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Kindergarteners' Conceptions and Representations of Temperature: An Exploratory Study on How Young Children Perceive Air Temperature

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KINDERGARTENERS' CONCEPTIONS AND REPRESENTATIONS OF

TEMPERATURE: AN EXPLORATORY STUDY ON HOW YOUNG

CHILDREN PERCEIVE AIR TEMPERATURE

by

Ryan Francis Cain

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ABSTRACT

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Utah State University, 2019

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As states continue to work on implementing ambitious science instruction with K-12 students, research is needed to inform how to engage the youngest students. Since weather is a prominent topic in the early grades, it is worth investigating how kindergarten children analyze and interpret temperature data. Previous research has shown that young children have difficulty using thermometers. Furthermore, conceptualizing heat and temperature can be fraught with misconceptions for children and even experts.

This exploratory study uses an interpretive qualitative design to examine how the participating kindergarteners perceive air temperature, how they interpret a specialized thermometer designed and built for the study, and how they make sense of graphic representations of temperature over time. The specialized thermometer, the Early Childhood Thermometer (ECT), included design features to make it more readable by

young children. Six participants were recruited from a public school in the intermountain west region of the US. Data for the study included transcripts and artifacts from a series of semistructured interviews that engaged the youth in the practices of analyzing and interpreting temperature data. Using an interpretive qualitative study design, I analyzed interview transcripts and children's illustrations using iterative cycles of process coding, thematic coding, and analytic memo writing.

The analyses revealed a range of ways that the children: represented temperature, read thermometers, and interpreted temperature graphs. These included showing temperature with colors, symbols, and effect on the human body. Furthermore, the children discussed and represented temperature in more complex ways that previous literature would predict. While all of the children were able to make temperature measurements with the ECT, only four were able to demonstrate a conceptual understanding of the temperature scale. Given the limited duration of the interviews, it is possible that a more extended engagement with the ECT to support sense making of temperature measurements could make quantitative measures more accessible. This work demonstrates that the ECT is a promising tool worthy of further investigation in full class settings. Additionally, the study provides detailed descriptions of the children making sense of air temperature and air temperature measurement, which may be useful in designing science curriculum.

(252 pages)

PUBLIC ABSTRACT

Kindergarteners' Conceptions and Representations of Temperature: An Exploratory Study on How Young Children Perceive Air Temperature

Ryan Francis Cain

As states, districts, and teachers work to make science classes more about doing the work of science and less about remembering science facts, research is needed to show what doing science looks like. This is especially needed for the youngest students, since much of the current research studies examine the upper part of the K-12 grade range.

Having been an early elementary science teacher, my work in this dissertation and beyond is focused on making the doing of science accessible to young children. One way to do science is to collect and interpret data – to measure something and make sense of changes in measurement over time. Kindergarten teachers already do this with the weather as called for in math curriculums and science standards, albeit in simplified forms with words like hot, cold, sunny, cloudy, etc. I was curious if the children could understand more complex ways of measuring the weather, using quantitative measurements with the help of a thermometer designed for young children.

Over the course of three interviews for each child, I asked six kindergarteners to show illustrate different temperatures, read thermometers, and interpret graphs of changing temperatures.

Based on my analysis of the interviews, my findings indicate that the six kindergarteners could all read the specialized thermometer and four of them

demonstrated an understanding of how the measurements related to air temperature. This work may help with the planning of future science classes.

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Ryan Francis Cain

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CHAPTER I

INTRODUCTION

What began as a persistent problem of practice 13 years ago, has since propelled me to pursue an investigation into supporting young children to meaningfully engage with the measurement of air temperature. As an early childhood science teacher, I began almost every single school day – over the course of 8 years – coaching two first or second graders in making the daily weather observation and announcement over the school's public announcement system. This morning routine was one of many ways I tried to meet the first-grade science standard "(o)bserve, measure, record, and compare weather data throughout the year" (NYC Department of Education, 2008, p. 2). Other approaches included installing a computerized weather station on the roof of the school, getting qualified to make citizen science observations with my students as part of the GLOBE Program (Kennedy & Henderson, 2003), and trying a variety of ways of graphing temperature data in my classroom. While many of the first graders could read analog or digital thermometers, few could interpret graphs of multiple temperature values. My committed curiosity in supporting students to understand such graphs began in my time as a teacher, but it is only now that I could pursue a scientific investigation of the issue as an emergent researcher having acquired an analytical toolset in my graduate studies.

Just as my days used to begin with a weather observation with my students, countless early childhood classrooms begin their days talking about the weather as part of the morning meeting routine. During these daily meetings, teachers and students typically discuss the calendar by talking about the date, day of the week, month, season, and

weather. This may be one of their first formal experiences learning science by recording data. Such observations might entail keeping tally marks for how many days are cloudy, sunny, or rainy in a given month in order to eventually discuss difference between months. Having early elementary students collect and analyze weather data addresses what the new science standards expect of kindergarteners with respect to weather, Next Generation Science Standards (NGSS) at the national level and derivatives such as Utah Science with Engineering Standards (SEEd; NGSS Lead States, 2013; Utah State Board of Education, 2019). Broadly these new standards require significant shifts in science instruction (Reiser, 2013), but in the case of weather in kindergarten it may not be drastically different from what is already happening in morning meeting. However, as I noted in my curiosity that began in my time as a practitioner, I wonder if kindergarten aged students could be supported to make sense of quantitative measures of temperature over time. While research on young children's observations of weather is limited, ambitious work engaging early elementary students in making sense of measurements more generally exists. For example, Lehrer and Schauble (2002a) found that first graders could compare growth rates of plants – they made sense of the differences in slope on the graphs of different plant species – after working on an investigation that involved measuring plant growth. The goal of this dissertation is to investigate how some kindergarteners make sense of more sophisticated weather data, that is quantitative measures and graphs of such data.

In order to accomplish this goal, I did the following: explored how young children understand phenomena related to air temperature (e.g., temperature differences between

sunny and shaded locations, temperature differences during the day), examined how children utilize several thermometers including one customized for young children, and investigated how the children interpret temperature representation. I chose temperature measurement for three reasons. First, measuring temperature addresses one of the six kindergarten NGSS performance expectations, *K-ESS2-1, use and share observations of local weather conditions to describe patterns over time* (NGSS Lead States, 2013). This standard requires kindergarteners to interpret weather data for patterns. While some teachers may use temperature measurements from a mobile weather app, these double-digit temperature measurements may be difficult for kindergarteners to understand. Second, temperature measurement provides an opportunity to develop conceptions of heat and temperature while leveraging children's experience. That is, the kindergarteners have a lifetime, 5+ years, of experiencing thermal sensation. For example, children in the study recall instances of feeling overheated during summer play or noticing that a jacket left in the sun feels warm. Third, as a practitioner I struggled to get children to see the patterns in temperature data over time. I attempted to address this by attending several multi day professional development workshops on teaching weather. While this did improve my knowledge of the science content related to weather, many of the suggested activities included making weather observations with scientifically accepted protocols. For example, teachers might have students record temperature in the shade like weather professionals do with a calibrated thermometer. Although these procedures served the goal of collecting accurate weather data, they did not support my students in understanding what we were measuring.

Problem Statement

As early elementary classrooms continue to have less instructional time devoted to the teaching of science (Blank, 2013), creative ways to leverage school schedules are needed (Lee, Drake, Cain, & Thayne, 2015). More recent data (Banilower et al., 2018) shows this is a persistent issue impacting early elementary grades. Banilower et al. found teachers in grades K-3 taught science on less days than compared to teachers in grades 4-6. Blank recommends that states take a more integrated approach to subjects to use time dedicated to Common Core subject matter to better include subjects like science.

If existing routines can be improved upon to better address the demands of ambitious science and math standards without requiring additional time, young children may have better access to these sorts of experiences. As mentioned earlier, the common activity of morning meeting is a preexisting routine already in many early childhood classrooms. In addition to discussing the calendar and weather, morning meeting often also involves counting number of days in school to practice numbers 1-100 culminating in the 100th day of school celebration. Schools do this in order to meet math standards such as the Common Core's K.CC-1 for Kindergarten, "count to 100 by ones and by tens" (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Since temperature measurement also falls within the same 1-100 scale, quantitative temperature measurement in the morning meeting is a second way to meet the above Common Core math standard within this existing classroom structure. While time spent teaching science has declined in grades 1-4 from 1993 to 2009, math and ELA instructional time has increased in response to school accountability measures

(Blank, 2013). Therefore, science instruction could benefit when it is infused in a primarily math activity, morning meeting. There is an ambitious math curriculum that addresses quantitative measurement of temperature and analyzing collected data, the research-based math curriculum Everyday Math (The University of Chicago School Mathematics Project, 2019).

Everyday Math has teachers establish a daily routine for students to measure with a thermometer or collect from the web the current temperature as part of the morning meeting. Students then translate that quantitative measurement into a color value by translating the number on a poster of an expansion thermometer with the scale broken into color segments. The measurement is recorded with a colored sticker on a sheet of paper representing a month. After a few months of collecting this temperature data as colored dots, the teacher then leads the class in a discussion comparing the months. This transposition of a temperature to a color may simplify the data to a range on the thermometer, but it may obscure the quantitative measurement. That is, translating a number into a color reduces the ability to make comparisons between measurements. Although young children may still be developing numeracy skills to know that 50°F is less than and cooler than 80°F, at least the number system is consistent with other domains such as money or counting blocks. In contrast, knowing that a green sticker represents a lower and cooler temperature than a yellow one requires specific knowledge of the color-based temperature scale. A possible reason to simplify the measurement might include the difficulty posed to kindergarteners by typical thermometers. This can be especially hard with expansion thermometers where only some of the tick marks are

labeled. Digital thermometers may be more readable, but lack the affordance of showing the entire scale including the range of possible values. In my experience as an early childhood science teacher, first graders often struggled making sense of both types of thermometers. My personal observations are consistent with research showing that young children have trouble recognizing the purpose of thermometer and how to use them to measure temperature (Havu-Nuutinen, 2007; Kampeza, Vellopoulou, Fragkiadaki, & Ravanis, 2016). While the overall design in the Everyday Math curriculum is strong for engaging the children in a cycle of observing, recording, and analyzing data, I identified a design opportunity to develop a thermometer with the color scale built in. As the initial reading of a thermometer or a weather website in the Everyday Math Curriculum could run into issues with kindergartener's numeracy skills, I propose an alternative approach by applying a color scale directly to the thermometer and by simplifying the scale into discrete 10°F increments. This way the kindergarteners can read the thermometer in two ways by attending to color or height, while also working on their ability to count by 10's from 0 to 100.

To evaluate my proposed redesign to the Everyday Math way of recording temperature, I have developed and fabricated a temperature measurement instrument, dubbed the Early Childhood thermometer (ECT). This interactive weather instrument is pictured below in Figure 1.

My intention was to provide an easier way for students to recognize representations of temperature. In addition to evaluating the designed features of the ECT, this dissertation study is also a focused inquiry on what prior knowledge children

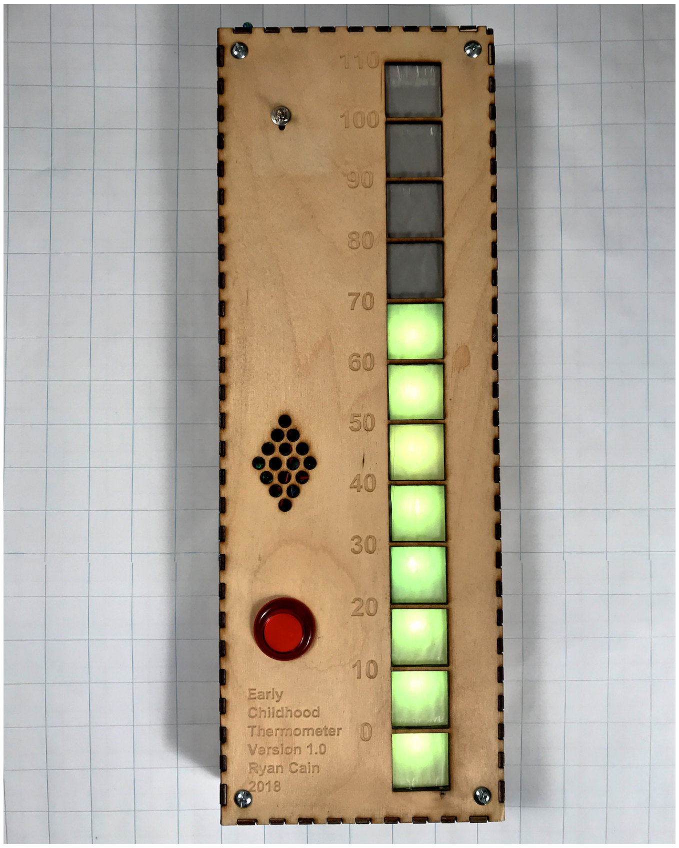

Figure 1. The early childhood thermometer displaying 70°F.

display when discussing air temperature and using the instrument. At its core, this dissertation explores how the participants' expressions about air temperature relate to their interpretations of temperature representations.

To support children with the quantitative measurement of temperature, we should consider what children already know that is relevant. We should also consider what is intuitive and difficult for them with respect to thinking about, representing, and describing weather conditions. On the one hand, we should expect a great deal of familiarity with weather conditions. People directly experience weather related phenomena any time we step outdoors. That is, we might: feel a breeze on our brow,

experience the burden of breathing summer air, or notice the silence that accompanies a fresh fallen snow. Weather phenomena impact the body's many senses. Temperature is constantly fluctuating throughout the day and across locations, all the while being in contact with our skin. These corporeal resources shape how we understand and talk about weather phenomena. These resources can be leveraged in service of promoting deep understandings of measurement of weather-related variables, but also must be disentangled from canonical views of heat and temperature to prevent misconceptions. For example, a person might think that metal makes things cold because metal objects usually feel cold to the touch. This misconception of thinking metal objects are always cold would involve learning metals often feel cold because they are good conductors of thermal energy by touching a metal that was at body temperature and discussing what thermal sensation involves. That is, temperature as observed through thermal sensation needs to be resolved with temperature as measured by a thermometer.

Research Questions

In this dissertation, I investigate the following three research questions.

1. How do the kindergarteners talk about and show air temperature?
2. How do the kindergarteners interpret the ECT and commercial thermometers?
3. How do kindergarteners interpret graphic representations of air temperature?

