find it useful to know about, like, the area of ice?

Esmerelda: Well, I know the—that the—since greenhouse gases, they tend to concentrate around the poles, then they have a bigger impact around the Arctic. So, scientists studying climate change would also use this to see how the increased greenhouse gases around the Arctic affect the ice.

Interviewer: Mm-hmm. Are there other people who might find the graph useful? (pause)

Esmerelda: Maybe. Since the Arctic stores a lot of water in the form of ice, and when the ice melts, it will cah (ph)—it will probably cause the sea level to rise. A decrease in ice or an increase in ice could cause the sea level to change. So, probably people living around coasts would find it useful to know what, maybe, the sea level will be like in the future. And I think the ice has a connection with that.

Interviewer: Mm-hmm. Okay. Great. So, looking at this graph, what do you think is the most important parts—part or parts—that people should notice when they are reading it? (pause)

Esmerelda: It's—well, it's measured in square kilometers, so it's looking at the area of the ice. It's measured from year to year, and it looks like it's decreasing more steadily than the increase of the previous graph, because the points are tighter in this one. They're tighter together. They don't vary as much.

Interviewer: Mm-hmm. Can you say a little bit more of, like, what you mean by "vary" and "tighter"?

Esmerelda: They follow a more strict path. Like, these ones, they're definitely higher at the beginning and lower at the end. And the points in the middle generally follow that pattern, instead of being in a perfect line, they're not in a perfect line. They go above and below. What I drew is like a line of best fit. And they—in the previous graph, they went above and below farther than in this one.

Interviewer: Got you.

Esmerelda: So, I think that's what I mean by "tighter."

Interviewer: Okay. Great. So, square kilometers of ice, right? Do you have ideas—

Esmerelda: Mm-hmm.

Interviewer: —about why these scientists are measuring square kilometers of ice versus something else?

Esmerelda: Well, when it gets warmer, ice melts. So, I'm guessing that they're trying to see what different effects are of the—of temperature and, I'm guessing, temperature increase. So, I think that eye—the melting of ice in the ocean, in the Arctic, is kind of a—is caused by temperature increase. So, it's probably why they're looking at it.

Interviewer: Mm-hmm. And you meant—like, you mentioned the Arctic. Do you have ideas about why they picked that location as opposed to some other location?

Esmerelda: Because I think the greenhouse gases, they concentrate near the poles. So—

Interviewer: Okay. So, you've said that.

Esmerelda: —they probably have the most affect around that area.

Interviewer: Got you. What about the time range that's displayed? Do you have ideas about why they, they're doing it during those times?

Esmerelda: It looks like this graph has more recent data. It only goes back to 1980. And I'm guessing that, maybe, that's when they were really able to start using more accurate maps. Maybe images from satellites or aircraft, because to measure the area of land accurately, it takes more technology than to say the measure—tempet—the temperature of the air accurately. Because, like, for temperature, you would need a thermometer, but to measure the area of land, you would—I'm assuming they use they pictures from up high, and for that, you'd need to take a picture from some kind of aircraft or satellite.

Interviewer: Mm-hmm. Oh, so now that we're speaking about how they're measuring it, do you have ideas about how they might have measured the CO_2 concentrations?

Esmerelda: I'm not really sure how they measure the CO_2 concentrations.

Interviewer: Okay. I'm just curious. Okay. Great. So, if I circle this point, what does that point represent to you?

Esmerelda: In the year 1995, it represents that the, there were 11 million square kilometers of ice covering the Arctic Sea.

Interviewer: Mm-hmm. And do you think it's a single measurement? Multiple measurements?

Esmerelda: It doesn't say average measurement. It says in September. So, I'm guessing they probably took a single measurement in September. But usually, in Sept—to keep the data more accurate, then they take multiple measurements and take an average. So, it could be—I think it would probably still be an average.

Interviewer: Even though they don't say it, they probably—

Esmerelda: Yeah.

Interviewer: —meant to do—so, are you thinking that it's single—multiple, then? Multiple measurements?

Esmerelda: I think so. Probably.

Interviewer: Okay.

Esmerelda: But if it's just in September, then I might only do one in September, instead of doing them throughout the year, like they did in the other graphs.

Interviewer: Mm-hmm. So, if they do—okay. So, if they do one—like, you said satellite before—

Esmerelda: Yeah.

Interviewer: —in September. And then—

Esmerelda: Then they probably take one picture, and they use that in September.

Interviewer: Okay. So then, are you s (ph)—going with single measurement? Or—

Esmerelda: Yeah.
Interviewer: —multiple? (Chuckling)
Esmerelda: Yeah. Okay. I'll go with single measurement.
Interviewer: All right. (Chuckling)
Esmerelda: I don't really know with this one. Because it doesn't say average, so I don't—I'm not sure if it's multiple.
Interviewer: Okay. But based on what you think—
Esmerelda: Yeah.
Interviewer: —is happening, you're going to say s—you're going to—
Esmerelda: Okay. I'll say single. Yeah.
Interviewer: Okay. All right. Just checking.
Esmerelda: (Chuckling)
Interviewer: Great. So, if you had to make one-year, five-year, fifty-year predictions, where do you think they would fall? (pause)
Esmerelda: My one-year prediction would be right around there. But I think, similar to the temperature graph, since it goes up and down, and it's not a strict line, it would probably be a little below or a little bit above.

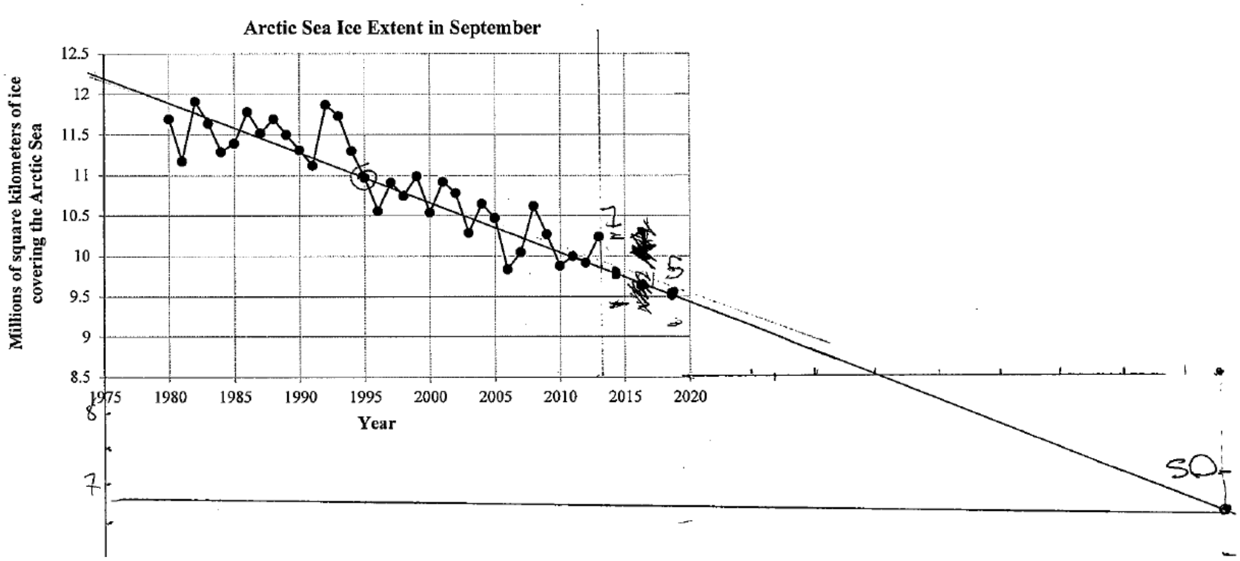

Figure G.2 Esmerelda's Arctic graph

Interviewer: Okay.
Esmerelda: So, kind of a range, just like I had before. And then, for—oh. For one year, it would be there. For five years—(pause)—it would be right around 9.5—
Interviewer: Okay.
Esmerelda: —millions of square kilometers. (pause) With also kind of a similar range. And then, it would keep decreasing. So—(pause) So, 50 would be right about there.
Interviewer: Okay.
Esmerelda: And the actual point would be probably down here. Assuming that it keeps decreasing. It would probably end up around—(pause) between six and seven millions of square kilometers, I'm guessing.

Interviewer: **Okay. Does the 50 also have the range that you put for the one and the five? Or were you thinking—**
Esmerelda: Yeah. It probably also has the, a similar range. Because they weren't—s—the points weren't tightly on a—strictly on a line. They were just generally decreasing.
Interviewer: **Okay. And then, how certain are you that these predictions will come true?**
Esmerelda: Just like the previous ones, I'm more certain about the first one than the other two. I'm more certain about the five than the fifty, because it's a shorter amount of time.
Interviewer: **Mm-hmm. And then, does your certainty also increase when you, like—if I said, "What is the chance of that it'll fall within the range, as opposed to the point?"**
Esmerelda: Yeah.
Interviewer: **Okay.**
Esmerelda: Yeah. Just like the early one.
Interviewer: **Okay. If they were to do—you mentioned that the greenhouse gases are concentrated at the poles. If they were to do a similar measurement in the—Antarctica—in Antarctica, do you think the graphs would be similar?**
Esmerelda: I think they probably would be. I think the poles probably have a similar climate. So, I'm guessing they would probably look fairly similar.
Interviewer: **Mm-hmm. So, the pattern would probably be similar. Do you think the numbers on the y-axis would be similar?**
Esmerelda: Yeah. I think so. Well, I mean, if the Antarctic, in general, has more ice area to begin with, then it would be larger. But as far as the amount that it's decreasing by, and the amount that varies from the line of best fit would probably be the same.
Interviewer: **Okay. Great. Let's see. What else did I want to ask? So, if we take a look at all three graphs now, do you see connections between them?**
Esmerelda: Like I said, with these two, they're both increasing, so they probably have a connection with each other. But also, this one is decreasing. So, I'm thinking that maybe when the concentration of carbon dioxide and the temperature has kind of an opposite relationship with the amount of ice. Because as the temperature increases, more ice melts, and there is less ice.
Interviewer: **Mm-hmm. And then, does loc—I know earlier, you said that location didn't matter. Does it matter when we're talking about the Arctic Sea ice?**
Esmerelda: I don't think it really does that much, because the—since the carbon dioxide and the other greenhouse gases concentrate near the poles, that's probably what's causing the ice to decrease.
Interviewer: **Mm-hmm. How do you know that the carb—like, that the greenhouse gases are concentrated at the poles? Like—**
Esmerelda: I just remember learning that in science at some point. I don't really remember.
Interviewer: **Okay. I was just curious, because I know you've said it a couple times, and I was curious to how you know that. Are there things that people do, on a daily basis, that you think that might affect the pattern that's in the Arctic graph?**
Esmerelda: I'm assume—I guess there aren't a whole lot—there aren't that many people living in the Arctic compared to other places. But since the gases move around

and affect all parts of the Earth, especially the Arctic and the Antarctic, pretty much the day-to-day lifestyle of people all around the world could affect this, to some degree. So, like with the other graphs, energy usage and agriculture.