The new science standards require students to engage in the practices of science and engineering such as asking questions and conducting investigations. The practices attached to the performance expectation of interest for this study, *K-ESS2-1* described

earlier, are to *analyze* and *interpret* data. More specifically, "(a)nalyzing data in K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations" (NGSS Lead States, 2013, p. 7). The research questions above inquire into the prior experiences of the youth with air temperature and how they interpret air temperature representations. Furthermore, I orient this dissertation with the idea that children come to school equipped with prior conceptions of how the natural world functions. Rather than replacing children's intuitive ideas about science phenomena with the correct canonical ones, teachers facilitate opportunities for children to problematize their prior conceptions to build revised conceptions of phenomena. One of the goals of the research questions is to surface temperature conceptions as they relate to expressing, measuring, and graphing temperature. First, RQ1 provokes description of what prior knowledge kindergarteners bring to conversations and representations about air temperature. Second, RQ2 examines the design features of the ECT in comparison with a commercial classroom thermometer. Third, RQ3 elicits descriptions of the ways in which the kindergarteners make sense of various representations of temperature. Together, these questions inquire into the utility of temperature measurement and recording with the ECT to promote engagement with children's intuitive temperature ideas while engaging in the practices of analyzing and interpreting data.

Dissertation Organization

Following this introductory chapter, Chapter II (Literature Review), consists of my theoretical perspective of investigating children's prior conceptions of the natural

world, my systematic approach to finding literature to include relevant background information on temperature and heat, a literature review on prior conceptions of temperature, an overview of practitioner literature on early childhood weather measurement, and a brief section on the general state of measurement education. While prior research indicates that children can be supported to refine their conceptions of heat and temperature (Clark & Jorde, 2004; Linn & Hsi, 2000; Wiser & Amin, 2001), most of the research examines middle-school aged children. While the research is limited for the age group I examine, there are exceptions. The research is mixed showing the benefits (Varma, 2014) and difficulties when making quantitative measures of temperature with early elementary students (Havu-Nuutinen, 2007; Kampeza et al., 2016).

Chapter III (Methods and Procedures) begins with my "interpretive qualitative" (Merriam & Grenier, 2019) study design to conceptualize this exploratory study. Next, I present the instrumentation for interviewing the children and measuring their receptive language ability. I then provide contextual information on the study participants. Having provided both the content of the interviews and the context of the participants, I document the design features of the ECT. Finally, I close the chapter with an explanation of my analytical approach including examples of the iterative approach to coding and analytic memo writing procedures.

In Chapter IV (Results), I present my findings organized by research question. Each section provides illustrative examples to show the range of ways the children responded to the interview prompts. This includes examples of how they reasoned through my questions out loud, often by describing their illustrations. Overall, all six

children were able to successfully read the ECT, but only four were able to demonstrate an understanding of the temperature scale. Other findings include the ways children depicted temperature with color, symbols, and effect on the human body.

Finally, the dissertation concludes with Chapter V (Discussion), where I present my interpretation of the children's perceptions of temperature with half of them approaching more normative conceptions. Next, I discuss the contribution and implications of the study including how the ECT supported the children to make quantitative measurements of temperatures and could potentially benefit classroom instruction. Limitations include a lack of similar supports for children interpreting all of the temperature representations and the possibility of understating children's temperature conceptions due to my method of analysis. Future work, which I intend to conduct, will include a full classroom implementation of daily measurement with the ECT and recording with color-coded bar graphs.

CHAPTER II

LITERATURE REVIEW

The chapter below presents relevant literature informing this dissertation. While there is a substantial amount of literature on youth conceptions of temperature related phenomena, such as conflating temperature and heat and thinking of hotness and coldness as substances instead of transfers of energy, much of the work examines secondary school-aged children (Lewis & Linn, 2003; Linn & Hsi, 2000; Nachmias, Stavy, & Avrams, 1990; Slotta, Chi, & Joram, 1995; Wiser & Amin, 2001). In the following sections I will summarize the literature on how children conceptualize heat and temperature and how they can be supported to develop more normative conceptions, how practitioner literature recommends young children collect and represent environmental data in service of learning about weather, and finally some of the limitations of how measurement in general is taught in schools. These bodies of literature inform this dissertation by providing examples of what older children know about heat and temperature, and how they can be supported to develop more normative conceptions. This is useful in both the design of the ECT and in the interpretation of my data. The current study examines the feasibility of having kindergarteners measure and make sense of temperature. The practitioner articles about early elementary weather observation and elementary measurement literature provide the context of the current state of how these topics are taught in schools. In summary, the heat and temperature literature demonstrate what is possible for developing normative conceptions of temperature related phenomena, the weather and measurement literature present the current state of weather

instruction in early elementary classrooms, and this literature review combines them to inform the design of a specialized thermometer to promote normative conceptions with air temperature measurement with early elementary students.

My theoretical perspective is rooted in the observation that students have prior conceptions related to science phenomena. That is, both the literature I draw on in this chapter and the research questions that I investigate examine what children already know about heat, temperature, and the measurement of temperature. While the children in the study are near the start of their formal education in kindergarten, they enter school with a lifetime of experiencing the natural world. Piaget (1960) investigated children's prior conceptions for a variety of natural phenomena. For example, when asking 5- through 9-year old children where rain comes from, their responses included conceptions such as pipe-fed water taps in the sky and God throwing down buckets of water (Piaget, 1960, p. 312). In this example, the children are drawing on their lived experiences including operating a water tap and being enculturated by an organized religion as resources for constructing an explanation of where the rain comes from. Piaget laid the foundation for decades of prior conception research.

The body of research on prior conceptions spans across a range of science topics, such as children's prior conceptions of: the cause of the day/night cycle (Kallery, 2011; Vosniadou & Brewer, 1994), Darwinian evolution (Keleman, 2012; Samarapungavan & Wiers, 1997), physics concepts (diSessa, 1993; Reiner, Slotta, Chi, & Resnick, 2000). In some cases, prior conception work identifies non-canonical conceptions as misconceptions in need of replacement (Vosniadou & Brewer, 1994), while other work

examines how misconceptions can be "stepping stones" towards developing canonical conceptions (Campbell, Schwarz, & Windschitl, 2016). Other work has examined how interview methods for eliciting prior-conceptions may influence what conceptions are surfaced (Sherin, Krakowski, & Lee, 2012). In summary, although there are multiple perspectives on the function of prior conceptions in developing canonical conceptions of the natural world, there is agreement on the utility of identifying nascent ideas held by children.

I take the position that prior conceptions are children's ways of making sense of the world around them based on the evidence in their lived experience. Educators and curriculum designers should value these prior conceptions, but also work to help children differentiate them from canonical conceptions. Identification of prior conceptions informs instructional design by mapping way-points towards developing canonical conceptions of scientific topics. That is, once naïve conceptions[1] have been identified, activities can be designed to support learners to refine their conceptions towards more canonical ones.

Before getting into the research on children's prior conceptions of temperature and heat, I first provide an explanation on my process for building the literature review and a brief overview on the normative view of heat and temperature. While much of the chapter addresses children's prior conceptions of heat and temperature, I also include related work from practitioner journals on early childhood science and mathematics

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[1] Although I use the term "naïve conceptions" throughout the dissertation, other researchers use terms such as "misconceptions" and "misclassifications." I deliberately choose naïve conceptions for its less valenced implication. I read the word "misconception" as meaning a person holds an incorrect conception, while the term "naïve conception" does not apply a negative judgement to a person's prior knowledge. Rather, a naïve conception indicates that a person may hold a conception of a topic based on their previous experiences that may contradict a canonical explanation of a topic.

education research on measurement.

Systematic Approach to the Literature Review

In order to conduct a thorough review of the literature related to children's conceptions of temperature, I used a variety of database searches including Google Scholar, Education Source, Education Full Text, ERIC, PsycINFO, and Psychology and Behavioral Sciences collection. Search terms included combinations of the following keywords: heat, temperature, thermometer, education, elementary, weather, science, secondary, measurement, and early childhood. Additionally, I followed up on relevant articles cited in the articles from my searches. Throughout my search, I found a limited amount of literature for early childhood.[2] To illustrate the paucity of work in this area, I analyzed articles citing Erickson (1979). I chose Erickson's article about how children ages 6-13 explain heat phenomena since it was cited in many of the articles in my search. Furthermore, according to Google Scholar, it had been cited 512 times. My analysis included categorizing the relevance to my topic and grade of participants in the study. To reduce the number of articles to ones that were most active academic discourse, I chose a threshold of having at least 15 citations according to Google Scholar, reducing the list from 512 to 216 articles. With the 216 articles, I then rated them for relevance to my dissertation,[3] further reducing the number of articles to 68. If a publication examined how

[2] The above searches did identify a fair amount of relevant practitioner articles that mainly provide best practices for making and recording weather observations with young children.

[3] This process involved analyzing abstracts and full articles, many of which had to be obtained through interlibrary loan. Articles that were not written in English were marked as not relevant not to discount the work of international scholars, but rather as a limitation of my resources.

participants conceptualize temperature related phenomena, I marked it as relevant. This enabled me to capture articles that were part of the academic discourse related to how children and adults conceptualize thermal phenomena.

As shown in Figure 2, most of the articles studied secondary and university students. It is also interesting to note that in the 6 elementary articles, only one looked at early elementary students, although the study also included upper elementary (Paik, 2007). This lack of research at the elementary level citing Erickson (1979) is consistent with my broader literature search. Regardless, I have tried to make connections to adjacent literature when possible and build on limited literature that match the age group that I am studying in this dissertation.

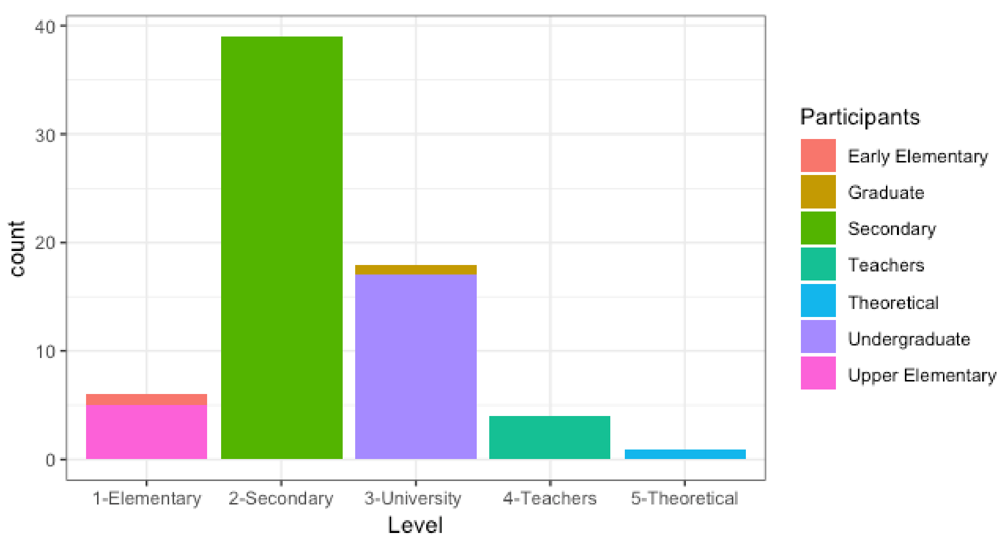

Figure 2. Distribution of relevant articles citing Erickson (1979).

Relevant Technical Details About Thermal Energy

Because temperature and heat involve a complicated set of topics that can be confusing for children, adults, and even experts holding advanced science degrees in

physics and chemistry (Lewis & Linn, 2003), I present an explanation relevant to this study. Temperature is a measure of movement at the molecular level (average amount of kinetic energy) within a substance, and heat refers to the transfer of that energy between substances of unequal temperatures. For example, if I take a can of soda out of the fridge on a warm day and place it on the counter, both the warm air and the surface begin to transfer energy to the drink speeding up the beverage's molecules, increasing its temperature. Figure 3 shows another example of thermal transfer of energy between to objects. If I want the beverage to stay cold while I drink it, I might pour it in a glass with some ice. Now the energy is passed on from the environment to the soda and transferred further to the ice, keeping the soda cold. In this example, thermal energy has been transferred and remained thermal energy. Alternatively, energy may be transferred without maintaining the type. Examples include electrical energy being transferred as thermal energy when a current is passed through a heating element (e.g., electric stovetop) or the reverse process when thermal energy from a fire is used to generate a current with a Peltier element (e.g., Biolite Camp stove).

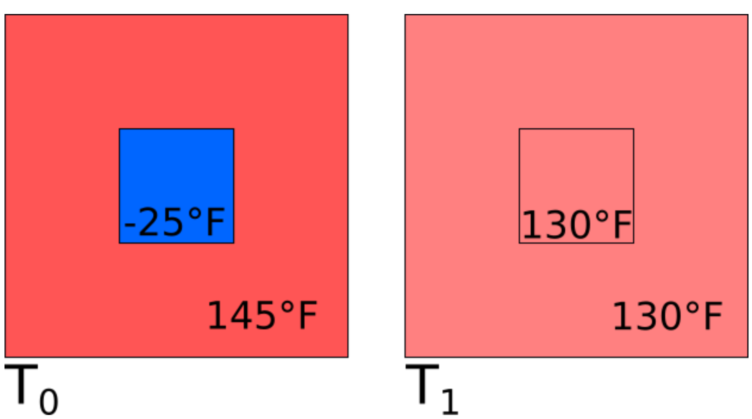

Figure 3. Thermal equilibrium model. Initially, a small block at -25°F is placed on top of a larger block at 145°F. After some time both blocks will be at 130°F due to a transfer of energy from the large block to the smaller one.

The salient feature about energy transfers is type of energy is independent between the source and the receiver. Therefore, heat is a transfer where the type of energy (thermal) happens to be the same type on both sides, where the molecular motion of one substance slows as it causes the others' molecular motion to speed up. The important detail to keep in mind is that heat and temperature are separate but related phenomena. The following section explains how human perceptions of hotness and coldness can conflict with normative conceptions of heat and temperature.

Research on Heat and Temperature

Children's Conceptions of Heat and Temperature

Children from ages 6 to 12 often conceptualize hot and cold as independent phenomena (Erickson, 1979; Lewis & Linn, 2003) as opposed to high and low values of a single variable. Furthermore, hotness and coldness are sometimes conceptualized as substances that can be transferred between objects. For example, we see evidence of this when people say "don't let the heat out" or "the cold got into my bones" (Erickson, 1979; Reiner et al., 2000), which I refer to throughout the dissertation as a *substance view* (Erickson, 1979; Slotta et al., 1995). Additional naïve conceptions of thermal energy include conflating heat and temperature (Kesidou & Duit, 1993; Slotta et al., 1995; Tiberghien, 1984; Wiser, 1988) and attributing states of hotness or coldness to materials based on previous experiences of touch (Lewis & Linn, 2003).