Interviewer: **Mm-hmm. And then, my last question is, like, have you seen this graph? We—I know you said you hadn't seen it before, but something like this in the news media? Elsewhere?**

Esmerelda: I don't think I've ever seen one that had the area of Arctic Sea ice before. I've seen images of the Arctic, and how, from year to year, how the ice—the amount of ice changes. But I haven't seen it represented in a graph before.

Interviewer: **Okay. Great. That's all the questions I have for you.**

Esmerelda: Okay.

Interviewer: **Thank you so much (ph).**

END TRANSCRIPT

G-3: Annika's interview transcript and sketched predictions for the Arctic graph

KEELING

Interviewer:	**Great. So here is the first graph. And so my first question is have you seen this graph before…**
Annika:	No.
Interviewer:	**. . . or something like it maybe in class or…**
Annika:	It, kind of, looks like the one we were doing in class, but I've never seen this particular graph before.
Interviewer:	**So not - nothing specific. The one that you'd mentioned in class, what do you remember about how it might be similar to this one? Or do you remember stuff?**
Annika:	I mean, it was the same kind of topic that we were doing in class, and then it was the way that it's going, I guess, the way that the graph is structured, too. But that's about it.
Interviewer:	**So, taking a look at this graph, what do you think it's about?**
Annika:	Monthly average carbon dioxide concentration. (chuckles)
Interviewer:	**And you're getting that from the…**
Annika:	From the title, yeah.
Interviewer:	**. . . from the title? Yep, yep. So who do you think might use this graph? Or what do you think it might be useful for? Or where might it be used? Like, do you have ideas about any of those?**
Annika:	Well, I mean, it says 'Hawaii.' I don't know. I guess people that are looking to see the concentration of carbon dioxide. Maybe – well, it says "annual cycle," so I'm guessing maybe in our atmosphere. Yeah.
Interviewer:	**Those people – do you have about – are they everyday people? Are they a particular type of people…?**
Annika:	Probably scientists. I don't really know if everyday people just pull out graphs and start annua- - like, looking at them. But…
Interviewer:	**So, when you looked at the graph, there's lots of different pieces that you noticed. Do you have thoughts about what might be the most important part, or other couple of things that tie? Or what do you think is important to notice?**
Annika:	Probably the two different things that we're looking at, like the concentration and the year that it's concentrated. And, probably, the information on the graph; so it's going up.
Interviewer:	**So you mentioned the two things, the concentration and the year. Like, why are those important to notice? And why is that thing going up important to notice, also?**
Annika:	Well, it's what the graph is about, so it's obviously information that they want to know, that they were trying to get from the graph. And then, well, this is the results, I'm guessing, 'cause they probably made the graph first and then, sort of, plotting where the different points were, and then this is probably the final result.

Interviewer: **So you mentioned points on there. Right? So let's say picked a particular point like this one right there. What do you think that point tells you?**
Annika: Somewhere in the year 1990, and the concentration. So it was around 360.
Interviewer: **So that point is for some time and then some concentration. Right?**
Annika: Mm-hmm.
Interviewer: **Do you think that point represents a single measurement or multiple measurements?**
Annika: The single measurement on this side, so the measurement. Well, I don't know because it's also the year, too, so I'm guessing multiple.
Interviewer: **So by "measurements," you're thinking that it's – the concentration is one measurement and the year is another measurement?**
Annika: Yeah, and the, kind of, put them together, I guess, to get which – what the overall, I guess, pattern is, maybe, is what they're looking for.
Interviewer: **And then you also mentioned – like, so, when you were talking about the concentration and the years, I – the year has a particular range. Right?**
Annika: Mm-hmm.
Interviewer: **Like, it was found 1960 to 2015. Do you have thoughts about why did they pick those years to show on the graph, or why did they use the five-year time intervals that are in there? Thoughts about why those numbers were used?**
Annika: Maybe five-year intervals so they could get as much information as possible. And then, probably, around here, it looks like it's just starting, so I'm guessing this was when we started getting concentrations from carbon dioxide, and then how much it's gone up, until the time that they did it. So they probably did it – it says, "Last updated – January 2014," so this is probably an estimate. And then they were tracking how much it's gone up or down or…
Interviewer: **So do you think 1960 is when they started collecting the data?**
Annika: Well, yes and no. I don't think the people who did this graph were collecting it in 1960, but maybe they got it from people who did collect it in 1960.
Interviewer: **But they – do you have ideas about why it may be the only – why they started showing just 1960 as opposed to if they have data from before 1960?**
Annika: Modern revolution? (laughs) I don't really know.
Interviewer: **So it was – yeah, I was just curious about that. So you mentioned CO_2 concentrations for the other part of the graph. Why do you think they were measuring CO_2 concentrations?**
Annika: Probably because they were looking at, like – Well, I'm, kind of biased 'cause we're doing this in class, but the global warming and maybe seeing is there's any way that we can, kind of, stop it from keeping – like, to keep going up, I guess. That was a really weird way to word it, but yeah. (chuckles)
Interviewer: **So is CO_2 concentration's related to global warming?**
Annika: I think so, (laughs) if I'm paying attention in class at all, yeah.
Interviewer: **(laughs) No worries. So the – that might be the reason why they're measuring CO_2. And then you also mentioned that you meant – monthly average concentration of carbon dioxide. And I also noticed that you said – saw that it was last updated in January 2014. So you're reading from the title. What other information does the title give you?**

Annika: Maybe – like, well, it says "data from," so I'm guessing this is where they got it, the Scripps CO_2 Program. I don't know where that is, maybe in Hawaii, maybe not. But it also tells us, probably, where they were doing the information, recording it. It's in the – I don't what to butcher the name, but the observatory in Hawaii. (laughs)

Interviewer: (chuckles) Excellent. No, it's Mauna Loa in this particular case. So, in Hawaii do you have ideas about why they chose to measure CO_2 in Hawaii as opposed to other places? Like, why did they make this graph in Hawaii?

Annika: I'm going to go, I guess, going out on a limb 'cause I'm not – it doesn't say anywhere or there's no article. But maybe that person was already located there and just – maybe they were going to start there and then go somewhere else and test in different places, or maybe something about Hawaii that I don't know about, that levels are really high or something like that.

Interviewer: So is it the people just happened to be in Hawaii or…

Annika: Yeah.

Interviewer: . . . other reasons? That's probably why those chose Hawaii? And then you mentioned that the data was, kind of, going up. Right?

Annika: Mm-hmm.

Interviewer: So that's one pattern. Are there other patterns that you see in this data?

Annika: I mean, it, kind of, has a little mountain-like shape, I guess. It just keeps, kind of, going up and down and up and down. I'm guessing that it's because of the seasons and stuff like that.

Interviewer: So part of – so can you say a little bit more about the seasons how it would make – cause that up-and-down pattern?

Annika: Well, based on the temperature and stuff, then it would be based on the season, is the temperature that comes with the season. So I'm guessing, depending on how cold or hot it is, the CO_2 will probably change, as well. It could be completely wrong, but…

Interviewer: But that's what you're thinking right now?

Annika: Mm-hmm.

Interviewer: Cool. Great. So this graph goes from 1960 to 2015. What I'm going to ask you to do is make a prediction. For one year later, where do you think a point on the graph might be? Five years later, where do you think it might be? And 50 years, where do you think it might be? And if you want to use this ruler right here, feel free to do that.

Annika: Probably do it just my lines are straight. It'll probably keep going up. It seems to go up two or three.

Interviewer: Yeah. If you could make marks on the paper, too, and just mark them "1," "5," and "50," that'd be great.

Annika: And I feel like it was just going to keep going like that, based on the pattern. So this is one. And then, five, I'm guessing - I mean, just going straight up to five?

Interviewer: Mm-hmm. Like, five years. Well, I mean, you can – like, you can do the in-between years, but where do you think the "five" would be? Like, where's it's going to (crosstalk)

Annika: Well, I just feel like it's going to keep going up like the pattern that it's going right now. So this is probably five years. It could be wrong; I don't know. (chuckles) And then 50 years?

Interviewer: Yeah, 50.

Annika: (laughs) I don't – I don't think I'm going to have enough room. Let me see how I'd do this. I'm just going to go pretty wild. Like, 50 years would be up here, pretty high unless we do something to change it up …like about… there…

Interviewer: So can you make dots where you think the one, five, and 50 are?

Annika: Yeah. And then one is just like this one here.

Interviewer: So the prediction that you made for one year, how certain are you that's probably going to happen?

Annika: I think it already happened, so… (laughs) Like, it could be higher, but I know that it was going to keep going up because we keep using more things that have CO_2 and – or produce CO_2. And then, five years, it might be higher, but I know that it was also going to keep going up. And then, 50 years, I'm not sure. I'm – if we don't really do anything to change how much CO_2 we're producing, then it'll probably be – go up really high, but, if not, maybe not. It just hasn't happened yet, so I'm not 100-percent sure. But…

Interviewer: Which one are you the least sure about: the one, five, or 50?

Annika: Fifty.

Interviewer: And then you mentioned about stuff that we do causing it. Can you say a little bit more about what are some of those things that…

Annika: Well, like our thermostats produce a lot of CO_2, like in our houses. And even just breathing produces CO_2. (chuckles) Think – I mean, also, depending on factories, they can also use a lot of CO_2. But, yeah…

Interviewer: So you mentioned thermostats and breathing. The first two, the – do you have ideas about how the thermostat contributes to the CO_2?

Annika: Well, I'm guessing, based on – I'm not 100-percent sure but I know we talked about it a little bit, based on the air that it's producing, it can also cause CO_2, that it releases.

Interviewer: And then breathing, how does breathing contribute?

Annika: We can breathe in oxygen and breathe out carbon dioxide. (laughs)

Interviewer: Makes sense. Whew, let's see. So the point that I pointed to earlier, do you think it was measured in one place or in a bunch of different places? Or not the one point but all the points that make up this dataset.

Annika: Well, I'm guessing it's an average. Well, it says "average," too, so I'm guessing it's like they took data from different places and, kind of, collected it and took out the, overall, what the data was.

Interviewer: And when you say "different places," do you have ideas about how far those different places might be or…

Annika: I'm guessing they were only doing it in - Well, I'm… (sighs)

Interviewer: If you had to, yeah…

Annika: They probably start small and then, once they get data - For, like – for example, maybe they just did start in Hawaii and they got data for Hawaii, but then they expanded it to the coastal states, and then maybe it was like United States as a whole. I'm not really sure. It really, I guess, depends, but I'm guessing they're not going to go out of the country to measure it, maybe. (chuckles)

Interviewer: **Do you have ideas about what's causing the overall trend going up? Is that different from what's causing the squiggly up-and-downs?**

Annika: Yes and no, kind of. I mean, I guess the weather does contribute to it, but, also, like I said earlier, I think there are other things that are producing CO_2 that also cause, I guess, the – it to stay trapped in the heat, to keep – continue the temperature to keep going up.

Interviewer: **So you said weather contributed to "it." Which part were you thinking about when you said "it?"**

Annika: I can (inaudible at 12:33)… Ach.

Interviewer: **The up-and-down or the overall.**

Annika: It says the colder. Well, what I'm seeing here and from what I remember, I think the colder it is, I think, the more CO_2, but – or maybe it's the other way around. But, either way, I feel like it also fluctuates based on the seasons and whether it's cold or hot.

Interviewer: **So the (crosstalk)**

Annika: It, obviously, won't solve it but it will probably fluctuate a little bit. Probably why…

Interviewer: **So the weather is causing the up-and-down pattern that you see. And then the overall up-trend that you had mentioned earlier, what do you think is causing that? Is it the same thing or something else, or…**

Annika: I don't know if global warming has anything to do with the weather, but that's - I think, is what it might be.

Interviewer: **Cool. So this pattern that you see here, this is in Hawaii. Do you think this pattern would be the same, similar, different if we were to compare it to other places like, say, Michigan or Texas, or Maine?**

Annika: Well, the weather's a little bit different in the different places, but I feel like the overall trend would be the same, like it would still fluctuate with the weather. Maybe the numbers aren't exact, but we're all experiencing - if it was - I'm – I guess I'm biased or something towards global warming, but if it was for the same reason for everybody, then I feel like the trend would, kind of, still be the same. It'd be like a pattern.

Interviewer: **(background noise) So you keep saying "biased towards global warming." What makes you think you're biased towards global warming?**

Annika: I don't know. 'Cause we're learning about it in class, and this is really similar to what we're learning in class. (laughs)

Interviewer: **Gotcha. No worries. Does this pattern that you see in this graph, like these patterns, do they represent relationships – do they connect with anything that you've done in school or at home, in real life?**

Annika: Like I said, I mean, we were just looking at – I mean, it was pretty different than this graph. It was, kind of, just explaining the temperature and this – the CO_2 producing, but it wasn't like this. It was like, "This is the amount of CO_2, and this is how the temperature is going up," but it wasn't, I guess, like this graph.

Interviewer: **Oh, can – I mean, if you want to sketch, can you sketch what it was like?**

Annika: But it was like, basically, they had it like this, and then these red circles represented the temperature, and then the black squares were presented like the CO_2. And so they had the numbers, the temperature, and then they had CO_2. And then the – they would, based on the amount that you changed it, there was a little panel on the side, and you would change the amount of CO_2 that we were releasing, and then the temperature would go up or down, and the CO_2 would, too. That's basically what the graph looked like.

Interviewer: Gotcha. And so CO_2 was on the X-axis, and the temperature was on the Y-axis?

Annika: Mm-hmm.

Interviewer: And then the triangles and squares, they represented - What did the triangles and squares represent, again?

Annika: The triangle – the triangles were the temperature, and the squares were the CO_2. They were colored, too.

Interviewer: Yep, cool. So those are things that you've seen in school. Do you think s- - there are things that you do, personally, yourself that might affect, contribute, affect this graph?

Annika: Yeah. Like I said, the thermostat. Also, cars, I know, release a lot of CO_2 emissions just like driving and stuff. And then - I'm really bad at thinking on the spot. (chuckles)

Interviewer: Oh, no worries, no worries. Yeah.

Annika: But there's two things, at least, that I could think of really, fairly quickly. Just I know driving and the thermostat-changing all the time usually produce the CO_2 emissions.

<u>TEMPERATURE</u>

Interviewer: Yeah, I mean, if you come up with something later, you can feel free to contribute or add those in later on. Cool. So we're going to set this graph aside (background noise) for right now, and I'm going to show you a second graph. And the questions I'll ask will be pretty similar. So, for the – here's the second graph. Have you seen this graph before?

Annika: No. (chuckles)

Interviewer: No? (chuckles) Pretty sure about that. All right, so taking a look at this graph, what do you think this graph is about?

Annika: Annual average temperature. (laughs) (background noise) Yeah.

Interviewer: Yeah?

Annika: I mean, that's – I mean, that's what the title says. I'm just trying to make sure I can read it or something.

Interviewer: Yep, so, yep, that's good. Where do you think you might see a graph like this being used? Or who do you think this graph would be useful for?

Annika: The weather people, I guess. (chuckles) I don't know if they ever – before they go on or if they just get their weather from somewhere, but whoever does weather calculations, I guess would find this useful. (chuckles)

Interviewer: So (crosstalk) people on TV who are talking about the weather?

Annika: I mean, I'm guessing that they get their information from somebody who studies this stuff so that they can, kind of, predict it. But I'm hoping not, because, again, they're also wrong a lot, so… (chuckles)

Interviewer: (chuckles) Right. So the ones – the weather people? When you say "weather people," are you talking about the ones – were you answering the part about who – it sounds like it could be about who created the graphs or who are using the graphs.

Annika: Yeah. I'm thinking, probably, scientists who are trying to predict weather changes or something like that.

Interviewer: They would use it, and then the weather people would also use it?

Annika: Yeah, probably.

Interviewer: All right, so, looking at this graph, if you had to say something, what do you think would be the most important thing to notice?

Annika: (background noise) Well, I guess the…

Interviewer: And it can be the same as the…

Annika: . . . first thing I notice is I don't know what this word means, but I don't (crosstalk)

Interviewer: Oh, the anomaly?

Annika: . . . has anything to do with that. I'm guessing that you should look for that stuff if you're trying to analyze the graph, yourself. But probably the title and what are the two elements that are being graphed, I guess, and then what the results are. Or, if you have to do it, then you can, kind of, get an idea from what you're supposed to be graphing.

Interviewer: So you mentioned title. The title told you that it was (chuckles) annual average temperature. Do you – do you know what the "NZ7" stands for, "7 Station?"

Annika: No.

Interviewer: The "NZ" stands for New Zealand.

Annika: OK.

Interviewer: Do you have ideas about why they might be doing this temperature graph in New Zealand?

Annika: To be completely honest, not really. (chuckles)

Interviewer: Yeah, yep, that's a good answer, a fair answer. And then you mentioned the temperature anomaly, you weren't quite sure what "anomaly" means. Do you have ideas about why are you measuring temperature anomaly versus just temperature?

Annika: It's probably more specific if they, like, try to put it, 'cause I know that, when you're trying to do data and stuff, you want to be as specific as possible. So maybe – I don't know – maybe anomaly is specific to change or something so then they have a more specific thing to graph. I don't know. Could be completely wrong, but… (chuckles)

Interviewer: So you mentioned change. Can you say a little bit more about what made you think about change?

Annika: Well, because, I guess, temperature itself is, kind of, vague. I guess you could be measuring hot or cold, or all of the different things, but, I guess, if you made it more specific, then you'd know what specifics you were looking for in the results of the graph, or you could come up with an idea of what specific things you should be looking for to graph, to come up with the results. I don't know. I just thought maybe the more specific, the better.

Interviewer: That makes sense. And then, for the other one you talked about, the other thing that they measure is year. This one goes from 1910 to 2010. Do you have ideas about why that time interval - and they do it every decade here – why they chose at that interval and that time period, maybe?

Annika: Well, I mean, I was just looking to see the stuff and, I mean, it says here that it's adjusted for site changes, so I guess, depending on where they did it and what they specifically wanted to measure. So maybe there was something specific what the year 1910 that, kind of, got them started and then, from then on, they just, kind of, measured it to maybe where, what time point that they were at, or so, yeah.

Interviewer: So, in 1910, do you have ideas about why they started in 1910, or do you think that this has more data from before, they just happened to pick that date?

Annika: I don't know. Maybe it's because that's all the data that they have recorded all the way up, until that point. And then – or maybe it's something they di- - I'm not really sure. I'm just, kind of, trying to… (chuckles)

Interviewer: Yeah, definitely. This – you're doing great.

Annika: Thank you.

Interviewer: It's, yeah. So then you've talked about that. And let's say we have this point right here. What do you think that point is telling you?

Annika: The temperature anomaly (chuckles) and the year, around 1965-ish. So…

Interviewer: So the temperature anomaly and the year. Do you think that represents one, a single measurement or multiple measurements?

Annika: Multiple? I – I'm guessing they had a bunch of data that they were trying to put into one, kind of, average or something. So I'm guessing it's multiple? I… (chuckles)

Interviewer: All right, no worries. And then all the data, all the points that are in here, in this graph, do you think that the data points were all collected, measured from the same place or from different places?

Annika: It says "changes," but it also says – I don't know. It could've just been the different places at New Zealand, maybe? I don't…

Interviewer: So it's not clear?

Annika: Mm-hmm.

Interviewer: No worries. And then, if you look at this, do you see – looking at this graph, do you see a pattern in the dots?

Annika: Kind of. It's, kind of, doing the same thing this graph is doing, but it's not so consistent. It's just, kind of, up and down, fluctuates a lot.

Interviewer: So it fluctuates a lot. Is there an overall direction that you would say that graph is going?

Annika: I would say up.

Interviewer: Up?

Annika: At the beginning, kind of, not really, but, I mean, here, it doesn't really reach these levels again until 1990. But then it goes back up and then, after that, it doesn't go back down.

Interviewer: So the data from – You were pointing to 1950 before, '40, '50, there?

Annika: Yeah. Yeah.