Prior work has focused on how children's conceptions compare to canonical views of heat and temperature. While the term heat may be both familiar to and used by a

child beginning at 2-3 years of age, a child's conception of heat is one of a hot-body – something that is associated with being hot (e.g., sun, fire, stove; Albert, 1978; Erickson & Tiberghien, 1985). Albert found that young children (4-6 years) could attribute warmth to a heat source (e.g., the sun makes it hot outside), and as children get older, they begin to discuss heat as an "entity." This is progress, moving from a conception of things that are always hot or cold (fire or ice) towards a view of hot or cold as something that can change and move between objects. Despite the progress, this view is incorrect because heat is not a substance or thing that gets transmitted; rather it is an intrinsic quality of a substance that can induce a change of the same quality of another substance. That is, there is no exchange of matter, instead one substance's molecules slow down as the molecules in substance receiving energy speed up. Energy is transferred in this case remain thermal energy, but could change to a different type of energy in a different scenario.

Erickson (1979) found that adolescents think of hot and cold with material-like properties, such as one participant saying "the cold left the ice-cube and went into the water" (p. 226). Wiser (1988) refers to this transfer of cold or hot material as the *source-recipient* model, based on the work of the Experimenters' in 17th century Italy who had made early thermometers. In the source-recipient model, sources like fire or ice emit hot and cold particles that enter recipients without an energy loss to the source. The above ice-cube example is wrong because the ice-cube on a hotplate melts due to the hot plate transferring thermal energy,[4] raising the temperature of the frozen water above 32°F. This

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[4] The hotplate activity in Erickson (1979) had participants observer the results of putting various substances on a hot plate, such as metal cubes, sugar, butter, and ice.

subtle difference includes a direction of energy transfer into the ice cube as opposed to cold as a substance leaving the cube. The substance view can be an indicator of ontologically rooted naïve conceptions. For example, one might say that a hot plate imparted heat into an ice cube, which Wiser and Amin (2001) would define as the everyday conceptualization of heat or “$heat_E$.” In contrast, Wiser and Amin define a science conceptualization of heat (“$heat_S$”), which is ontologically different from $heat_E$ by not being hot and instead being energy that is transferred from the hot plate to the ice cube. They indicate that this $heat_E$ conception based on hotness makes it “impossible to believe that heat is energy within the student conceptualization” (p. 338). An example of heat not being hot might involve two blocks of iron in contact with each other. If block 1’s temperature is -100°F and block 2 is at -50°F, the warmer block 2 will heat the colder block 1 despite both of them being quite cold to the touch. To overcome the limitations of the $heat_E$ conception of heat, Wiser and Amin used metaconceptual teaching to explicitly teach the difference between the two versions of heat, where $heat_E$ is how our brains perceive hotness with our sense of touch and $heat_S$ is a transfer of energy between substances. Working with soon to be ninth graders, Wiser and Amin used guided inquiry with computer-based models, explicit instruction distinguishing the two versions of heat with molecular kinetic theory, and pen and paper activities. The metaconceptual teaching approach allowed the participants to problematize their lay-person understandings of heat in service of “achieve(ing) a fundamental ontological reorganization” yielding an understanding of both versions of heat and more importantly how the two are related (Wiser & Amin, 2001, p. 351). Other work looking at ontologically based naïve

conceptions of thermal phenomena distinguish the miscategorization of heat as a substance instead of a process (Reiner et al., 2000; Slotta et al., 1995).

In addition to problems associated with a substance views or ontological mismatches related to thermal energy, other naïve conceptions include considering hot and cold as separate entities. Lewis and Linn (2003) found that middle school students held separate beliefs about keeping things cold and hot with conductors (e.g., metal) being good at keeping things cold and insulators (e.g., wool) being good at keeping things warm. Taking a perspective of how things feel when we touch them – metals usually feel cold while we put wool on our skin to keep warm. For example, the intuitive view that metal objects are associated with a cold feeling contributes to the naïve conception that wrapping a cold soda with aluminum foil can prevent it from getting warm. Conversely, how we perceive temperatures can be a productive resource for learning about thermodynamics, how the temperature of an object changes while in contact with its surroundings. For example, children are able to describe how a mixture of hot and cold water would feel, but may be less likely to express the feeling of warm (mix of hot and cold) quantitatively, which I present in the next section.

Quantification of Temperature

As will be discussed later in the chapter, schools tend to teach measurement (and math topics in general) as procedures without developing the conceptual understandings supporting such procedures (Hiebert & Lefevre, 1986). An opportunity exists to build on children's intuitive knowledge of thermodynamics. For example, intuitive beliefs might include knowing that mornings before school are cold and windy as compared to the walk

home from school or that metal objects often feel cooler than wooden objects despite being the same temperature. Before showing how students can be supported to leverage intuitive knowledge while learning to solve thermodynamics problems, I first illustrate the difference in what children intuitively know about thermodynamics compared to the measurement of thermodynamics.

Research has shown that children are better at explaining temperature phenomena qualitatively than quantitatively (Cowan & Sutcliffe, 1991; Shayer & Wylam, 1981; Stavy & Berkovitz, 1980). Stavy and Berkovitz (1980) found that 8-9 year olds could make qualitative predictions of the final temperature of a combination of 2 cups of water at different temperatures. In contrast, they observed that the children could not make quantitative predictions. A common mistake included answering with a sum of the two temperatures (60°C + 60°C = 120°C) even though this disagrees with their qualitative interpretation of the same problem. Despite Stavy and Berkovitz's treatment resulting in significant increase in correct quantitative responses, less than half of all the participants were proficient, which they attribute to the substance view of temperature and applying familiar math operations. In a similar study, Cowan and Sutcliffe found that children 7 to 12 scored significantly higher on qualitative as compared to quantitative questions about combining water of different temperatures. Taking a Piagetian approach, Shayer and Wylam's results examining 9-13 year old's conceptions of heat and temperature indicate that although participants at the novice (early concrete) stage of development could make qualitative connections with the linear temperature scale, some summed temperatures for when liquids of the same temperature were mixed. Together these studies (Cowan &

Sutcliffe, 1991; Shayer & Wylam, 1981; Stavy & Berkovitz, 1980) show that quantification of temperature can be problematic for children. These difficulties may be the result of children conflating ideas of heat, hotness, and temperature while not being familiar with the temperature scale.

Wiser, Kipman, and Halkidakis (1988) found that using a computer-based model could support children's performance on quantitative temperature problems, but conceptual gains towards the normative understandings of heat and temperature were more limited. Described in the next section, work that includes perceptions of temperature in computer-based simulations has demonstrated success with improving conceptual understanding of heat and temperature. Said another way, digital tools provide ways for youth to make sense of quantitative changes in temperature while accounting for perceptions of temperature and the kinetic temperature model.

Tools for Teaching Heat and Temperature

Thoughtfully designed technology tools have been shown to be able to identify conceptions of heat and temperature (Nachmias et al., 1990) and support the development of distinct understandings of heat and temperature with the collection of real-time temperature data (Clark, 2010; Clark & Jorde, 2004; Linn & Hsi, 2000; Wiser & Amin, 2001), albeit for secondary school aged students. Real-time collection and visualization of temperature data has been effective in teaching temperature concepts (Clark & Jorde, 2004; Linn & Hsi, 2000; Zucker, Tinker, Staudt, Mansfield, & Metcalf, 2008). Linn and Hsi found that students using the 12-week thermodynamics curriculum were able to achieve a 400% increase in understanding the difference between heat and temperature

by using the computer to graph temperatures sensed with a probe in real-time and simulations coming from virtual probes. The curriculum included activities such as making predictions and running virtual experiments observing how different wrapper materials (e.g., aluminum foil, wool) affected the cooling rate of hot baked potato (Linn & Hsi, 2000). Similarly, Zucker et al. observed a large effect size of 1.54 with students in grades 5 and 6 when using probeware to measure the temperature of a mixture of hot and cold water after making a prediction from initial temperatures.

Probeware is a term given to sensing devices that can measure, collect, and display environmental variables typically connected to a computer.[5] The use of real-time temperature data from a probe and displayed on a live graph makes the process of temperature change visible. Considering the example of coffee cooling in ceramic and Styrofoam mugs presented by Slotta et al. (1995), a person might be able to more readily consider heat as a *process* as opposed to a *substance* if they could view a live graph displaying time vs temperature as both cups reach thermal equilibrium with room temperature. Having a continuous representation of temperature may help displace naïve conceptions caused by thermal sensation. While both cups of coffee might feel warm if we were to pick them up, the temperature visualizations provide an alternative perception with the ceramic cup's coffee being cooler. Snir, Smith, and Grosslight (1993) argue that making nondirectly observable aspects of scientific phenomena explicitly visible in computer simulations can be more effective for promoting conceptual change as

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[5] Early probeware included sensors plugged into personal digital assistants like a Palm Pilot (Metcalf & Tinker, 2004), but contemporary devices like Pocket Lab utilize wireless connections to tablets and laptops to collect and analyze real-time data such as temperature, particulate matter, and acceleration.

compared to a traditional lab activity. For example, Wiser and Amin (2001) support students' development of the science view of heat (heat$_S$) by visualizing energy as multiple *E*'s transferred between a hot plate and a block of metal. In the model, students can select how many *E*'s to apply and then observe how hot the temperature of the metal block changes. Similarly, Clark and Jorde (2004) make energy flow visible with arrows and also include a representation of thermal sensation. The salient feature of all of these studies (Clark & Jorde, 2004; Snir et al., 1993; Wiser & Amin, 2001) is that making the non-visible process of thermal energy transfer visible can support children in refining naïve conceptions about such transfers of energy.

Clark and Jorde (2004) asked high school students to make predictions about temperatures of and how objects would feel in certain scenarios, such as taking some strips of metal and wood out of a hot car and then bringing them indoors, and then had the students interact with computer-based models depicting the substances in the scenario. In both the control and experimental groups, students could view representations of materials with a numerical label of the temperature and color-coded scale (white for 10°C, red for 80°C, and a gradient in between) applied to the block representing the object. In addition, the models had arrows indicating direction of heat flow. Students in the experimental condition had the ability to click for a "tactile visualization" of how the object would feel, displaying and reading aloud statements like "This is burning hot!" This resulted in the experimental condition performing significantly better on posttests measuring both tactile explanations of heat and thermal equilibrium. For the control group, many of their explanations of thermal equilibrium

were incorrect due to their perceptions of how different materials feel.

Together, these studies (Clark & Jorde, 2004; Linn & Hsi, 2000; Wiser & Amin, 2001) demonstrate that middle and high school-aged children could develop more scientific conceptions of heat and temperature by making the invisible quantifications of heat, temperature, and energy visible for discussion. In addition, the use of temperature sensors (probes) made the process of energy transfers in the real world visible on the computer models. More recently, Varma (2014) demonstrated that first and third grade students could improve their concepts of thermal transfers by using a probeware connected to a handheld computer while conducting guided experiments. For example, the students compared cooling rates of cups of hot water wrapped in different materials by recording temperatures from the handheld computer at 5-minute intervals in their notebooks. The handheld device displayed current temperature and a graph. While this is only one study looking at supporting early elementary students' conceptions of thermodynamics, it demonstrates that young children are capable of making these conceptual strides when making repeated temperature measurement.

Although measuring temperature does not easily map onto children's naïve conceptions of heat, the previous sections have shown that with the proper supports children can resolve issues between temperature and thermal sensation productively. In summary, although there is quite a bit of work exploring how children understand heat and temperature as it relates to lab-based heat scenarios,[6] this study is more concerned

[6] Lab-based as in observing classroom thermodynamic demonstrations. For example, children observing hot coffee cool in cups made of different materials or making predictions about final temperatures when containers hot and cold water are mixed. In contrast, this dissertation examines young children's ideas and observations of air temperature.

with how children deal with heat and temperature in the context of weather.

Weather Study in Early Elementary Classrooms

The study of weather in kindergarten classrooms is common in both science and math content areas. One of the local standards for the school in the study requires children to make, record, and interpret weather data – "K-2 (c)ompare the changes in weather over time, (o)bserve and record that weather changes occur from day-to-day and weather patterns occur from season to season" (Utah State Office of Education, 2010, p. 13). As mentioned in the last chapter, the NGSS includes a similar performance expectation "K-ESS2-1, use and share observations of local weather conditions to describe patterns over time" (NGSS Lead States, 2013, p. 7) on which this dissertation is focused. Observations of weather might include measurements of: cloud cover, temperature, precipitation, or wind speed. Weather observation spans both science and math classes in elementary schools. For example, *Everyday Math*, a research-based math curriculum in use by over 4 million students per year (The University of Chicago School Mathematics Project, 2019) includes weather observations as part of the prescribed daily morning routine for kindergarten, typically referred to as morning meeting by early childhood educators. In this curriculum, kindergarteners record daily weather observations (e.g., rainy, sunny, foggy) and the temperature (Bell, 2012). In addition to adopted curriculum materials, weather observation examples for early elementary students can be found in practitioner journals, which I reviewed.

From the NSTA's elementary science teaching journal *Science & Children,* there

are some recommendations for recording weather observations with early childhood students (K-2) using familiar materials and pictures. Miller, Smith, and Trundle (2014) present an inclusive approach to weather observation for kindergarteners, where the children make weather observations of wind by: feeling it on their faces, observing the motion of a flag, categorizing the level of wind qualitatively (no wind, some wind, or strong wind), charting their observations, and discussing their data (interpreting and making predictions). Ashbrook (2006) suggests having young children measure rainfall with blocks and plot the data on charts that expand across the classroom walls. Royce (2014) recommends having kindergarten through second grade students observe and record cloud cover, precipitation, and temperature, but notes that temperature should be measured in whole numbers or qualitative terms (e.g., warmer, colder). Taken together, these *Science & Children* articles seek to support young children in collecting and interpreting weather data with accessible design (e.g., picture-based representations of weather, measurement with familiar materials such as blocks, and a simplified temperature scale). While these may be promising instructional strategies, they are not empirical studies.