Interviewer: Yeah, they were, kind of, low.

Annika: Yeah.

Interviewer: Oh. Yeah, so, you said, overall, it's going up. And then you said it's going up and down like the first one but not as consistent.

Annika: Yeah.

Interviewer: So if you had to predict one, five, and 50 again, can you make those predictions (background noise) and sketch them onto the graph?

Annika: I can…

Interviewer: Best guess.

Annika: Ah? (laughs) Well, I mean, these ones seem pretty – they're – they just seem like they're going up, so I'm just going to do that 'cause I don't really know if that's…

Interviewer: And those ones you were pointing to, the last – how many years was that?

Annika: The last five-ish years, from – well, maybe no; maybe the last two. Well, 'cause it only goes up to 2010, and it's about right here. Oops. I'm just going to – that's probably the first year. That's only one more. And then five and 50. Right?

Interviewer: Right.

Annika: Yee, yeowza. (chuckles)

Interviewer: No worries. No wrong answer.

Annika: Some of these are going to go up a lot (chuckles) just based off these past few ones. I'm not really sure if this is right, but it's OK.

Interviewer: Yep, it is.

Annika: Is it?

Interviewer: Yeah.

Annika: Oh, that's cool.

Interviewer: Yeah. Oh, yeah, definitely. Nobody's going to see this but me and my advisors. But…

Annika: (chuckles) They're not going to…

Interviewer: See, yeah.

Annika: . . . know (ph) who's going to assume that this is how it's going to go, based off the other years. So this is – I just jumped up to five, and then I just jumped up to 50, so there's – oops. Probably going to keep going. It's right there, but (crosstalk) good (ph) idea. (chuckles)

Interviewer: Yeah, gotcha. So can you say it – say a little bit behind your thinking about why you picked those points for one, five, and 50?

Annika: Well, I don't really – I don't have the entire data; I just have, kind of, have what they wrote down on here. But, at the beginning, it's not very consistent, but the past few years were, kind of, based off what I'm seeing. They were, kind of – they went up. I mean, they fluctuated within that but they, kind of – the overall trend is going up, so that's, kind of, just what I tried to mimic on one five, and 50.

Interviewer: **So out of those three points, which one are you – for instance, for the one-year one, how confident are you about your prediction for that one?**
Annika: 80 (ph) percent, maybe.
Interviewer: **80 percent?**
Annika: The other ones are four. (chuckles)
Interviewer: **So both of them would be 4 percent for the five and 4 percent for the 50?**
Annika: No, not 4 percent for 50. Two percent for 50. Right, (laughs) right.
Interviewer: **Two percent for 50? (laughs) All right, you're very unsure about that one?**
Annika: I'm not very – I don't, I don't really know 'cause, at first, it wasn't like that. I'm just thinking maybe it was a trend that it just, kind of, went up a little bit, and then it'll go back to being super-crazy.
Interviewer: **So this was taken in New Zealand, and the predictions that you made. So do you think this pattern that you see here would also be similar to in other places, kind of like what I asked earlier.**
Annika: Well, if it's specifically about temperature, probably not. Well, I don't – probab- - I'm just going to go with probably not because the temperature in different places are different; some places are going to be hotter or colder. So, yeah. (chuckles)
Interviewer: **So the – so other places are going to be hotter - hotter or colder. But what about the shape of the graph? Do you think that would be similar?**
Annika: Oh, in other places? Yeah, probably, because they're also going to experience changes in the weather and stuff, so it's probably going to be a lot of movement in the graph. But I think it'll look a little different because the temperatures won't be the same. But, yeah.
Interviewer: **So the patterns way, like you said, they might be different in other places, they won't be exactly the same. What do you think are causing those patterns?**
Annika: Well, like I said, the biggest thing would probably be – 'cause if the weather's different in different places, it might be hotter, might be colder. But, also – I don't know – well, yeah, I think that would pretty much be the only difference if we're talking about just temperature.
Interviewer: **And you mentioned, so you mentioned hotter and colder. Are there things that you've seen in school or that – or at home that connect to that graph, to that pattern, or in the news, or wherever?**
Annika: Maybe – maybe in school, but I don't know if I've ever seen actual graphs or something at home, or on the news or anything.
Interviewer: **What about things that you do, yourself? Do – do you think they would contribute to the ups and downs of this graph?**
Annika: It would be really cool if I could control the weather, but I don't think so. (chuckles)
Interviewer: **(chuckles) So it's not likely that you can make the graph go up and down?**
Annika: Probably not.
Interviewer: **So then (background noise) what about connections to this graph? I know you mentioned earlier, you were comparing the ups and downs between these two graphs and, overall, they were both going up. Do you think there are other – do you – other connections between those two graphs?**

Annika: Well, I mean, they're both, kind of, measuring the – I guess this is a lot of graphs, though. (background noise) Uh, they're, kind of, measuring a certain thing. The one of them is measuring CO_2 concentration. One of them is measuring temperature over the years. And maybe they could be connected. Maybe one of them is measuring how much concentration causes this much temperature, and I just don't know, but it just depends. But…

Interviewer: So – so there might be, but you're not… (background noise)

Annika: 100-percent sure, yeah. (chuckles)

ARCTIC

Interviewer: Gotcha. Great, thanks. And now I'm going to show you a third graph. (background noise) Again, I'm going to ask you very similar questions. Have you seen this graph before?

Annika: No. (chuckles)

Interviewer: No. All right, so, looking at this graph, what do you think it's about? Who do you think it's useful for?

Annika: Hmmm…Arctic Sea ice, in September. (chuckles) And I don't know anything it's about. And I think it would benefit (makes sounds) – I don't know – people who (background noise) look at the ice, maybe the people who invest – the scientists who, I guess, investigate the changes in this ice and whether it's melting or not. Well, looks like it's going down, so maybe how much ice there is or…

Interviewer: What's the most important part of this graph?

Annika: (background noise) I feel like they work hand in hand. I mean, these are what you're looking at to get your results, but then this is your result, so probably that, but… (background noise)

Interviewer: So the – you were pointing to the – the two axes?

Annika: Yeah.

Interviewer: So, again, you mentioned the title. Do you have ideas about why they're measuring Arctic Sea ice as opposed to…

Annika: Feel like they're all related. They're looking at, well, the ice, specifically, because the higher the temperature, then there – there's going to be melting ice, which probably heightens sea levels, so they're probably looking at a bigger picture. But I feel like they're connected just 'cause they have to do with each other. (chuckles)

Interviewer: So you feel like all three graphs are connected to each other?

Annika: I mean, yeah. Maybe. I could be wrong, but it's just like they're, you know…

Interviewer: Well, when you said they're connected, what were you thinking? What was in your mind at the time?

Annika: (background noise) Well, I'm just thinking, I mean, they have to do with each other. CO_2 concentration contributes to higher temperatures, which contributes to ice melting, so, yeah, it was just a thought. Then I also get way ahead of myself, so (chuckles) that could be wrong. (chuckles)

Interviewer: Oh, yeah. No, no, that's great, that's great. And then – so I'll just go in order of the things that you mentioned. You mentioned the - the y-axis earlier. What does the y-axis tell you about the graph?

Annika: Millions of square kilometers covering the Arctic Sea.

Interviewer: Do you have ideas about why the millions of square kilometers (ph) of ice? Is it the thing that they measured, or why they put it on that graph?

Annika: They probably want to – I mean, they might just be measuring how much there is compared to how much there was, or to see if it's changed, if it's gone down, it's gone up. It's probably what I'm guessing since they're measuring ice. (chuckles)

Interviewer: Yep, yep. And then this one has a different time period than the other two graphs. Do you have ideas about why they measured from 1975 to 2015-ish, or almost 2015?

Annika: I mean, I know, probably, why they would keep studying here, probably – 'cause that's the time period that they're at – but I don't know why they picked the random dates in the 1900s. It could be an event that happened. It could just be because that's where they have data to. I really don't know. (chuckles)

Interviewer: So you don't know? You're not quite sure about why the start dates were chosen?

Annika: Yeah.

Interviewer: But you think the end dates are because…

Annika: Probably 'cause they're around, it's around that time period when they're doing the graphs. (inaudible) yeah. (background noise)

Interviewer: So when you say "they're doing the graphs," who are "they," again? The…

Annika: Probably – I'm just going to assume that it's scientists. I don't know if it's maybe – maybe it's (background noise) other students who are curious, but I'm just going to assume that it's a scientist who's curious as to what's going on with there (ph). (chuckles)

Interviewer: Sounds good. All right, so when we're looking at points, like the – in this graph, if we picked any point, do you think it represents a single measurement or multiple measurements?

Annika: I'm going to say single. Maybe it represents a chunk of ice. I don't know. I - - I, to be honest, don't know, but that could be something (crosstalk)

Interviewer: But that's your gut? That's where you (crosstalk)

Annika: Yeah, I'm – yeah, I'm trying to guess on these results (ph), so… (chuckles)

Interviewer: Yep. No worries. And then, looking at all those data points, do you think they were all taken in the Arctic Sea?

Annika: Yeah, because that's what the graph is about.

Interviewer: Sounds good. (makes sound) So what do you think the line tells you about the data?

Annika: The line, like, this one?

Interviewer: Mm-hmm.

Annika: Well, it's going – it moves a lot within itself, but the overall trend is that it's going down.

Interviewer: So it just connects the different points?

Annika: Mm-hmm.

Interviewer: This one, the overall trend's going down. Are there other patterns, other than the going-down trend that you mentioned?

Annika: It, kind of, does again. And I don't really know how – what other word to describe it, (background noise) but it does little mountains on the way down. It, kind of, goes up and down. (background noise)

Interviewer: Cool. So mountains going all the way down. So can you make one-year, five-year, 50-year predictions again for this one?

Annika: Just one-year and then five-year. It's two, three. So this five. And maybe it'll move, but, yeah. And then 50 would be all the way down to here. (chuckles) But, yeah, this would be the 50.

Interviewer: So can you put the points, yeah, for the one, five, or 50 again? (background noise) Great. Out of those points, which one are you – ones with…

Annika: Most confident. (laughs)

Interviewer: Most confident is number one? (chuckles) And least confident is…

Annika: 50. (chuckles)

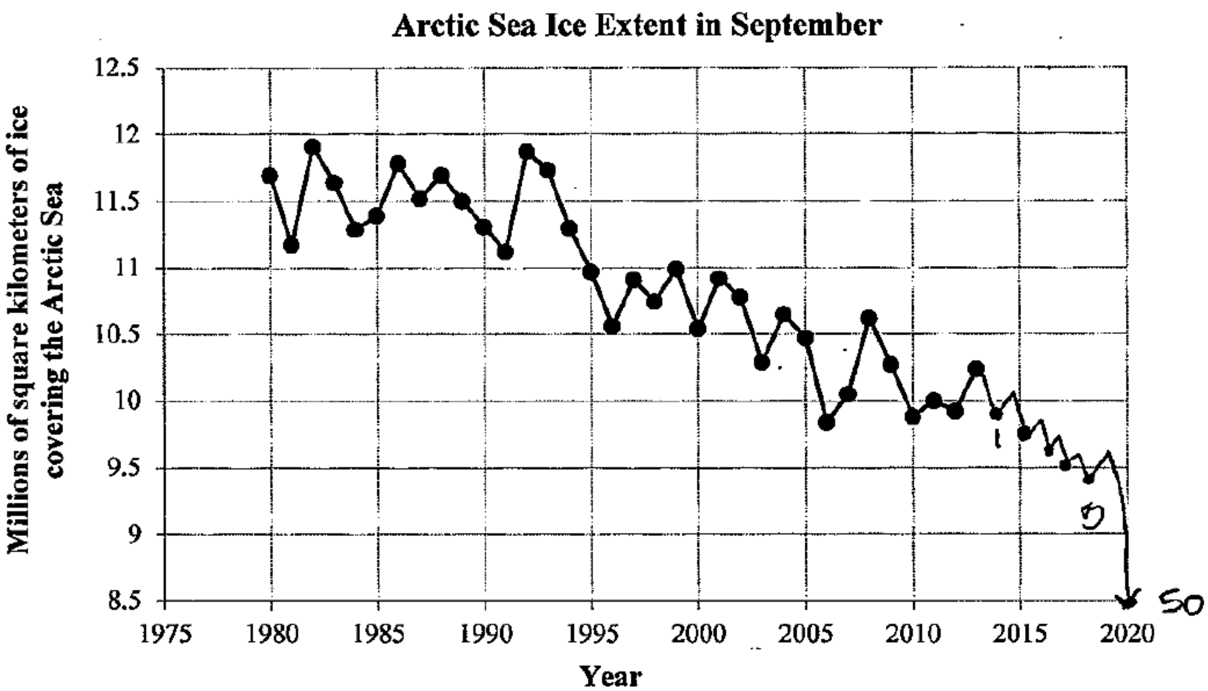

Figure G.3 Annika's Arctic graph

Interviewer: And, then, so this pattern that you've - that you see here, (background noise) do you think it'd be – this was done in the Arctic Sea, but if we were going to other places, say, the Ant-, Antarctica, do you think the pattern would be the same, similar, different?

Annika: I think it would be similar but, obviously, wouldn't be the same 'cause they're not the exact same places. But I feel like, if the heat – if there's heat all around, I guess, they'll go over (ph). Don't really know what other way to say it, but then everything would be suffering; all the ice would be melting like that idea. But I feel like they would be similar 'cause they're both places with lots of ice, and they would go – be melting, is what I'm guessing.

Interviewer: **So you – earlier, you mentioned the connection to the other two graphs. Yeah? Is it – are you still…**

Annika: Yeah, (chuckles) a little bit because they're – I mean, they all have to do with each other. Maybe these specific ones aren't – don't – they weren't measuring anything to do with what I'm talking about, but I just have that idea. It's the most fresh thing in my mind, so… (chuckles)

Interviewer: **Yep. You said you - you think they're connected but you're not quite sure how they're connected? Or do you have ideas?**

Annika: Yeah. It could be, again, because this – this first graph affects this one, and the second graph affects the third one. But it could be three completely different things, and they just so happen that, normally, they have to do with each other.

Interviewer: **So the affecting, it doesn't matter that this is in Hawaii, this is New Zealand, and this is in the (crosstalk) Arctic? Does that make - make a difference? I'm just curious as to what you think.**

Annika: Yes and no. I mean, maybe. I mean, I hadn't thought about the different places that – that they did it, but from – if I have learned anything, (chuckles) global warming affects everything, everybody because we're all contributing to it. So I'm guessing that, even if these are taken at different places, everybody's, kind of, going through the same thing, maybe not as extreme. But maybe that's why they were testing at different places, to make sure it was all – we were all going through the same thing. I don't know. Could be wrong, but… (chuckles)

Interviewer: **That sounds good. All right, those are all the questions I have for you. Do you have any other questions?**

Annika: Are they related? (chuckles) Just - if you're asking. They are?

Interviewer: **Yeah, they are related. (laughs)**

Annika: Yea.

END TRANSCRIPT

G-4: Susan's interview transcript and sketched predictions for the Temperature graph

KEELING

Interviewer:	**Great. So here is a picture of the first graph. Have you seen this graph before?**
Susan:	I don't think I've seen this exact graph before. No.
Interviewer:	**Uh-huh. But have you seen something similar to it?**
Susan:	Yeah.
Interviewer:	**Yeah? What do you remember about like the graph you saw?**
Susan:	This looks familiar because like how it's staying the same, but it's kind of like rising and decreasing over and over again.
Interviewer:	**Mm-hm. Okay. So what do you think this graph is about?**
Susan:	Something about carbon dioxide. Like the rate at which it's going, I guess, throughout the earth (ph).
Interviewer:	**Mm-hm. Mm-hm. Where do you think you might see a graph like this being used?**
Susan:	Maybe somewhere like in a science lab or where they're researching carbon dioxide or something.
Interviewer:	**Uh-huh. What makes you think that scientists would use it?**
Susan:	I guess graphs kind of help in the science… like if they want to more so plan things out and have a better feel at it.
Interviewer:	**Mm-hm. Okay. Are there people that you think this graph would be useful for?**
Susan:	I think it would be. I'm just not sure who to.
Interviewer:	**Okay. That's good. Okay, so then in looking at this graph, what do you think are the most important features that people should notice about it?**
Susan:	I think they should notice how it is increasing throughout the years but at the same rate within because it seems like they're figuring out slowly. But they're using the same technique.
Interviewer:	**Mm-hm. Can you say a little bit more about like the increasing between the years?**
Susan:	So it looks like it's increasing just a little, seeing as it looks like a straight line with both of them. But it's still going up in a way.
Interviewer:	**Mm-hm. Okay. So the going up, so you mentioned the… okay, so those are the features that you think you should notice. What about some of the other features on the graph?**
Susan:	There are like the numbers. They don't really go that dramatically… like there's not a big change in them. So it is kind of a short number graph (inaudible).
Interviewer:	**Okay. Okay, great. So the in-betweens that you were talking about and how it increases, can you say a little bit about like what you think might be causing it?**
Susan:	Since CO_2 is gas, right, maybe there're more cars or something going around or like more traffic because I guess during certain months, it could go up. Like if there're seasonal things like sports, people have to use more CO_2 and stuff. But

the decreases could be when it's kind of just more… I guess not so much going around. So like maybe it's a season change amongst cars or something.

Interviewer: Mm-hm. When you mentioned sports people use CO_2 more, like can you say a little bit more about like what you mean by that?

Susan: Oh, I guess there's more buses and like people changing and like going around from place to place since there are a lot of competitions.

Interviewer: Mm-hm. Okay. Cool. And then you also mentioned something about seasons. I was wondering if you could say a little bit more about that?

Susan: Yeah, like each season… like there're certain things for the season, that season. Like one day, there's football for this one. And then the other one, like it's winter. And maybe not a lot of people are into winter stuff, so they just stay home. And those would be the decreases. But summer, everyone goes out.

Interviewer: Gotcha. Okay. And so that's what was causing the up-and-downs?

Susan: Maybe. (Laughing)

Interviewer: Okay. Yeah, and then you mentioned the transportation is what's causing the general up?

Susan: Yeah. And maybe like power plants, they could be using more so in the winter, so that could be to where it's not decreasing too much. So it's still keeping around about the higher part.

Interviewer: Okay. So when you mention like the power plants not using it as much in the winter, like can you say like what part of the graph like might be an example of that… were you thinking might be an example?

Susan: I would think it might not be the very last. I'm not sure what that would be. But it could be like there're two little middle ones, seeing as there're four dots. So maybe one of those ones.

Interviewer: Okay. So one of the four dots like on a downward trend? Or an upward trend?

Susan: I would say maybe it could be both. I'm not sure.

Interviewer: Okay. So either going up or down, but one of the middle dots, that would be where the winter would be?

Susan: Yeah. Maybe.

Interviewer: Okay. Cool. So I see that you mentioned… like you mentioned like it going across over time and the seasons. What about like the timescale? Like do you have ideas about why they might have chosen 1960 to 2015?

Susan: I guess maybe people started to actually do things, or like more things were being invented, more cars, so everybody was like… I guess prices changed, too. So people could start buying more cars and getting out of the horses and stuff or like, likes…

Interviewer: Do you have ideas about like when the prices might have changed?

Susan: I think around… I'm not sure. But like the earlier 1900s. But not the beginning of it. Just maybe in the middle.

Interviewer: Mm-hm. So middle-1900s? When you talk about price, are you talking about the price of –?

Susan: Like cars and automobiles because there's more of them. So the prices have to go lower because it's not the main thing people are going for anymore.

Interviewer: **Gotcha. Okay. So I just want to make sure I got this right. So the cost of the car is what's causing there to be more… this pattern that you see in the graph, the increasing pattern?**

Susan: Yeah, maybe like bikes would probably be more expensive back in the day. But then cars came. So the price of bikes kind of slowly decreased because cars were there. So there wasn't much of a need, I guess. But then you have to think of people that didn't buy cars. So they're still existing, if that makes sense.

Interviewer: **Yeah. (inaudible). Cool. All right. On this graph, now that we've talked about the x-axis, there's also this axis over here. What do you think that part of the graph tells you?**

Susan: Like just this part alone?

Interviewer: **Mm-hm.**

Susan: I guess it's showing like how much is being used but like the numbers which you see it kind of goes up. I don't know. Yeah, I'm not sure how to answer that question.

Interviewer: **Okay. No worries about it. Do you have ideas like maybe why they chose those numbers, that range?**

Susan: Maybe it wasn't that high. It was just more so. Like this was their lowest, and this was their highest. So they're just adding what's all between.