Looking at the research literature, studies on children and the weather often focus on naïve conceptions or misconceptions of young children on weather processes (e.g., the water cycle and its phase changes; Malleus, Kikas, & Marken, 2017; Stephans & Kuehn, 1985; Villarroel & Ros, 2013). In her synthesis of research on children's misconceptions of weather, Henriques (2002) identifies this focus on weather processes as mostly related to physical science topics instead of earth science. It is possible that this is due to more

traditional approaches to science instruction, where a student is shown a diagram of the water-cycle, maybe creates a copy of the canonical model of the water cycle, and is expected to understand the model of the water cycle. That is, physical science concepts (e.g., evaporation, condensation) are used to explain the mechanisms behind water cycle. The current approach called for in the NGSS (NGSS Lead States, 2013), might delay the use of the canonical water cycle model until after students first engaged in the practices of science in relation to the study of the weather, such as measuring and interpreting. As mentioned earlier in this section, students could observe: daily rainfall (Ashbrook, 2006), wind speed (Miller et al., 2014), or temperature (Bell, 2012) to engage in the practices called for in the NGSS.

Although the research examining young children making weather-related measurements are limited, here are a few exceptions. Havu-Nuutinen’s (2007) study of Finish children ages 6-9 indicated that most 6-year-old participants could not fill in a blank thermometer when shown a weather scene (e.g., snowy day) but about half of the 7-year-old participants could, attributing this to the younger children’s limited ability with numbers. Kampeza et al. (2016) found that although many of their kindergarten participants recognized what an expansion thermometer was, only about 11% of them knew how the height of the liquid was used for interpreting temperature. Since many of the 6-year-old children meaningfully engaged with the thermometer, Kampeza et al. recommends future research to determine how thermometers could be used with kindergarten children and how a thermometer could be modified to facilitate such experiences. This dissertation seeks to investigate the design of such a thermometer, the

Early Childhood Thermometer (ECT), described in the following chapter.

In summary, although the study of weather though observations in early childhood classrooms (e.g., *Everyday Math* curriculum, the practitioner articles in *Science and Children*), this is less common in the research literature. In the few research articles above, it seems with the proper supports young children could meaningfully measure temperature to learn about weather-related phenomena. I use the word meaningfully to distinguish knowing what it means for the temperature to rise or fall on a thermometer from simply being able to read a value off a thermometer. This difference will be explained further in the next section on measurement and data modeling.

Measurement and Data Modeling

Measurement is a common math activity in the early childhood and elementary classrooms – sometimes starting with the use of informal units of measure (e.g., measuring the length of an unsharpened pencil with blocks, using footsteps to measure the length of a classroom carpet) as a way to justify the use of standard units of measure to reduce variability. Examining U.S. math standards across the country, Kasten and Newton (2011) found that the math standards focus primarily on measures of length. Despite this focus, many elementary students still struggle with measuring length, especially when asked to measure something not placed at the 0 mark of a ruler. Smith, Males, Dietiker, Lee, and Mosier (2013) posit a potential contributor to this may be the overly procedural way typical math curriculums teach measurement. That is, children are taught the rote procedure of aligning an object with the 0 mark on a ruler and reading off

an endpoint number without a conception of what the measurement means. Furthermore, the types of questions teachers ask may also contribute to limited conceptual understanding of measurement. Consistent with this view, Bragg and Outhread (2001) found that first through fourth graders did not possess a conceptual understanding of the unit of measure (cm). These may be examples of what Hiebert and Lefevre (1986) theorizes is a tendency of many students to acquire math procedural knowledge without developing conceptual knowledge. In the case of measurement, the conceptual knowledge means understanding: what attribute is being measured, what a unit represents, and how the procedures of measurement relate to the attribute and unit. While this appears to be a persistent issue, there are ways to promote the construction of conceptual knowledge related to measurement with children. Below are some examples that provide opportunities for children to make sense of measurements through data modeling.

Returning to the *Everyday Math* (Bell, 2012) curriculum described above, the temperature measurement routine engages students in a monthly review of their collected temperature data (recorded as colored dots). During this session: the children summarize their data into histograms, discuss comparisons between months and seasons, interpret differences, and make predictions for the next month. This is one way the *Everyday Math* curriculum facilitates student creation and translation of mathematical representations, which is a design feature to support mathematical modeling and problem solving throughout the curriculum (Isaacs, Carroll, & Bell, 2001). Similarly, Lehrer and Schauble (2002a) demonstrate how children can develop robust understandings of data and data

modeling through engaging in iterative rounds of measuring, representing and discussing data. In one example in Lehrer and Schauble (2002a), Wainwright (2002) describes how her second-grade students were able to build an understanding of how shadows work and change throughout the day by creating and revising multiple representations (bar graphs, charts, physical models, and drawings) of the shadows their bodies cast at different times during the day. Lehrer and Schauble (2002b) refer to this iterative process of representing, revising, and communicating abstractions of the world around us as cascades of inscriptions, a term borrowed from the sociology of science (Latour, 1986). Lehrer and Schauble (2002b) argue that children's ability to engage in these cascades of inscriptions and building conceptual understanding co-develop. For example, Lehrer and Schauble (2005) describe first graders building conceptions of plant growth rates when they noticed that various plant bulbs grew at different rates after having created bar plots. In addition, Lehrer and Schauble (2005) argue that children should be regularly engaged throughout the elementary years in data modeling as "progressive mathematization of nature." If schools are to enact this call for data modeling throughout the years of elementary school, it would be logical to include this at the very start in Kindergarten. As I have shown throughout the chapter, temperature measurement could begin to serve this purpose, but some questions remain that I address in the chapter summary below.

Summary

In summary, we know that children hold prior conceptions of thermal phenomena that can be in conflict with the normative views. Naïve conceptions of temperature and

heat include: attributing hot or cold to particular objects (e.g., sun is hot, ice is cold) (Albert, 1978), considering heat and temperature as the same phenomenon (Erickson, 1979; Kesidou, Duit, & Glynn, 1995; Lewis & Linn, 2003; Tiberghien, 1984), holding a view that heat or cold as a substance that can be transmitted between objects instead of a process (Slotta et al., 1995; Wiser, 1988). Research has demonstrated that children (mostly grade 5 and above) can be supported with technology tools to resolve the conflict between the naïve conceptions and normative ways of explaining thermal phenomena (Clark & Jorde, 2004; Linn & Hsi, 2000; Wiser & Amin, 2001). Currently, we don't know how technology could be used to support younger learners to resolve naïve conceptions of temperature and heat.

The NGSS require Kindergarten students to engage in the practice of collecting and interpreting weather data as part of reform efforts for elementary science. Although practitioner journals like *Science and Children* have recommendations for best practices for recording weather data with young children (Ashbrook, 2006; Miller et al., 2014; Royce, 2014), research shows that this age group has difficulty making sense of the temperature scale with expansion thermometers (Havu-Nuutinen, 2007; Kampeza et al., 2016). These difficulties with temperature measurement are consistent with research findings on the broader topic of measurement in schools; findings that indicate that students know the procedures of measurement without a conceptual understanding (Bragg & Outhred, 2001; Kasten & Newton, 2011). Lehrer and Schauble (2002a) demonstrate that children can develop conceptual understandings of measurement when engaged in an iterative process of recording, displaying, and discussing data.

This chapter shows that we know how older children can refine naïve conceptions of temperature and heat to develop more normative ones when supported with tools to disentangle ideas of heat and temperature while accounting for the difference in the sensation of temperature and the measurement of temperature (Clark & Jorde, 2004; Linn & Hsi, 2000). While young children may struggle with temperature measurement, research has shown that they can engage with linear measurement data in sophisticated ways (Lehrer & Schauble, 2002b). It remains unknown what sorts of tools and activities might support young children to develop more normative views of temperature phenomena related in the context of weather, a topic many Kindergarten classes discuss on a daily basis. As a reminder, this dissertation examines the design of a tool, the ECT, as a means of supporting young children to make sense quantitative temperature measurement by inquiring how the tool relates to their existing conceptions of temperature and heat. Furthermore, the study elicits what prior conceptions the kindergarteners demonstrate in their drawings and talk about temperature, and how those prior conceptions relate to their interpretations of thermometers and temperature visualizations.

CHAPTER III

METHODS AND PROCEDURES

This study involved studying six student volunteers' way of expressing air temperature (both verbal and illustrative) and how they interpreted thermometers and air temperature representations. Each met with me and were interviewed three times for approximately 30 minutes each time. The students represented a range of prior language and numeracy skills. This study was intentionally exploratory and designed to describe how kindergarteners' expressions about air temperature relate to the measurement of air temperature with a thermometer designed for young children. As stated in the last chapter, temperature measurement can be challenging for children as the temperature scale does not easily map to the naïve conceptions about heat and temperature. Furthermore, typical measurement instruction in elementary schools is also of concern, where students are likely to learn the procedures without a conceptual understanding of what is being measured (Bragg & Outhred, 2004; Smith et al., 2013). In this study, I examine children's prior conceptions of temperature as they relate to weather to contextualize how they make sense of temperature measurement.

In this chapter, I cover the study's methodological rationale, the instrumentation – including the language assessment, the semistructured interviews, and the design of the Early Childhood thermometer – the participants, and the data analysis procedures.

Research Design

The current study was a part of a larger design project to support teachers and

early elementary students in enacting the three dimensions of science instruction called for by the NGSS (practices, disciplinary core ideas, and cross-cutting concepts). In particular, this dissertation and the larger project respond to the NGSS Performance Expectation *K-ESS2-1, use and share observations of local weather conditions to describe patterns over time* (NGSS Lead States, 2013). In support of performance expectation K-ESS2-1, kindergarteners are expected to engage in the science practices of analyzing and interpreting weather data. As discussed in the last chapter, young children have difficulty making sense of thermometers (Havu-Nuutinen, 2007; Kampeza et al., 2016), and children and adults hold naïve conceptions of temperature and heat (Erickson, 1979; Kesidou et al., 1995; Lewis & Linn, 2003; Slotta et al., 1995; Tiberghien, 1984). The literature is clear on the effectiveness of computer models to support the development of normative views of temperature related phenomena for middle school students (Clark & Jorde, 2004; Linn & Hsi, 2000; Wiser & Amin, 2001). The current study explores how we might approach modeling temperature with the ECT (a computer-based model[7]) to support young children to analyze and interpret temperature data. With limited research focused on this age group, I conceptualize this dissertation as an "interpretive qualitative study" (Merriam & Grenier, 2019) to examine how young children make sense of temperature measurement and representation.

Merriam and Grenier (2019), in their textbook *Qualitative Research in Practice: Examples for Discussion and Analysis*, describe the interpretive qualitative study as a way for researchers to seek understanding of how participants "make meaning out of a

[7] Upon a press of its button, the ECT uses a small computer to read a temperature sensor and then simulate the behavior of an expansion thermometer with a string of multicolored RGB LEDs.

situation or phenomena" (p. 7). Interpretive qualitative research designs developed in response to research that was either framed as a qualitative study without explicating their epistemological and ontological commitments (Thorne, Kirkham, & O'Flynn-Magee, 2017) or demonstrated "method slurring" where a study may be framed as a certain qualitative methodology without a congruent approach to methods (Baker, Wuest, & Noerager Stern, 1992). This interpretive qualitative approach allows me to use first and second cycle coding and analytic memo writing. The end product of this interpretive qualitative study is a descriptive account of the findings discussed in the context of the literature review (Merriam & Grenier, 2019, p. 7).

I developed a series of semistructured interviews to elicit participants': prior conceptions of temperature through their talk and illustrations, interpretations of the ECT and commercially available thermometers, and interpretations of temperature representations. I used a recursive process for interpreting the transcripts and artifacts from the interviews. This process included, process and thematic coding of turns of talk, the development of analytic memos, and drafting of the results chapter. A full description of this analytical process can be found later in this chapter.

Instrumentation

Peabody Picture Vocabulary Test (4th Edition)

In order to provide context on the participants beyond the scope of the interviews, I administered the *Peabody Picture Vocabulary Test, Fourth Edition* (PPVT-4; Dunn & Dunn, 2007) to measure their receptive language ability. The norm-based instrument

provides a measurement of the test-taker's command of the English language, albeit as how they can identify pictures that match words they hear. By using this language assessment, I was able to make sure that my sample included a range of language abilities Had all the students scored at a single part of the normal distribution, the results would be overly narrow, limiting the implications of the study. Having variability in the participants scores on the PPVT-4, the study's results may include broader insights (Neergaard, Olesen, Andersen, & Sondergaard, 2009). Conversely, had I not recruited children with a range of scores on the PPVT-4, the implications for the dissertation would be constrained further.

The administrator of the instrument places a flip-book with four images on a page in front of the test-taker and asks the test-taker to point to the image that best matches the word the administrator says. For example, the tester might say "show me truck" or "point to afraid," being careful to avoid using a definite article or any other clues. The assessment continues by working through the pages of the flip-book until the test-taker makes 8 or more errors in a given set of 12 words/pages. The test typically takes about 11-20 minutes to conduct.

Semistructured Interviews

Semistructured interviews lasted about 20-30 minutes. I chose this time span as not to be a burden on the students, instead breaking it up into three interviews. Interviews were spread out over the course of three weeks to minimize disruption of the classroom schedule. I provide an overview of how each of my research questions connected with the interviews in Table 1. Full interview protocols are found in Appendix A.

Table 1

Research Question Alignment

Research question	Interview	Interview themes	Data sources	Analysis
How do the kindergarteners talk about and show air temperature?	1,2,3	Showing and discussing temperature difference, measuring temperature with thermometers, interpreting temperature graphs	Transcripts and artifacts[8] of interviews 1,2,3	Process and thematic coding, analytic memo, drafting results
How do the kindergarteners interpret the ECT and commercial thermometers?	2,3	Trying out various thermometers including the ECT, measuring temperature in shaded and sunny locations with the ECT and a commercial classroom thermometer	Transcripts of interviews 2,3 including gestures (e.g., where children touch thermometer)	Process coding, analytic memo to evaluate thermometer readings, drafting results
How do kindergarteners interpret graphic representations of air temperature?	3	Interpreting three temperature representations, one based on the ECT to show a day's worth of temperatures, a color-coded weather map of the US, and a line plot of showing 48 hours of temperature values	Transcripts of interviews 2,3 including gestures (e.g., where children touch parts of the graphs while making an interpretation)	Process coding, analytic memo to evaluate temperature graph interpretations, drafting results

I designed the interviews to elicit the children's prior conceptions of temperature and observe how they could interpret thermometers and temperature representations. To surface their conceptions of temperature, I asked them to show and explain temperature differences. I provided opportunities during interviews 1, 2, and 3 for the children to discuss and draw temperature comparisons. These included both first-hand experiences of air temperature differences and hypothetical ones. For example, making a comparison between inside and outside after visiting both locations or by asking how they could

[8] Artifacts include drawings and still images of drawings and block constructions captured from video.

change their illustration to show a hypothetical increase in temperature.