Interviewer: **Uh-huh. Okay. Sounds good. What about like if we look at like this point right here. What do you think that point tells you about the graph?**

Susan: I guess like if you're here, you could say that was your best because you weren't up to here anymore. But if you were here, then you could say like this was your middle, and this was your starting point. So it's not the best they've had, but it's a good starting point for being in the middle of things.

Interviewer: **Mm-hm. So it's like the middle of the data?**

Susan: Yeah.

Interviewer: **Mm-hm-mm-hm. Do you think like that point represents like one measurement or a bunch of measurements?**

Susan: I think it has something to do with all of these because it wouldn't be where it is now if it didn't have the old measurements because they have to like have new technologies and go from history to advanced to the future of stuff.

Interviewer: **Okay. So like when you were pointing to all this, like you're talking about all the points that were before it. Like can you say a little bit more about like how you think those points like affect that point right there?**

Susan: I guess from here, they were trying to get better as they go on. So you can see an increase just from the top. So from here, this might have been the best they had if you're not like including all this stuff–

Interviewer: **Afterwards.**

Susan: Yeah.

Interviewer: **Okay. So like –**

Susan: They're bettering it all they have. And then… yeah.

Interviewer: **Okay. And then that's up to year…?**

Susan: Like '87ish or something.

Interviewer: **Okay. Sounds good. Okay. So that's the one point, right? And then what do you think all these different points, as a whole, tell you?**

Susan: I would say they're not increasing every day and like being their best because they have to fail every now and then. So that's what the little decreasings are is… like if you had just a straight line, then that wouldn't really tell you much because you can't be advancing or learning much if you're just kind of doing your best all the time.

Interviewer: Mm-hm. Mm-hm. Cool. Are there any other parts of the graph that are important to notice?

Susan: This is important to notice. I'm not sure what it has to do, like what it means.

Interviewer: Mm-hm. So you're talking about this tiny little graph inside the –

Susan: Yeah, it seems like a key or something. Like it's zooming in.

Interviewer: Uh-huh. Okay. Cool. So this pattern in the graph that you see here, right, so this is like… you said it was going up, right?

Susan: Yes.

Interviewer: So on the paper, can you – you can use this ruler if you'd like – make predictions. So like where do you think a data point would be 1 year later, 5 years later and 50 years later?

Susan: Okay. I think it's just showing like this would be the start, that would be the middle of the year. And then the third one would be like the ending of the year or something.

Interviewer: Oh, okay. No, so what I meant… oh, sorry. I didn't explain very well. So like at 2015, right, or 2014, like this is sort of the last dot. And so like can you like write on the paper like for 2015, one year later, where do you think the next dot will be? And then in 2020, where do you think it's going to be? And then 50 years later, where do you think it's going to be?

Susan: Okay. I think it would kind of like… it would stay the same. But I feel like nowadays, it might be like going higher. So kind of not shoot up exact but like increase more so. So the line wouldn't be exactly like that which is soon (crosstalk).

Interviewer: Well, go ahead and sketch it… if you want to use a ruler, feel free.

Susan: Maybe like that. And then here're the bottom lines. (pause) So I think we have more like technology and things using CO_2 nowadays. So it would kind of boost a lot.

Interviewer: Okay. Can you mark on the graph that you drew where you think the 1-year would be, the 5-year and the 50-year would be? Like just put a dot and then write down 1, and then 5 and 50.

Susan: You mean like 1 as a whole and then like 5 as a half? Or what do you mean by that?

Interviewer: Oh, so like I was asking one year later, what do you think the next dot would go? And so, whatever that dot is, put on 1 next to it. And then five years later –

Susan: That would be here.

Interviewer: Okay. Cool. And then five years later, where do you think the dot would be?

Susan: Okay. So I think this would be the middle of the year, so this would be 2, 3, 4, 5 right here.

Interviewer: All right. And then where do you think 50 would be? (Laughter)

Susan: I think it would still like increase, but somewhere, I feel like there would be a dramatic drop maybe.

Interviewer: A dramatic drop?

Susan: Yeah.

Interviewer: What makes you think there would be a dramatic drop?

Susan: I feel like usually we have like a downfall. So kind of like things were going well, and then the (Great) Depression came. And then after that time, it started increasing slowly again. So I think somewhere, we're bound to have like a little drop coming soon.

Interviewer: Okay. So what do you think… like I mean feel free to draw wherever you want like on the paper. Where do you think that drop might happen?

Susan: Like not soon, so like maybe 2050. That is far away. (Laughing)

Interviewer: It is far away, but go ahead and put down your best guess.

Susan: Okay. So this would be 2020. And then (pause 0:13:50 to 0:14:00). That's a lot of lines. Okay. I guess it would be like over here, this could be 2050. But I think it won't go too far down and not pass like the middle from when we were talking about that's our medium. So I think it would just kind of sort of be equal with where we ended off here but a little higher because this would be like up here-ish.

Interviewer: Okay. So you're saying that like where the printed graph ends, that lowest point, it's not going to go below it?

Susan: Yeah. It's not going to go below it.

Interviewer: Okay. Cool. Great. So these predictions that you've made, right, how sure are you of the first one, like Year 1, that that's where the data point would be?

Susan: It just seems like maybe that's an easy guess because if you're starting here, then you could see it's just going up little by little. So it would soon go up there. Like maybe not that high, but somewhere right around there.

Interviewer: But you're pretty sure like, yeah, it's going to follow the pattern?

Susan: Yeah. I feel like –

Interviewer: Okay. And how sure are you about like Year 5?

Susan: I think the lines would be smaller and like shorter but still maybe around right there.

Interviewer: Okay. So relatively. And then like for 50?

Susan: I do feel like it's not going to be that high. It's going to drop a little. But not like dramatically. Just through the years. But then I feel like it would start going back up.

Interviewer: Mm-hm. Okay. And it would go back up because…?

Susan: People would start figuring out ways and like working together to figure out what they can do to bring it all back up.

Interviewer: Mm-hm. Okay. Cool. So this pattern that you see here, does this represent things that connect to things that you've like seen in school, at home, on the news? Anything…?

Susan: I would say it doesn't match with the weather because that would be everywhere. And like I guess you could say… I'm not really sure.

Interviewer: **Okay. Yup. That's all right. Yeah. I guess along those lines, like do you think there're things that you do that might affect this pattern? Like daily activities?**

Susan: I guess school because a lot of people are using school. But then you have your seasons to where the school year's out, so you don't have as much. But you still have people going around doing things. Like maybe football practice or working. You still have all those people using their cars. So I think maybe the drop could be when people aren't really using cars. Like maybe we have… I think there're electric cars to where like solar panels and things. So maybe we could just somehow find something else to do but then realize we made more money if we were like increasing with our CO_2.

Interviewer: **Mm-hm. So then can you say a little bit more like about how the increase and making more money would affect that?**

Susan: I guess if you have like better cars, then it's more money. But you have to think that a lot of the newer cars have a lot of faults and flaws. So like maybe gas prices go higher. They use diesel which is more money, I think. And then diesel, I think, also is worse for the environment which… it would be more CO_2. And then we'd finally realize we were like… maybe we lost interest in cars or we just found like solar panels things, different ways.

Interviewer: **So that's where like this 50 would like show up?**

Susan: Yeah. So maybe it won't necessarily be a bad thing. But it would be like we're figuring different ways to go.

<u>TEMPERATURE</u>

Interviewer: **Okay. Cool. All right. Great. I'm going to show you a second graph now. So let's set this up here for a sec. Here is the second graph. Taking a look at this graph, have you seen this graph before?**

Susan: I don't think so, no.

Interviewer: **No? Okay, great. So what do you think this graph is about? I'm pretty much going to ask you very similar questions?**

Susan: It says "temperature," so maybe like weather or seasonal changes.

Interviewer: **Mm-hm. Where do you think like a graph like this might be used?**

Susan: I guess on a weather station, it could help like determining next year rates, or whatever the weather changes were, so you can more so just see how we're advancing or something.

Interviewer: **Mm-hm. You mentioned temperature. How do you know like this is a graph about temperature?**

Susan: It does say right here. So like if you read a – what do they call them – map or like the title, that usually gives a name. But sometimes not.

Interviewer: **Okay. So you were looking at the axis over here? Okay. So you mentioned the weather stations. Who do you think this graph might be useful for? Like what kind of people could use it?**

Susan: Yeah, I think like scientists and weather stations because when they're making their guesses for what tomorrow's weather is going to be or like just making a guess of there's going to be more so rain this time or something… or high winds.

Interviewer: **Mm-hm. Mm-hm. Okay. What do you think like is the most important thing to notice about this graph?**

Susan: It's not always… like it's not a straight line anywhere. It's kind of just all over the place, but it's staying in the same general area from around -1.5 to 0.5. I mean it does go above it, but not that much.

Interviewer: **Okay. So it basically stays within that range?**

Susan: Yeah.

Interviewer: **Okay. Can you say a little bit more about like the -1.5 to 0.5? Like the numbers that are there?**

Susan: It doesn't exactly go down to -1.5. But it does go below 1.5. So instead of going weird like 1.2 or something, it's just an easier estimation.

Interviewer: **Mm-hm. Do you have ideas like about why maybe they chose those numbers to use?**

Susan: I guess half-numbers are good because sometimes it's not going to just go from 2 to 1. So it's good to have like a middle.

Interviewer: **Mm-hm. Mm-hm. Okay. Cool. So what if I pick a point? Like let's say I pick this point here. What do you think that point tells you?**

Susan: There are kind of… like over here, there are a lot that are equal to that point. But over here, not so much. So maybe you could say there was a change here because over here, these are all low, and up here, it's really high.

Interviewer: **And on the right, they're high.**

Susan: Yeah. So maybe that could like mark a change.

Interviewer: **Uh-huh. What kind of change?**

Susan: Like when it's going up, is that like getting warmer? Or is that getting cooler?

Interviewer: **Well, like it's basically how you're making sense of it. So like what do you think they're trying to… like what do you think the change is?**

Susan: I think it would be between cold and hot. So maybe it's like a season change. Or no, because it has the years. I'm not exactly sure.

Interviewer: **Okay. That's alright. And it's like ideas come up later on, feel free to like jump in. But for now, you could say like, "Uh, I'm not sure for now."**

Susan: Probably like maybe it's talking about in-house because we have different ways to keep us warmer. I'm not sure the names of the heaters. But we have different heaters and like house companies that come and like help install things, I guess.

Interviewer: **Oh, okay. So like you were pointing to the in-house like heaters for the second half of the graph. Can you say a little bit more about like how that applies to the second half?**

Susan: Like over here? Or –?

Interviewer: **Where does it apply, I guess?**

Susan: I was thinking just like maybe since they're higher, maybe if you're like in your house, then you're not exactly just using a blanket which may be over here at your lowest, you would, because that's all you have or something. But over here, there're more advancements.

Interviewer: **Mm-hm. Okay. So that's the change. Like that's one possible reason why the change might have happened? Okay. Cool. And then you mentioned like there are years, right, across the bottom? Can you say a little bit more like why you think they chose 1910 to 2010 to use the range, or the intervals?**

Susan: Maybe over here, they saw that we're more advanced. But over –
Interviewer: By 2010?
Susan: Yeah. Over here, we were kind of still… I would say we still had like advancements and things. But maybe not a lot of people were wanting to work in certain things like temperature or heating or like different ways to make heat or advance to bring different ways, I guess. (Laughing)
Interviewer: Okay. So when you say "advancements", can you say a little bit more, like examples of advancements?
Susan: Like we have fans. And maybe before… I'm not sure what came before a fan. But now we have… like I'm not sure what they're called, but it was really big. They're kind of like windmill things. Or like –
Interviewer: Are really are inside the house?
Susan: No, they're outside. There's one in the front of the like property with the three little things. I'm not sure–
Interviewer: Is it a windmill?
Susan: Yeah, I think –
Interviewer: Yeah, yeah. I think those are windmills. Yeah.
Susan: Okay. So maybe there're more people who are inventing or working these work fields. But over here, not so many people like knew what they all were or wanting to work in it.
Interviewer: So like they didn't know about it, or they didn't –?
Susan: Yeah. Like they didn't have all the knowledge for it, maybe.
Interviewer: Mm-hm. Mm-hm. Okay. Cool. All right. So I'm going to, again, ask you to make predictions. One year, 5-year, 50 year. So like in one year, where do you think the next data point dot is going to be?
Susan: I think it's kind of going to stay around the same place as it moves on. So maybe… I don't want to say like in the middle of it. But not at the very bottom. So probably right there for 2011.

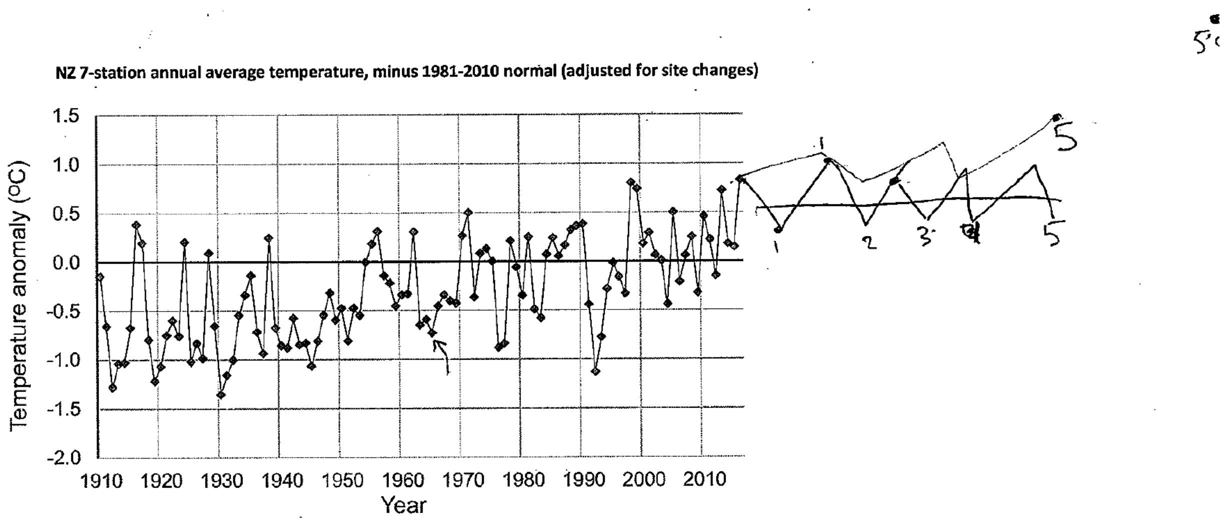

Figure G.4 Susan's Temperature graph

Interviewer: **Okay. Cool. So go ahead and put a 1 next to that one. And then for five years?**

Susan: Okay. I would say it's going to stay the same, but it's going to always come back like just a little bit to equal out here. (pause) I would say there would be like little jumps. So (inaudible). (pause) I'm not sure. I think it would be a little higher. But like kind of like it would go high and then low. And then kind of just every other one. So it might be around here. Sorry. (Laughing)

Interviewer: **Oh, that's okay. Feel free to cross off like the ones that you don't want. And then the ones that you do want… yeah.**

Susan: So this would be the 5. So it's kind of still there, but not so much.

Interviewer: **Mm-hm. And then 50?**

Susan: I would say 50, again, we might have like more so solar panels. But I'm not really sure how you could fit that into temperature. So, yeah. So maybe it would be kind of just like over here. So not that much, but still higher than it was right here.

Interviewer: **Okay. And then… yeah, these are all just predictions. So it's good. How confident are you about your prediction for Year 1, like the first year after?**

Susan: Not so confident. But I think it would be somewhere around that majority, I guess. Yeah.

Interviewer: **How about Year 5?**

Susan: I really don't know anything much about temperatures so I'm just guessing. But I think it would be maybe a little towards the 1 because over here, you can see it took a long time. So it might be like… I don't know. (Laughing)

Interviewer: **Are you like more confident or less confident than your prediction for 1?**

Susan: I'm more so confident about 1. I'm not sure about these ones.

Interviewer: **Okay. So 5 and 50, you're less confident. But 1, you're definitely more confident. Okay. Cool. Do you have ideas what might be like causing this pattern, like this up and down?**

Susan: I'm not exactly sure. Maybe seasons or like not everyone's in their house all the time. So temperatures are going to kind of not always go like straight up, but not straight down.

Interviewer: **Mm-hm. Are there other patterns that you see in the data?**

Susan: I guess you could say with the sign, it is staying within it. So it's not at the very bottom of it. Maybe it's like where they want to stay above each time it comes up and down.

Interviewer: **Mm-hm. So you're talking about like this axis line that's like this dark line that's right in the middle?**

Susan: The dark one.

Interviewer: **Uh-huh. Why do you think it stays like around there? Do you have ideas about –?**

Susan: Maybe they know it would be bad to go down to -2.0. But they're not ready for 1.5 yet. So they're trying to keep everything over towards the 0.0.

Interviewer: **Mm-hm. And so when you say like they know that they're not ready for it yet, can you say a little bit more about who "they" are?**

Susan: I'm not sure. I'm just thinking like if they don't have the resources to tell what could happen, if they get to the very top or very bottom. Or they just know like it's not going to be the greatest thing ever. I'm not exactly sure who, though.

Interviewer: **Mm-hm. Okay. Yup. No worries. Let's see. I got lost for a second. Oh, yes. Okay. So then this pattern, right, it goes up and down. And then earlier, you said that it changed from like a little bit more points below to a little bit higher up on this side?**

Susan: Yeah.

Interviewer: **Do you think you see this pattern anywhere in like school, at home, on news. Like does it connect to things that you see in school?**

Susan: I guess the weather does change things. Like maybe you could say someone's mood or like sleep events because different things happen through the day. So maybe this could be like a sleeping chart or like a heart kind of thing. Like if you're running one day for a few weeks, then it would be maybe like higher or lower than it would normally be.

Interviewer: **Cool. Awesome. Are there things that you do that you think might cause like the changes in this graph?**

Susan: I think it could possibly like more so the (inaudible) see like the sports thing because when we don't have the school season out, like when that's gone, then I do more so not really do as much of the physical activities. But then it goes up when that season is in. So I think that's maybe the same with most of the population because now a lot of people are motivated to run every day or something.

Interviewer: **And then when the running, right, can you say how like the running relates to this graph?**

Susan: There are a lot of people… like I don't really know many people that run every day. So it is kind of like maybe this is Tuesday to where you don't really do much. But then over here, you start doing more on Tuesday. And this is like Monday, and you run every Monday. But maybe not the same distance, but maybe not too far away from that distance.

Interviewer: **Mm-hm. So all these low points like could be an example of Tuesdays.**

Susan: Yeah.

Interviewer: **And all the high points could be examples of Mondays?**

Susan: Yeah.

Interviewer: **Okay. Cool. Yup. That's all the… oh, one more question. Like this graph, like do you see connections between… does this relate to anything you've seen in this graph? Like do they connect?**

Susan: The numbers are still kind of… like you still have your little halves. Like it's not just like 110… or 300 all the way up to 350. There're still your in-betweens. And then here, you kind of still have that, too (ph), because it's 2 to 1.5.

Interviewer: **Mm-hm. So there're in-betweens between numbers on both graphs?**

Susan: Yeah.

Interviewer: **Okay. Are there other connections that you see?**

Susan: I guess there are increases but not as dramatic as this one, seeing as they're keeping with it. But this one, it's kind of just… you can't really control it, I guess.

Interviewer: **Okay. So you can't control the one in this temperature graph. But in this first graph –**

Susan: We can more so see how we deal with it or want to deal with it to change it.

ARCTIC

Interviewer: **Mm-hm. Okay. Great. That's all the questions I have for these two graphs. And then here is the third graph. Okay. So have you seen this graph before?**

Susan: I don't think so. No.

Interviewer: **No. Okay. (Laughing) Looking at this graph, what do you think it's about?**

Susan: Ice and the sea, like water, oceans, maybe.

Interviewer: **Mm-hm. And what makes you think that?**

Susan: It does say the Arctic Sea. And then it says ice extent (ph) in September. So that's kind of around the winterish.

Interviewer: **Mm-hm. So you were looking at the title. Do you have ideas like why they were like measuring Arctic Sea ice?**

Susan: Maybe if they had to like take a boat to take a shipment from one place to another. So they were just wanting to see how the ice was or if it was kind of somehow you could go through it in a certain area.

Interviewer: **Mm-hm. Mm-hm. Okay. Where do you think a graph like this might be used?**

Susan: I'm not sure what they're called. Like the people that administrate the boats and like control where they're going and stuff.