I introduced the thermometers to the children in interview 2 by offering an introduction to four different types of thermometers and how they worked. The thermometers include the ECT, a classroom expansion thermometer, a digital thermometer, and a pocketsize metric thermometer. The children were given a choice to pick two thermometers to try out for a temperature comparison. As the thermometers took time to acclimate to the comparison site outside, during that time the children worked on their illustrations to compare the difference between the temperature inside and outside.

During the final interview, the children once again made a temperature comparison. This time they compared the temperatures of sunny and shaded locations by reading both the ECT and the classroom expansion thermometer. To expedite this comparison, I had a pair of thermometers in each location prior to making the observations. In addition to reading the thermometers, I also asked the children to record the reading of the ECT using a stack of Unifix cubes. After discussing what the children noticed was different about the two locations, we went inside to make an illustration of the temperature observations. This included having the children place the stack of Unifix cubes near the part of the picture that it corresponded with. Following a discussion of what the children had depicted in their illustration, I next asked them to interpret a series of temperature representations.

The representations included a bar graph depicting temperature over the course of a day, a color-coded weather map of the US, and a line plot showing temperature over the

course of a 48-hour period. I created the bar graph to be similar to the ECT, basically showing what the ECT would look like if you took the temperature 7 times over the course of a day as shown in Figure 4. The weather map and line plot were both sourced from the National Weather Service's website at weather.gov[9] as shown in Figures 5 and 6.

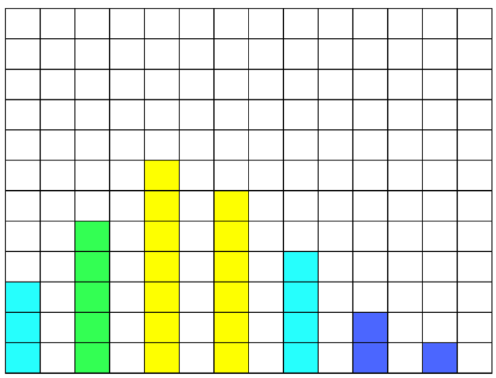


Figure 4. Temperature bar graph based on the ECT.

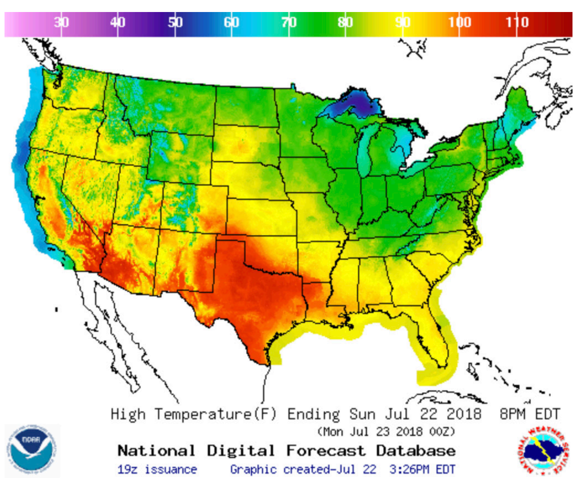


Figure 5. Weather map of the U.S.

[9] "The information on National Weather Service (NWS) Web pages are in the public domain, unless specifically noted otherwise, and may be used without charge for any lawful purpose so long as you do not: 1) claim it is your own (e.g., by claiming copyright for NWS information -- see below), 2) use it in a manner that implies an endorsement or affiliation with NOAA/NWS, or 3) modify its content and then present it as official government material. You also cannot present information of your own in a way that makes it appear to be official government information." https://www.weather.gov/disclaimer

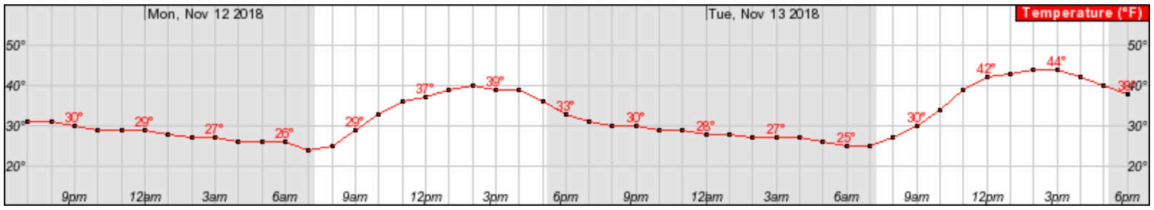


Figure 6. Line plot depicting 48 hours of temperature observations.

Interview 3 also included the numeracy assent where I asked the children to read the numbers 72, 80, 14, 60, 55, and 102 off a printed page. I chose these numbers since they are all possible temperatures at the location of the study. Finally, I concluded the third interview with any follow-up questions that I had identified when reviewing the videos of interviews 1 and 2. For example, I asked several of the children to explain parts of their drawings that were unclear.

The three interviews provided children multiple opportunities to discuss and depict temperatures adding additional levels of temperature measurement with each interview. Starting in the second interview, children had the opportunity to quantitatively measure temperature with the ECT and commercially available thermometers. In the last interview, the children interpreted a series of temperature representations. Together, the three interviews provided context for how the children used and made sense of the ECT. In the following section, I provide the motivation and development of the ECT.

Early Childhood Thermometer

For the purposes of this dissertation, I developed and built a specialized thermometer to be accessible for kindergarten-aged children. My desire to acquire such a device began during my eight years of teaching weather phenomena to early childhood

science. Since such a device did not exist, I created it. Even though weather is a common topic in early childhood classrooms, there is a lack of thermometers designed for young children. As shown in Figure 7, a typical classroom thermometer has large text on a contrasting background and a relatively large size of 14” x 2.5” with a thin glass tube bearing a red liquid. While this may be useful for children who can interpret the tick marks between the numbers, this would not necessarily be accessible to young children. In addition, the thin glass tube is only clearly visible at certain angles. Some might suggest using a digital thermometer as this is how many people read the temperature daily on smartphones, as seen in Figure 8, but this would remove the magnitude-illustrating feature of the singular bar graph-like display. Making sense of what the

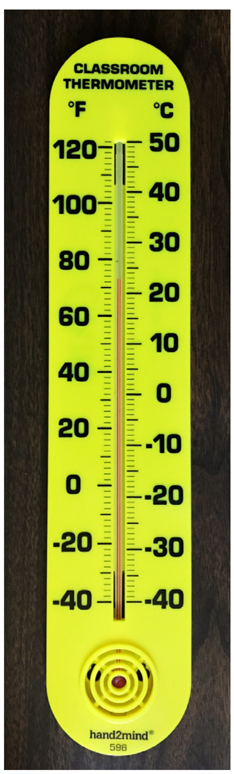


Figure 7. Classroom expansion thermometer by hand2mind.

Figure 8. Screenshot of temperature display on smartphone.

forecast of temperatures describes in the week ahead assumes the person has a sense for what the numbers feel like. This is why it is hard to make sense of a weather report using an unfamiliar temperature scale, such as when an American visits any other country.

Thermometer Design

The above classroom expansion thermometer is visually complex with its display of two scales and inconsistent tick mark value (2 degree and 1 degree). Kali and Linn's (2008) recommendations for effective elementary science visualizations include reducing visual complexity to make most salient features observable. In order to make relative temperatures observable while reducing visual complexity, the ECT does not have the typical gradations visible on a typical analog-expansion thermometer. While a standard

thermometer would have tick marks for every degree with a whole number at every increment of ten degrees, the ECT has its entire scale divided into twelve 1.2 in^2 boxes. This way the benefit of the height shown on an analog thermometer is preserved without the burden of numbers and tick marks to overwhelm pre-numerate children. Furthermore, this feature also scaffolds the construction of explanations and modeling by allowing children to talk about higher and lower temperatures without having to compare double-digit numbers, instead comparing relative heights. Additionally, the ECT has a color-coded scale, described below, adding another way of interpreting the thermometer. This design decision to include a color-based scale was informed by *Everyday Mathematics'* kindergarten curriculum, where teachers are asked to hang a poster with a color-coded scale (white, purple, blue, green, yellow, orange, and red) to an expansion thermometer. This color scale provides an alternative to recording the number of degrees, instead recording with a colored sticker. The poster is used to convert a numeric measure of temperature to a color. Table 2 summarizes the design considerations of the ECT.

Table 2

Early Childhood Thermometer Design Considerations

Challenges	Features
Visual complexity of expansion thermometer's measurement scale (tick marks between numbers)	12 backlit segments preserve linear scale, yet each has a physical division between segments making the scale discrete both visually and to the touch
Limited numeracy skills of kindergarten-aged children	Rounded numbers next to illuminated squares (relative heights can be compared without recognizing the numbers)
Static display of an expansion thermometer	Interactive interface (button activation) permits more agency
Air temperature is not directly visible without a thermometer	Multiple scales – color and height

Early childhood thermometer fabrication. The Early Childhood Thermometer (ECT) consists of a plywood enclosure measuring 17” x 6” x 1.5”; containing a temperature sensor, a Python-based microcontroller,[10] a strip of 12 addressable RGB LEDs, and a button to activate it. I digitally fabricated the ECT’s case, soldered a custom circuit board, and programmed the code for its operation. The ECT skip counts by tens on its scale from 0°F-110°F. I chose this scale for year-round temperature measurement. The scale consists of 12 1.2^2 inch recessed cells with a raised barrier between each. If one runs their finger from cell to the next, they would feel the barrier between cells. In addition to displaying the temperature as the number of boxes illuminated, there is color scale applied similar to the one in *Everyday Mathematics* as mentioned above. The color scale is as follows: T < 15°F blue, 15°F ≤ T < 35°F cyan, 35°F ≤ T < 55°F green, 55°F ≤ T < 75°F yellow, 75°F ≤ T < 95°F red, 95°F ≤ T magenta (see Figure 9).

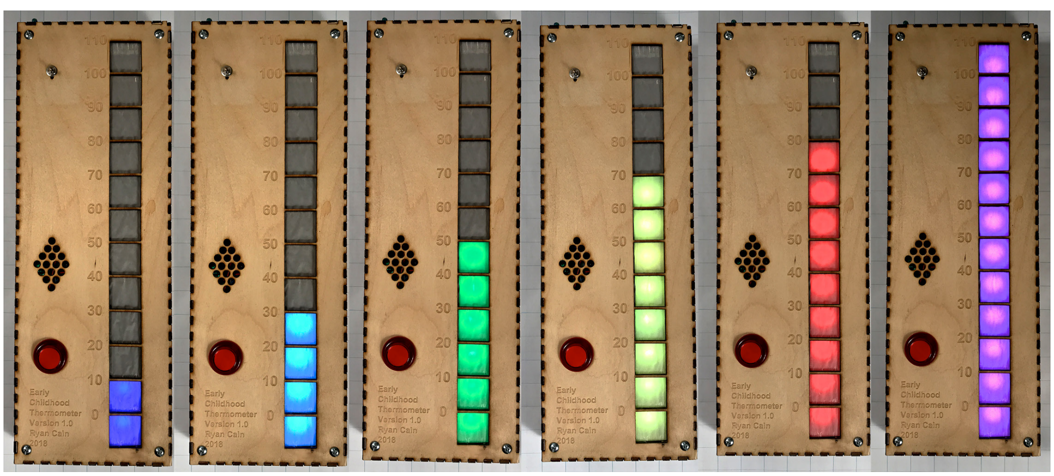


Figure 9. Early childhood thermometers depicting 10°F, 30°F, 50°F, 70°F, 80°F, and 110°F.

[10] The ECT’s microcontroller is an Adafruit Trinket M0 running a Circuit Python program. Although I wrote the code running the ECT, Adafruit staff provided extensive live support on their Circuit Python chatroom in the Discord platform. Design documents for the ECT can be found in Appendix C.

Participants

The children in this study were recruited from a single kindergarten class at a public elementary school in the intermountain west where about 60% of the school population qualifies for free or reduced lunch. Upon approval of USU IRB and the school's district, I held an informational session to distribute consent forms to parents and answer questions about the study using the Recruitment Script in Appendix B. A total of six consent forms were submitted, fulfilling the target of recruiting three girls and three boys. To protect the participants' privacy, I have replaced all names with pseudonyms.

To compensate the children for participating in the study, each child received two nonfiction books about weather and water (Rattini, 2013; Stewart, 2014). All six children completed the three interviews.

While this was a convenience sample, I verified that there was some variation between the participants. This included an equal mix of boys and girls and range of receptive language ability (see Tables 3 and 4). Receptive language scores ranged from the 42nd to the 96th percentiles on the PPVT-4 (Dunn & Dunn, 2007). As children in kindergarten are typically still learning numbers 1-100, I also administered a numeracy assessment of my own design. To see if they could read numbers typically on a thermometer, I asked them to read the following numbers 72, 80, 14, 60, 55, 102 off a sheet of paper. Credit of 1 was given if they read the number correctly, see Table 5. The numeracy scores ranged from 0% to 100% correct.

Table 3

Participant Age and Gender

Participant	Age (*M* = 5y8mo, *SD* = 4 mo)	Gender
Jonathan	5 years 5 months	Male
Cheyanne	6 years 1 month	Female
Malcolm	5 years 8 months	Male
Erica	5 years 5 months	Female
James	6 years 1 month	Male
Catherine	5 years 7 months	Female

Table 4

Peabody Picture Vocabulary Test, Fourth Edition Results

Participant	Percentile score	Score band
Catherine	42	Low Average Score
Malcolm	50	Average Score
Erica	68	High Average Score
James	84	High Average Score
Jonathan	96	Moderately High Score
Cheyanne	96	Moderately High Score

Table 5

Numeracy Assessment Scores

Participant	Number Correct (*M* = 3.33, SD = 1.97)	Percent Correct (*M* = 55.5%)
Catherine	6	100
Malcolm	0	0
Erica	3	50
James	4	66
Jonathan	4	66
Cheyanne	3	50

Data Sources and Analyses

Data Sources

Using a tripod-mounted video camera fitted with an external-shotgun microphone, I recorded all of the interviews. Except for the administering of the PPVT-4, I transcribed each of the interviews with NVIVO for Mac Version 12. A summary of the data sources can be seen in Table 6. The resulting transcripts are mostly participants' talk, but I also noted: gestures, descriptions of their drawing process, and values displayed on the thermometers. Gestures included: nodding their head up and down, shaking their head side to side, and crossing their arms and shivering their body. I decided to include the gestures in the transcription because the children's gestures were often part of their response to my questions. For example, when Malcolm depicted cold in a picture with a human with their arms crossed across their chest, he showed me what that looked like on his own body. Additionally, I wanted to capture how the children interacted with the thermometers and temperature visualizations. This often involved using a finger to point to a temperature or count the boxes on the ECT.