Interviewer: **Oh, okay. So like the people who work in the water. Like the –?**

Susan: Yeah.

Interviewer: **Okay. Gotcha. Who do you think this graph would be useful for?**

Susan: I'm not exactly sure. Maybe people that are studying like animals in that certain sea area or are planning to travel over there.

Interviewer: **Mm-hm. So if people were using this graph, like what do you think is the most important part of the graph they should pay attention to?**

Susan: I think the numbers. Like in all of them, the numbers are one of the most important things because that determines what's happening.

Interviewer: **Which numbers are you like referring to?**

Susan: Just like the dates because you could see… so this is this year. And then you get a look at where it is. Like what numbers. So basically, all of them.

Interviewer: **Yeah. So you mentioned the dates for this graph. And the graph shows from 1975 to 2020. Do you have thoughts about like why they might have chosen these dates?**

Susan: Maybe this is when they started to develop an interest in it? Or it could just be the middle of the good and the bad or something? I'm not sure.

Interviewer: **Okay. What about the other set of numbers that are running up and down? Do you have ideas about why they chose those numbers?**

Susan: Again, I think it's better to have like the little halves instead of just going straight up to one number to the other.

Interviewer: **Mm-hm. What do you think those numbers are measuring or representing?**

Susan: Over here, it says "kilometers of ice." And then this one is just the years again.

Interviewer: **Mm-hm. Mm-hm. So the… "kilometers of ice." Okay. If I picked, let's see, this point right here, what do you think that point tells you about the data?**

Susan: That's when things started to change. Like here, it did change. But here, it changed again. So that would be your middle, I guess, because it's not below all of these. But it's not that much above it.

Interviewer: **Mm-hm. So when you say it's changing, like how can you tell it's changing?**
Susan: Up here, things are more so higher. And then over here, something just all of sudden happened to make it go change.
Interviewer: **Uh-huh. What if I like wanted you to talk about this last point right here?**
Susan: Okay. If you were really not ignoring these ones, I guess you say. If you were thinking of like this is the winter, so there's more ice here. And then here, the summer starts to come within these four dots. So then things are warmer, and there's not so much ice. But then right here, it'd be the start of… like it's the opposite of this. So you're gaining your coldness and your ice.
Interviewer: **Okay. So like the middle four dots right here?**
Susan: Yeah, that's what develops most of the changing part.
Interviewer: **Okay. Changing part. And then what season did you say this was?**
Susan: This could be winter because there's more ice. And then this would be summer because there's less.
Interviewer: **That's winter, and this is summer. And then what did you think this last part would be?**
Susan: This would come up to winter again.
Interviewer: **Okay. So that would come up to winter again. All right. Cool. So like let's look at this point at the end. Do you think this point represents one measurement, or do you think it represents multiple measurements?**
Susan: I would say multiple because I think these three would have something to do with it.
Interviewer: **Mm-hm. The three right before it?**
Susan: Yeah.
Interviewer: **What do you think those three points have to do with this last point?**
Susan: So like up here, you start from there. But here is when things start to change because you're changing but not dramatically. And then here, it just shoots up. So these have… like they're helping this one change in some way.
Interviewer: **Do you have ideas about how they might be helping it change?**
Susan: By melting or getting colder, actually, in this case. So it would be getting colder but not exactly… like you could say when it's sunny and then it's raining the next… and then sunny again. So you could tell you're changing in weather.
Interviewer: **Okay. And like also like the melting and the sunny and the cold, like those are these three points. And then can you say a little bit how like all that like creates like this point, this last point here?**
Susan: I guess sometimes you can tell the difference or like a change in how something's behaving or acting before it actually starts being what it's about to be.
Interviewer: **Mm-hm. How can you tell? Like how do people tell like that something's going to happen?**
Susan: I guess you could say with someone like their behavior because their grades, if they're grade is like, "Here's an F or a D". And then here is like a C, so you can see they're getting a little better. So maybe they're studying. And then up here, things get better. So you would see like from here, they were working on it and showing progress. And then up here, that's what happens once you actually start doing your best and doing what you need.

Interviewer: **Okay. So this last point, you think like the three before it sort of like helped like predict that one. What about this middle point, that first point, that I drew an arrow to. Is that a single measurement or multiple measurements or what?**

Susan: I would say, again, it's multiple, but not as much, because right here, again, it's kind of like this one. So it's low here and then it's kind of high. And then you could see it's dropping again.

Interviewer: **Mm-hm. Mm-hm. So the three points before that also?**

Susan: Yeah.

Interviewer: **Okay. Do these points over here, by the first arrow, like do this and everything in between affect this last time? Do you think it does?**

Susan: In a way, I think it does. But you can't really, from here, think too much about this. Like maybe you're not looking ahead, but all your actions and things, they do eventually like catch up to this one somehow.

Interviewer: **Mm-hm. So like are you thinking that maybe these last three points closest to the last point, the dot with the last arrow, has more influence than maybe all the other dots before on it?**

Susan: Maybe not, because I guess you could… like again, with the grades thing, these are all good. And then maybe you just hit a low point. Or like you get really busy with like work, sports and school. And then here, the sport season ends, so you just have school and work. But you're gaining a little bit more because you have more time.

Interviewer: **Mm-hm. Okay. So it depends on what's going on?**

Susan: Yeah.

Interviewer: **Okay. Cool. Do you see a pattern in this graph?**

Susan: The numbers all kind of like… in this bunch, they all stay around together. And then again, here. So I guess they're not even. They're just around the same general area.

Interviewer: **So like you basically see like two areas like where one's all up here, and one's all down here?**

Susan: So I guess this group is working together, and they all have something to do with the next dot.

Interviewer: **Mm-hm. Can you just circle the dots that you think are one group? And then circle the dots that you think belong to the other group?**

Susan: So these are the major groups. And then within those groups, you have your smaller ones which would be… I guess these ones would be a group. And then there're just these two because those are dramatic changes. But this one is just more so in the same area. And then same with this one. I guess these would be in their same group, just not so much these ones.

Interviewer: **Okay. Cool. And then like given that this is sort of the patterns that you see, if you had to make predictions for 1 year, 5 years, 50 years, where do you think they would be?**

Susan: It seems like they're more so shaped in W's than M's. So I want to say it's going to go up a little bit. So that would be one year. And then five years, it would be another. So this would be an M. And then, W. So it would kind of be like this part of the W which they seem to be kind of equal if you look over here in the same general groups. So this, again, would probably be another circle, I think.

Interviewer: **Yeah, go ahead. And if you want to draw a circle like… or you can dotted-line it if you're just sort of like – (pause)**

Susan: So this would be a W because here's your M, somehow. That would be right here.

Interviewer: **Okay. Cool. And then 50 years?**

Susan: I think in 50 years, there will be more dots in one group. They're like more little W's and M's, I guess I can call them.

Interviewer: **Mm-hm. What do you think it would be like on the graph?**

Susan: Well, right here, it seems like it's going down. So I'm not exactly sure if these are correct because maybe it could be like an up and then down and then back, like on repeat. So I'm going to guess it would be maybe like a middle medium. So kind of along with those, but not–

Interviewer: **Okay. So the 50… like this point that you have for 50, is it like higher or about the same height as that first group?**

Susan: I would say it's about the same height but not too much higher. But not too much lower. So somewhere around that general area.

Interviewer: **And then you're making that prediction based on like…?**

Susan: I'm just guessing, really, because I'm not exactly sure like what's the pattern.

Interviewer: **Mm-hm. Okay. How confident do you feel about these predictions?**

Susan: With the one, I kind of feel like I think it's going to go higher after a while. So it's just going to be this on repeat. So I think I am positive with this one. And then this one would be maybe like not full positivity about it, but I still think it's kind of similar rate. This one, I have no clue. (Laughter)

Interviewer: **Fifty, because it's just so way off there. Okay. No worries. So this pattern, like the groupings that you see, have you seen this anywhere in like school or home or in news?**

Susan: Maybe with… yeah, I'm not exactly sure. Maybe just with the weather or something again. Or like the grades and the work.

Interviewer: **Mm-hm. Okay. What about stuff that you do on like a regular basis?**

Susan: I guess this could be like the school year, and then this is the summer year because there's not that much that goes on around summer, I guess. Or this could be like your (ph) studying and all your education stuff. And then this is just whatever else you do on the end time which is just you.

Interviewer: **Mm-hm. So that first group would be something like studying. And then the second big group that you circled is the non-studying?**

Susan: Yeah.

Interviewer: **Okay. Do you see any connections between these three graphs? Like you can look across all of them now.**

Susan: These two are more so. They go together. Yeah, these ones go together because, again, they're not like this just increasing continuously. But I would say these two are still different seeing as they're not… I guess they're both going up and down, not just one direction.

Interviewer: **Okay. Cool. You mentioned [to title here] (ph). What about the titles from these graphs? Do they tell you anything?**

Susan: This one was kind of confusing. Like I understood this and that.

Interviewer: So you understood the CO_2 and the year?
Susan: But the actual title was kind of –
Interviewer: Confusing?
Susan: Yeah, like once you read it, you didn't exactly know what was happening for certain personalities.
Interviewer: Yeah? And then what about the second graph? What about this title? (inaudible)?
Susan: That one was kind of… it gave a little more information. But like this one, once you read it, you just automatically knew like water, the Arctic Sea and like in what month. So you kind of knew so what it was talking about. Like you could imagine it in your head.
Interviewer: Okay. So the third graph, you could. But the first one, you didn't know. And the second one was kind of –
Susan: You were getting there. Yeah. (Laughing)
Interviewer: Okay. Getting there. Okay. And then I think I forgot one question I wanted to ask that I forgot to ask in the second graph is like here with the dots, do you think that this one, the dot that I drew the arrow to, is a single measurement or multiple measurements?
Susan: I think it is more so a single one, but you do have to add these two. So I'm not sure how many add up to a group or just a single.
Interviewer: Mm-hm. It's not as clear in the second graph as it… like you could see more of the groupings in the third graph? What about the first graph? Were there groupings for this one also?
Susan: I think the grouping is more so just like that thing. That would be a group because all those little dots have something to do with each other. But then again, it is on repeat. But I don't think you could say the whole entire system is a group.
Interviewer: Mm-hm. Okay. So it's each one of those… the up downs.
Susan: Yeah.
Interviewer: Okay. Great. That's all the questions I have for you. Do you have any other questions?
Susan: I don't think so.
Interviewer: No? Okay.

END TRANSCRIPT

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