Table 6

Data Sources

Source	Format	Quantity
Transcribed interviews	NVivo Transcript for analysis, Word document for quantification	160 pages
Temperature illustrations	JPG digital file	23

In addition to the transcripts, I also photographed each of their illustrations, resulting in 22 images. A 23rd illustration was lost during data collection, so I captured a still image of it from the video recording. In cases where they built something with

blocks, I captured a still image from the video.

Data Analysis

My data analysis involved performing a first cycle of process coding, a second cycle coding for initial themes identified, writing analytic memos for each participant by returning to the process codes and transcripts and incorporating the artifacts, followed by revision to the thematic codes in Figure 10.

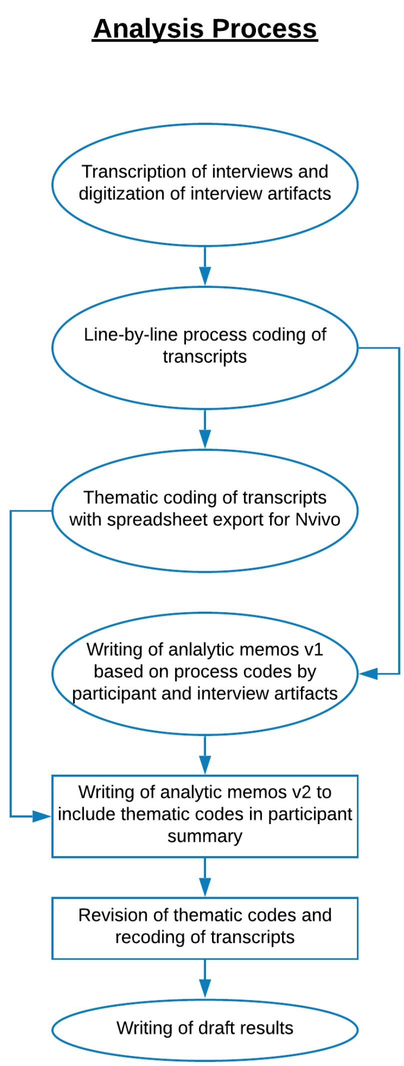


Figure 10. Data analysis workflow diagram.

Process Coding

For my first cycle coding, I chose to use process coding (Saldaña, 2009) as a way to make sense of how the children were responding to the problems posed to them in the interviews. Problems included prompts such as: “how would you change your picture to show that it got hotter?” and “what do you think this weather map is showing about the temperature?” Corbin and Strauss (2008) write, “(p)rocess is ongoing action/interaction/ emotion taken in response to situations, or problems, often with the purpose of reaching a goal or handling a problem” (p. 97). Therefore, coding the problem-solving process was a reasonable approach to gain insight into my data. Saldaña describes process coding as a versatile approach to analyze action. Process codes use gerunds (words ending in “ing”) to summarize or surface a salient feature of what is happening in the data. Using the node feature in *Nvivo 12* for Mac, I coded each participant’s turn of talk while asking myself, “what is the participant doing?” This resulted in in a list of 154 process codes, where the utility of the codes varied. Some codes acted as markers in the data for when they were doing a particular action requested in the interviews, such as *reading thermometer*. Other codes indicated how children responded to certain requests, for example the codes *depicting hotter with a bigger sun* and *depicting hotter with additional red stickers*.

The example below shows the process coding from Erica’s first interview. We had just returned inside after visiting shaded and sunny areas outside the school to compare the two. As part of the Interview 1 Protocol, I ask Erica to create a representation of what it was like in the two places. Erica has just completed one part of a picture depicting the sunny side where she used red stickers.

662	Ryan	OK, so that is the other corner you were standing in. Can you show me what that looks like?	
663	Erica	<places blue stickers> They are very sticky. Come off! Sometimes they are very sticky. <Places a total of 6 blue stickers> There is just a little spot of cold. <places one more> And there.	CODE: Depicting with color as temperature, hotness, or coldness
664	Ryan	So tell me about the different parts of the picture.	
665	Erica	Well first I was standing in the cold. <Touches blue stickers> <Touches red stickers> Then I got into the hot and it was kind of warm.	CODE: Describing a difference in temperature between shade and sunny spots
666	Ryan	And what was making one side cold and one side hot?	
667	Erica	<picks up paper and stands up> The reason this side was cold <taps blue side with thumb> was because there was shade. And the reason this one was hot <holds red side in right hand> was because there was no shade. <makes motion extending her arms outward>	CODE: Attributing cold to shade, CODE: Attributing warmth to lack of shade
668	Ryan	Alright, yeah. Let's pretend we went back outside after lunch, and it got hotter in the sun. How would you show that the sunny spot got higher?	
669	Erica	<grabs sticker sheet and adds six more red stickers> When hot spots get hotter, they want to make a bigger spot. That's how it looks. <touching larger red spot.	CODE: Depicting hotter with additional red sticker or stickers

In the above excerpt, I have applied five codes to four turns of talk of transcript (663, 665, 667, and 669), where one turn of talk includes two codes. As process codes include a gerund, on turn of talk 663 the word depicting is not enough to capture the interaction between us. To fully capture the *what* she was doing I have also added the *how* she was depicting, resulting in the code depicting with color as temperature, hotness, or coldness. While some of my codes included both the what and how, others were less detailed. In the next turn of talk, 665, the code *describing a difference in temperature between shade and sunny spots* serves more as a marker to possibly revisit later in analysis, but ultimately was not of much interest. In turn of talk 667 I applied two codes to be able to account for how Erica attributed hot and cold differently with the codes

attributing cold to shade and *attributing warmth to lack of shade*. I distinguished these to preserve the reciprocal nature of what shade meant to Erica. Finally, I coded turn of talk 669 as *depicting hotter with additional red sticker or stickers.* This last code summarizes how Erica responded to my question about showing warmer, making the scope of the code limited to this particular interview question. In the next section I demonstrate how this code evolved into a thematic code that was able to be applied more widely across the interviews

Thematic Coding and Analytic Memos

After completing the process coding for all of the interviews, I created initial thematic codes to be able make comparisons between participants and look for patterns within individuals. Using the *depicting hotter with additional red sticker or stickers* process code as an example from the last section, I will demonstrate how this process code became part of the *Magnitude of hot or cold* thematic code.

Starting with Erica's entry in Table 7, I have applied the thematic code *Magnitude of hot or cold* to her process code of *Depicting hotter with additional red sticker or stickers.* I did this and other thematic codes by going through all of the transcripts by each turn of talk after reviewing all the process codes and re-reading the transcripts.

Initial thematic codes included: *Corporal, Depicting with visual similarity, Wind/air, Season, Cultural, Hot or cold body, Magnitude of hot or cold, Hot and cold as inverse properties, normative temperature explanation.* While these thematic codes began to capture some patterns in the data, they did not share a common ontological

Table 7

Examples of Thematic Coding

Name	Transcript	Process code	Thematic code	Thematic category
Erica	<grabs sticker sheet and adds six more red stickers> When hot spots get hotter, they want to make a bigger spot. That's how it looks. <touching larger red spot.>	Depicting hotter with additional red sticker or stickers	Magnitude of hot or cold	Temperature Conceptions

level. For example, the *Seasonal* code might refer to a child saying it was cold because of winter, and the code *Depicting with visual similarity* could be applied to a child drawing a shadow. The *seasonal code* refers to an association between season and a temperature, but the *visual similarity* does not make a connection to temperature, and instead referred to a style of representation. To refine the thematic codes and establish categories of themes with shared ontological levels, I returned to the process codes and the transcripts to better understand the children's interviews by producing analytic memos.

Developing the analytic memos involved creating a document for each participant that included: frequencies of process codes for the participant, grouping process codes with research questions, pulling transcript examples for prominent process codes, and adding the images of the artifacts. This allowed me to analyze each participant's data from a mid-level view while attending to each individual research question. I define mid-level view as being able to attend to bird's-eye views with process codes while simultaneously viewing close-up views of children's illustrations and representative segments from the transcript. Continuing with the viewing metaphor, the data can be thought as online map zoomed out to show an entire city with street level views overlaid

in certain areas to show individual buildings. This view enabled me to make comparisons between individual children's responses across the three interviews. Additionally, having broken the memos down by research question allowed me to compare children by research question. After getting all the components into the analytic memo, I wrote a high-level summary of the child's participation in the study. All six analytic memos can be found in Appendix E.

My first step in creating the analytic memos involved indicating which process codes could inform each research question. While most of the process codes related to RQ1 with 96/154 (96 out of a total of 154 process codes), RQ2 and RQ3 accounted for 37/154 and 28/154 respectively. This distribution makes sense since RQ1 was deliberately investigated in all three interviews with the most time devoted to it as compared to two interviews on RQ2 and a single interview on RQ3. In some cases, a process code was marked as relating to two research questions. For example, the code - *explaining a change in temperature* could relate to both RQ1 and RQ2. This allowed me to create a list of process code frequencies for each participant by research question. These lists were helpful in two ways. First, for RQ1 they enabled a revision of the thematic codes, which I detail below. Second, they served as markers for where to look in the transcripts to evaluate how the children were interpreting thermometers (RQ2) and temperature representations (RQ3).

The analytic memos functioned differently for RQ2 and RQ3 as they did for RQ1. First, I will detail the analytic memo process for RQ2 and RQ3 since they are similar. The process code counts for these questions served mainly as markers in the transcripts to

note when the children were interpreting the thermometers and the temperature graphs. For each child, I scored these instances of reading thermometers and temperature graphs as either a successful or unsuccessful reading or interpretation. In addition, I included representative transcript excerpts and descriptive text to illustrate how they responded to these interview questions. I also summarized this data in a table with 1 noting acceptable interpretations and 0 noting unacceptable interpretations corresponding transcript turn of talks in order to make comparisons between children. These results are reported in the subsections for RQ2 and RQ3 in the results chapter. The summary table and descriptive text in the analytic memo served as a starting point for drafting the results for these two questions. While my results for RQ2 and RQ3 were evaluations of the children's interpretations, the results for RQ1 are more interpretive of the children's conceptions of temperature. Therefore, the thematic codes would categorize children's expressions of temperature and eventually interpret their conceptions of temperature.

For RQ1, I was trying to understand how the children talked about and visualized temperature. As I noted earlier, the initial thematic codes did not belong to the same ontological levels. In order to resolve this, I needed to better understand what the children were doing during instances of talking about and showing the temperature. Starting with the process code frequencies for RQ1 by student, I next added all the artifacts the children created over the course of the three interviews. Using the more prominent codes, typically more than five occurrences, and artifacts as landmarks in the transcript, I placed the corresponding transcript excerpts in the analytic memos beneath the artifact images. I then developed descriptions of how the children were expressing temperature by drawing

on each of the three views, a satellite-level view with the process counts, bird's-eye view with the artifacts, and hand-lens view of turns of talk in the transcript. Having these descriptions of how the children were expressing temperature for all of the children allowed me to refine the thematic codes, which I explain further below.

The analytic memos served as a way to develop and refine the *Expressions of Temperature* thematic codes to answer RQ 1 and take an inventory of how the children interpreted the thermometers (RQ2) and temperature representations (RQ3). However, the memos did not directly refine the temperature conception thematic codes. Rather, the *Temperature Conceptions* codes were more interpretive. Therefore, I placed the results from the *Temperature Conceptions* thematic coding in the discussion chapter. Besides dropping the *Normative Temperature Conception* code, these codes remained unchanged throughout my analysis. I developed these codes after finishing the process coding in conjunction with finalizing my literature review. I explored my data for evidence prior conceptions outlined in previous research. These included how children less than 8 years old are expected to talk about temperature in terms of hot bodies (Albert, 1978) and in later years as hot and cold substances or entities, a prior conception that can persist into adulthood (Lewis & Linn, 2003; Reiner et al., 2000). By placing *hot and cold bodies* at one end and *normative conceptions* on a continuum of most naïve to most normative conceptions, I created the thematic codes *magnitude of hot and cold* and *hot and cold as inverse properties* based on what I noticed during the process coding. *Temperature Conceptions* was a way to illustrate the variety of ways the children may have operationalized temperature during the interviews.

The other thematic category, *Expressions of Temperature*, was a way to summarize the themes of how the children showed temperature in their pictures and the associated explanations, this category is presented in the results chapter. Table 8 includes an overview of how I revised the thematic codes by separating in two thematic categories. While most of the thematic codes became part of the thematic category *expressions of temperature* and *conceptions of temperature*, others were dropped for not answering the research questions or not being well represented in the data.

Table 8

Thematic Code Revisions

Initial code	Revised code	Final thematic category
Corporal	Temperature as an effect on a body	Expressions of temperature
Depicting with visual similarity	Temperature as color	Expressions of temperature
	Temperature as a symbol	Expressions of temperature
	Visual similarity of the observation location	Code dropped for not attending to temperature
Wind/air	Temperature as a symbol	Expressions of temperature
Season	Temperature talk of a hot or cold body	Expressions of temperature
Cultural	Temperature talk of a hot or cold body	Expressions of temperature
Not originally captured in thematic codes, but later identified from the process codes	Temperature talk of a process	Expressions of temperature
Hot or cold body	Hot or cold body	Temperature conceptions
Magnitude of hot or cold	Magnitude of hot or cold	Temperature conceptions
Hot and cold as inverse properties	Hot and cold as inverse properties	Temperature conceptions
Normative temperature explanation	Normative temperature explanation	Dropped for limited occurrences in the data set

Table 9 shows examples of thematic coding of temperature conceptions. As mentioned earlier, this thematic category's interpretive perspective will be explained in the discussion chapter. Table 9 is ordered to show temperature conceptions from less normative towards approaching more normative conceptions ranging from *hot or cold body* to *hot and cold as inverse properties*. The earlier example from Erica falls in the middle of the range.

Table 9

Examples of Thematic Coding

Name	Transcript	Process code	Thematic code	Thematic category
James	A block of ice and it's in the shape of a square	Depicting cold as ice, Depicting with color for visual similarity	Hot or cold body	Temperature Conceptions
Cheyanne	And the moon is cold	Attributing cold to the moon	Hot or cold body	Temperature Conceptions
Jonathan	<Points to yellow> Sun <points to gray area where he wrote the word "cold"> Moon	Depicting cold with the moon	Hot or cold body	Temperature Conceptions
Erica	<grabs sticker sheet and adds six more red stickers> When hot spots get hotter, they want to make a bigger spot. That's how it looks. <touching larger red spot.>	Depicting hotter with additional red sticker or stickers	Magnitude of hot or cold	Temperature Conceptions
Catherine	It would get more higher <touches top of green illuminated ECT and motions up to the top> this one	Describing temperature increase shown as higher line in thermometer	Magnitude of hot or cold	Temperature Conceptions
Malcolm	The sun is bigger than this sun <points to sun in upper left corner> cause how it is heated and hot <crosses arms above shoulders> it heated more then it heats the humans so hot that it's dying	Depicting hotter with a bigger sun, Depicting heat as how it affects a person's body	Magnitude of hot or cold	Temperature Conceptions
Erica	Like, how it is showing 4 <points to cold> and this one <points to hot> is showing all the way up	Explaining illustration of the thermometer	Hot and cold as inverse properties	Temperature Conceptions
James	I am going to make it hot. <Makes a tall stack of orange blocks> So this one is the hot. And this one is the, this one's warm <places a smaller orange stack>, and this on3 is cold <places an even smaller stack of orange>	Depicting warmer with increased stack of blocks	Hot and cold as inverse properties	Temperature Conceptions

Note. The thematic codes are listed in increasing order of sophistication for the thematic category of Temperature Conceptions.

After refining the thematic codes through developing the analytic memos, I began writing the first draft of the results chapter organized by research question. For each question I present the range of children's responses to the interview prompts. The above table provides an example of the overall structure of the results chapter, typically providing detailed examples of children's explanation in increasing order of more normative ways of describing temperature.

Summary

My goal of this methods chapter has been to make my entire approach to the study transparent to establish trustworthiness. This has included: an explanation of the study's interpretive qualitative design (Merriam & Grenier, 2019), description of the receptive language assessment and interview protocols, justifications of the designed features of the ECT, and my data analysis procedures using process coding, thematic coding, and analytic memos.

Using Lincoln and Guba's (1985) four criteria for establishing trustworthiness: credibility, applicability, consistency, and neutrality, I explicate how each is met in the chapter. In order to improve credibility, I have used triangulation of sources to make the interpretive claims about temperature conceptions in the discussion chapter. Triangulation is a tactic for confirming findings from multiple sources (Miles, Huberman, & Saldaña, 2014). The three sources include the children's drawings of temperature, their explanations of temperature, and their interpretations of temperature representations. In addition, I have documented my procedures for the interviews and analysis for inspection

by my readers by including process and thematic coding examples. Furthermore, I have provided interview protocols and an example analytic memo in appendices A and D.

Attending to applicability, I provide a thick description of the children's participation in the findings chapter including numerous transcript excerpts with my interpretations. In addition, I chose a Title 1 public school in order to draw participants from a population where science reforms efforts, such as the NGSS (NGSS Lead States, 2013), are focused. Furthermore, I administered the PPVT-4 (Dunn & Dunn, 2007) as a way to recruit a range of receptive language abilities for the interview. Although the findings from the six participants are not broadly generalizable, they do offer insight to what may be possible with kindergarteners at similar schools.

To address consistency, I followed the same analytic memo writing for each participant. Initially during my first thematic coding pass, I was attending more to what had stood out to me as interesting in the data as a whole. By constructing the analytic memos, I was able to consider each research question by participant while examining the process codes and transcripts in the medium-view described above.

Considering Lincoln and Guba's (1985) fourth criterion for establishing trustworthiness, neutrality, I constantly balanced my identities as an educator and a researcher. I did this by regularly asking myself, "what conclusion about the children's conceptions of temperature does the evidence support," to temper my eagerness to say, "the children are demonstrating the performances called for in the standards document." This self-check does not position me as neutral, rather in a position of seeing both the mechanics of the children's conceptions of temperature and the and logistics of

measuring temperature with young children as a researcher and a practitioner respectively. I expand on this position in the research contribution and implications for instruction in the discussion chapter. Furthermore, this dissertation has been developed under the supervision of a committee of experts across multiple education disciplines. While I have worked to address all issues that came up during this peer review process, the judgement for trustworthiness belongs to the reader. In this chapter I have provided a rationale for what I did. The chapter that follows presents what I found.

CHAPTER IV

RESULTS

In this chapter, I present the results of the dissertation organized by research question. This included themes for how the children (a) talked about and showed air temperature (RQ1), (b) interpreted the ECT and conventional thermometers (RQ2), and (c) interpreted three temperature representations (RQ3).

Research Question 1

Research question asked, "*How do the kindergarteners talk about and show air temperature?*"

Showing and Talking About Air Temperature

I asked the children to create visual representations of temperature with materials common to kindergarten classrooms. These included markers, colored pencils, colored circle-shaped stickers, and Unifix cubes (colored plastic blocks). Using these materials, the children depicted temperature in three distinct ways: temperature as color, temperature as an effect on a body, and temperature as a symbol. Most of the children used a mix of these representation styles, except for Catherine who exclusively used symbols and Erica who used only color, as shown in Figure 11.

Starting with examples of showing temperature with a symbol, James and Catherine both depicted the sun to show a warm temperature during the day, shown in Figure 12 and Figure 13. Catherine included a sun drawn as circles with rays extending in

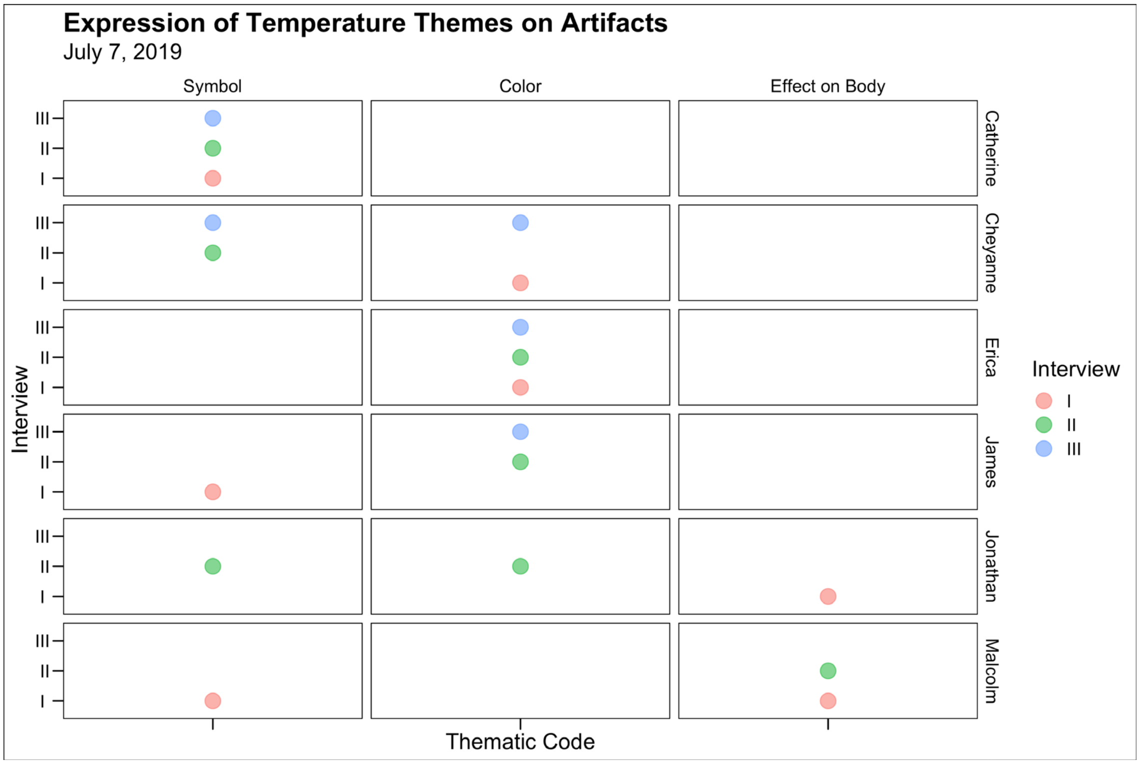


Figure 11. Expressions of temperature observed in children's representations.

Figure 12. Catherine's illustration from interview 2 comparing temperatures between inside and outside.

249	Catherine	It was hot here a little bit. I am going to spell hot. I know hot is H O T. I am going to put a sun for hot.
250	Ryan	Great
251	Catherine	You know, what are the lines on the sun for?
252	Ryan	I am not really sure. What do you think?
253	Catherine	I think because it is shining or something
254	Ryan	Yeah, and why did you pick to put a sun there?
255	Catherine	Because it was hot, see hot. …

all three interviews. It is interesting to note that she included the sun to show that the inside was hot as compared to the cold outside in Figure 12. Her depiction of the sun to show hot indoors was a symbol of heat, where the sun was not visible to Catherine from the location she was depicting. During this second interview, I was asking her to make a picture comparing outside and inside temperatures.

For the outside, she used a symbolic representation of wind on the right side of Figure 12. Here she explains how the sun represents hot and the lines represent cold.

267	Ryan	So can you tell me about your picture. How are the two sides different?
268	Catherine	This side is hot <points to sun side> and outside is like cold. <points to side with lines>
269	Ryan	How did you show hot?
270	Catherine	I put a sun there because the sun is hot.
271	Ryan	How did you show cold, what did you draw?
272	Catherine	Like lines
273	Ryan	And do those lines mean something?
274	Catherine	Wind or something

While Catherine created similar illustrations with combinations of the sun and wavy lines in all three interviews, James depicted temperature in a variety of ways. These

included symbolic representations depicting the sun and ice and color-based representation of hot and cold. During his interview 1, I asked James to make a representation of cold after he had indicated that it felt cold outside when we opened the door. He chose to make his representation with the Unifix cubes and described his construction as "a block of ice and it's in the shape of a square" shown on the left of Figure 13. Following his construction and explanation of the block of ice, I asked James to create a warmer representation. He responded by creating a sun as seen on the right in Figure 13 and noting that he was had to make a triangle instead of his original plan to make a circle for the sun.

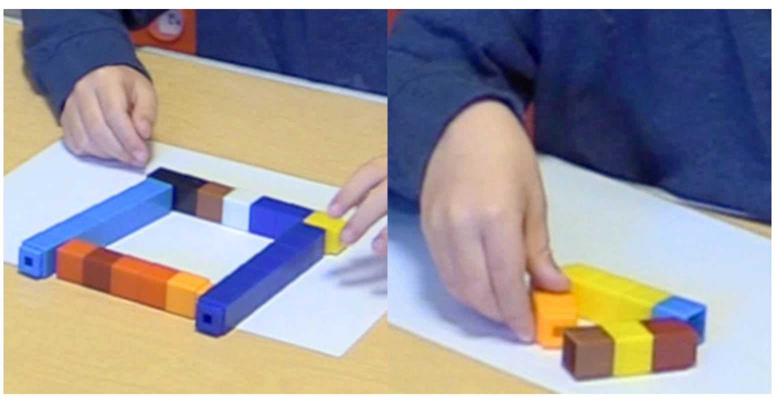


Figure 13. James' block constructions depicting a block of ice on the left and the sun on the right.

In addition to Catherine and James, Cheyanne, Malcolm, and Jonathan represented temperature with symbols including the sun, wavy lines depicting wind, the moon, and a star. Although the sun and wind were present during some of the temperature observations, the moon and stars were never visible. I point this out because the symbols used may be part of a pre-existing scheme for showing hot and cold, such as

Catherine's sun to show a hot indoor temperature or Cheyanne's moon to show cold outside despite the moon not being visible in the sky at the time of the air temperature observation. Lee (2010) has also shown how students often default to canonical imagery for depicting hot and cold. Similar findings appear here.

In James' later interviews he switched to using color to represent hot and cold. While four of the children used more than one representation style, Catherine and Erica used exclusively one form. Erica used color to show temperature in all of her drawings, for example one from interview 1 is shown below in Figure 14. For interviews 1 and 2, she used red and blue stickers to depict hot and cold.[11] She picked these colors off a sheet of circle stickers that also included beige, green, pink, purple, yellow, cyan, and magenta.

Figure 14. Erica's depiction temperature from a shaded and a sunny location.

During interview 1, I asked Erica to make a picture to show how it felt in two locations, one shaded and the other sunny. She began by using the red stickers to show the sunny spot.

[11] In interviews 2 and 3, she used markers as another way to show temperature with color.

649	Erica	So the sun was warm. So I am going to put some red I think. The sun is usually hot. So way back here <places red sticker in corner>
650	Ryan	And you can use as many as you like.
651	Erica	<places second red sticker> I just like to bunch them together so that it is one big old spot.
652	Ryan	How come? Tell me why.
653	Erica	Cause that whole spot <makes a circular motion with her palm facing out towards where the corner was> right there where I was standing, it was all bunched together and warm. <shows a bunching motion with both hands and then spreads them out when saying warm>

After a placing a few more red stickers, she then goes on to represent the shaded side with blue stickers.

663	Erica	<places blue stickers> They are very sticky. Come off! Sometimes they are very sticky. <Places a total of 6 blue stickers> There is just a little spot of cold. <places one more> And there.
664	Ryan	So tell me about the different parts of the picture.
665	Erica	Well first I was standing in the cold. <Touches blue stickers> <Touches red stickers> Then I got into the hot and it was kind of warm.
666	Ryan	And what was making one side cold and one side hot?
667	Erica	<picks up paper and stands up> The reason this side was cold <taps blue side with thumb> was because there was shade. And the reason this one was hot <holds red side in right hand> was because there was no shade. <makes motion extending her arms outward>

Having been asked to compare temperatures between shade and sun, Erica responded a similar contrast of cold and hot represented by blue and red stickers respectively. When making the observation outside for the illustration, she explained why the sunny side was warmer, “cause the sun is very hot, it’s just like flaming fire.” Based on her explanation, this may explain why she chose red stickers to show hot. Alternatively, she may be using the convention typically found on faucets of marking the cold-water handle with blue and the hot one with red as shown in Figure 15.

Figure 15. Thermostat and faucet as examples of the convention of representing hot as red and cold as blue.

When I asked her how the picture might change if it were to get warmer, she added more red stickers to the existing red stickers. To show what happens at night, she added more blue stickers to the other blue stickers.

Similar to Erica's use of the red as hot and blue as cold convention, Cheyanne also used the red and blue stickers during the first part of her interview 1. Having gone outside when the sun was obscured by the mountains, Cheyanne depicted one temperature that she described as "cold hot" with one red and one blue sticker. When I had asked her to change her picture to show a warmer temperature, she removed the blue sticker leaving the single red and added second red when I asked to show even an even hotter temperature. In the second part of interview 1 after going outside to observe the temperature both sunny and shaded locations, Cheyanne created a representation with Unifix cubes pictured in Figure 16.

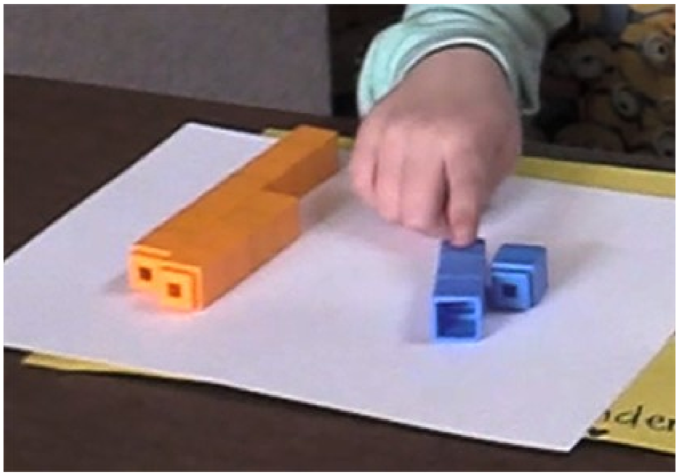


Figure 16. Cheyanne's representation of temperature in sunny (left) and shady (right) locations.

Prior to Cheyanne making the representation with blocks pictured above, I had shown her how some people might represent hot and cold with a tall stack of orange blocks and cold with a short stack of blocks. My modeling temperature with the blocks likely influenced this second representation, but she used different colors to represent temperature. In the transcript excerpt below, Cheyanne explained how her representation shows how the sunny side is hotter.

2469	Cheyanne	It's hotter <points to orange block side> than cold <points to the blue block side>
2470	Ryan	OK, Why? Why did you choose to use the blocks that you used? Tell me about what the difference is between the blocks.
2471	Cheyanne	Cold would usually be just ice which is blue.
2472	Ryan	Oh OK, yeah. How about the other side?
2473	Cheyanne	<places hand on mouth and then opens eyes wide> Lava is orange <places index finger on orange blocks> and lava is hot.

When asked to explain the block choices, she responded in turn of talk 2471 that since cold is associated with ice and ice is blue. She used a similar logic for hot in turn of talk 2473 that lava is orange and lava is hot. Based on these responses, Cheyanne uses colors to stand in for visually similar substances that she associates with hot and cold.

Comparing Cheyanne and Erica's use of color to represent temperature, Cheyanne used color to represent entities that are typically cold in contrast to Erica's more direct reference to red as hot and cold as blue.[12]

The third way that children represented temperate in their illustrations was to draw how the temperature affected a person. Both Jonathan and Malcolm took this approach in their drawings how a person might respond to a change in temperature. For all of Jonathan's drawings throughout the three interviews, he made drawings that included details to make the drawing visually accurate of the observation site. For example, Jonathan included the shaded and sunny corners of the building with black and yellow shading in Figure 17. Also in this image, he drew me with color accurate shoes, pants, and shirt. Initially, I had just one yellow patch below my face to show my yellow visitor's badge. I had asked Jonathan to make a picture about how the temperature felt in the two locations, but up until this point he did not include anything showing temperature.

1193	Jonathan	Cold <touches the one with gray/black> Warm <touches the yellow one>
1194	Ryan	Now let's pretend that I was outside and it started to get hotter, how can you change the picture to show that. Let's say it is getting later in the day.
1195	Jonathan	<takes blue pencil and draws on the picture of Ryan> Sweating

In response to my question about altering the picture to show if it were to get warmer during the day, Jonathan responds in turn of talk 1195 by adding the blue water droplet at the base of my face, shown in the magenta circle in Figure 17.

[12] In addition to showing hot with red and cold with blue during interview 2, she also made a representation similar to Cheyanne's by adding two small marks next to larger red and blue sections. The additional marks represented leaves in summer in fall.

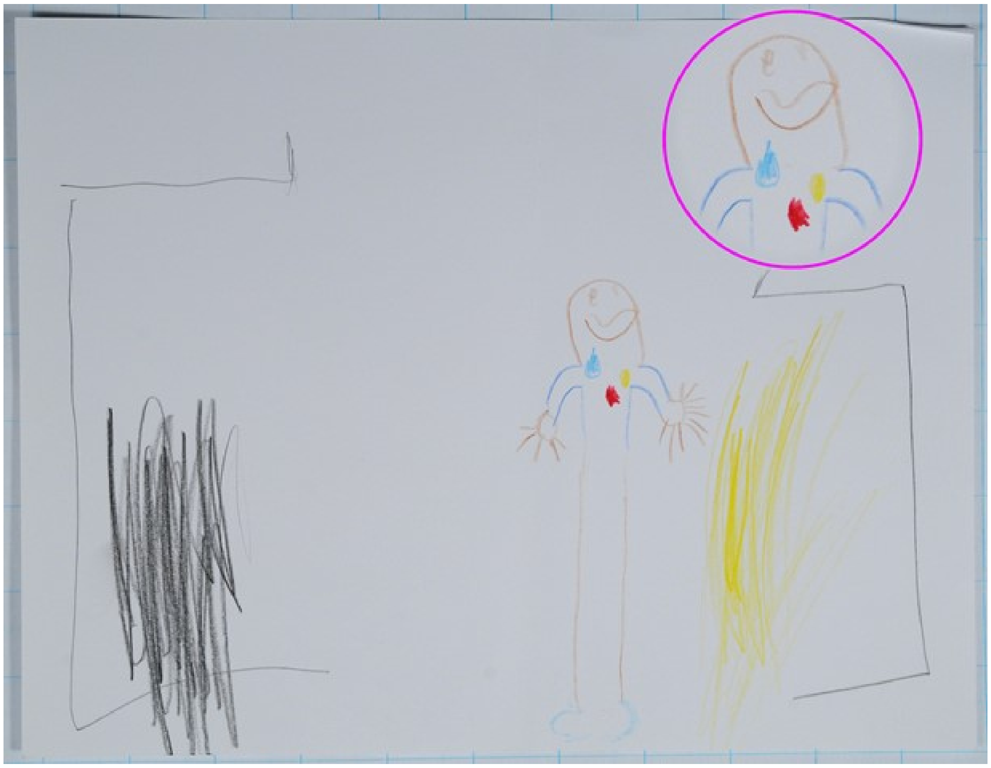


Figure 17. Jonathan’s representation of temperature at shaded and sunny locations. Detail of person enlarged in circle.

Rather than making any changes to the observation sites, Jonathan chose to show my body’s response of sweating to represent a hotter temperature. He added the red dot when I had asked how the picture might look it were to get even hotter to show me bleeding. I find this a bit surprising since it is not likely that he would have experienced some bleeding due to heat.

Similar to Jonathan, Malcolm represented an increase in temperature on the human body when he created two separate illustrations during interview 1. In his first illustration, shown on the left side of Figure 18, Malcolm drew a “human” outside in the cold after. He drew this in response to my request for him to draw how it felt outside. After stating that it felt cold, he drew the “human” with arms crossed.

Figure 18. Malcolm’s representations of a cold setting on the left and a warmer one on the right.

When asked about the drawing, Malcolm said the human was “getting freezed” while crossing his arms over his chest.

1543	Ryan	Can you tell me about your picture? Tell me what I am looking at here.
1544	Malcolm	The weather is cold.
1545	Ryan	Tell me what is on the paper. <points to picture> What are the different part of your picture?
1546	Malcolm	A human getting freezed <crosses arms over chest> and some yellow air <points to yellow part with pencil> and some grass and some dirt and some flowers
1547	Ryan	Some grass, some dirt, and some flower, a human. And what was the human doing?
1548	Malcolm	Freezing <crosses arms over chest>
1549	Ryan	Oh, freezing, show me that again <points to m’s arms>
1550	Malcolm	<crosses arms over chest and shrugs shoulders> Freezing

Malcolm’s picture showing a warmer depiction at my request on the right of Figure 18 includes a human with arms outstretched instead of crossed as enlarged in the magenta circle. This second picture also includes a sun in the left-hand corner. He explains that the sun is “warming up the flowers” and that “the human is warm.” When asked to show even warmer, he adds the larger sun with the squiggly lines in the top center. Malcolm explained that this larger sun “heats the human so hot that it is dying.”

Malcolm's even hotter modification picture inflicts bodily harm, similar to Jonathan's.

Temperature Talk Themes

Since all three of the interviews involved making and discussing representations of temperature, much of the talk about temperature overlaps with the previous section on showing temperature. In this section I highlight temperature talk where the children are talking about hotness or coldness during one of our outside observations or instances they are recalling. Additionally, I have not included the temperature talk surrounding the interpretation of temperature representations that is covered below in RQ 3. In this section I provide an explanation and examples of the two main ways the children talked about temperature, as a fixed state of temperature resulting from a cause or as a process of changing temperature. I refer to the categories as *temperature talk of a hot or cold body* (TT H/C Body) or *temperature talk of a process* (TT Process). While I identified these two categories as part of my thematic coding, they do not capture the full breadth of the data as is case in the following discussion chapter.

Most of temperature talk falls into the first category of TT H/C Body (56/64 instances of temperature talk) and spans across all six participants. The remaining instances (8/64) all belong to Erica except for one by James. The TT H/C Body ways of talking about temperature involved children attributing a state of hot or cold to "hot or cold bodies" (Albert, 1978) such as the sun, moon, fire, wind, and the four seasons. I added wind and the four seasons to Albert's definition of a "hot or cold body" despite not being bodies, because they do serve a similar function in the children's talk. The logic of TT H/C Body follows a "if x then hot or cold." For example, Cheyanne justified the

drawing of the moon to show cold for an outdoor observation by saying, “because the moon makes us colder” despite the moon not being visible at the time. This is similar to Catherine’s example above of using the sun to show hot indoors. In another example, James described what happens to the temperature at night he attributes cold to the wind; “the trees blow really hard, make a lot of wind, so it’s really cold outside.” The common thread among all of these TT H/C Body descriptions is that they do not include how temperature is changing over time. In contrast, the limited TT Process responses included attention to how temperature change took time. For example, Erica noticed how the thermometers felt cold from being outside; “well this is starting to get warm. <touches the yellow thermometer> It’s still pretty cold. And on the <touches ECT>, the metal is still pretty cold even though it’s not outside. I was very surprised.” While Erica demonstrated TT Process seven other times, the only other instance was by James. Overall, the children’s temperature talk was of the H/C Body type.

RQ 1 Summary

Previous research has shown that children conceptualize temperature, that is states of hotness or coldness, as being associated with particular objects or substances (Albert, 1978; Erickson & Tiberghien, 1985). For example, a child might talk about hotness by making reference to an oven or the sun. As shown in the previous section, this was largely the case for temperature talk by the children in the current study as I coded 56/64 instances as hot/cold body descriptions. However, a more nuanced view of how the children were conceptualizing temperature became evident in the drawings and related conversations about temperature. The symbolic and color-based representations mapped

onto the hot/cold body way of talking about temperature, where the children drew the sun or the color orange to represent a hot temperature. Both the symbolic and color-based representations are consistent with research on color cognition (Davidoff, 1991) where meanings of color are intertwined with our knowledge of objects. This is why the color orange could represent hot lava and blue could do the same for cold ice.

The symbolic and color-based ways of representing temperature are similar in that they are both referring to objects that are typically hot or cold for the most part. However, Erica's use of color-based temperature representation appears to be more canonical where she refers to the stickers in her depictions as "cold spot" above in turn of talk 663 and "hot spots" in the following quote from turn of talk 669. To show a warmer temperature later in the day, Erica responds, "when hot spots get hotter <grabs sticker sheet and adds six more red stickers>, they want to make a bigger spot, that's how it looks. <touching larger red spot>." The distinction from the hot/cold body representations by other children is that Erica is describing a quality of an object, the spot getting hotter as shown with additional red stickers. This more canonical representation by Erica is consistent with her instances of talking about temperature as a process. These included the above example commenting on how a metal part on the thermometer felt cold after being outside and in a discussion where she described heat as something that "develops." These three examples from Erica considering temperature that changes over time are evidence of a conceptualization beyond one based on hot/cold bodies, where temperature is a quality of an object that changes over time.

While the color-based and symbolic representations were tied to objects, the

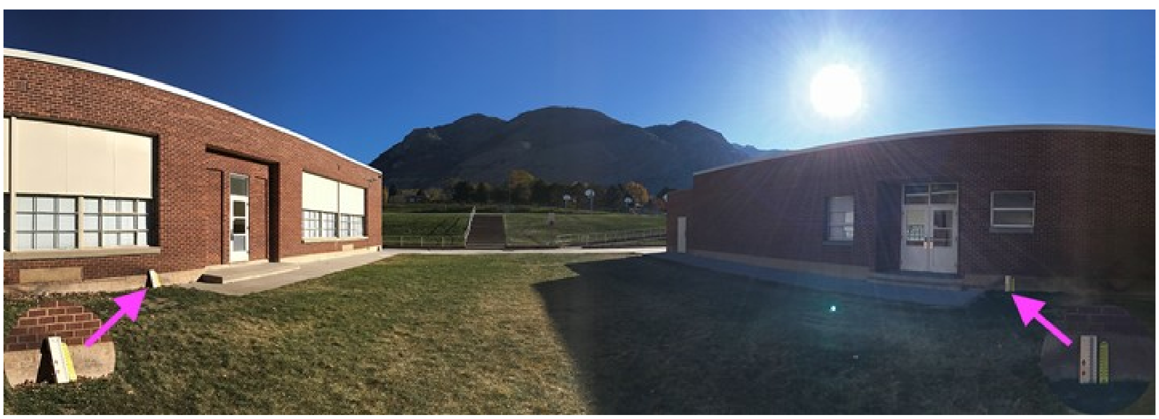
effect on body representations refer to a more thermal sensation-based perspective. That is, Malcolm and Jonathan showed how the human body would react to different temperatures. For Malcolm, this involved showing cold with arms crossed over a person's chest and hot with arms extended. Jonathan showed an increase in temperature with sweat and a further increase with blood. These embodied expressions of temperature could be used as a resource to support the disentanglement of how temperature feels compared to how it is measured. Although temperature sensation can be leveraged to support the development of canonical temperature conceptions, it must be made explicit how it relates to quantitative temperature measurement (Clark & Jorde, 2004; Linn & Hsi, 2000; Wiser & Amin, 2001). When it is not explicated, it can reinforce misconceptions such as hot and cold as separate entities as is the case with the hot and cold body ways of discussing temperature. This section on RQ 1 has demonstrated that the children's ways of representing and talking about temperature can be more nuanced than simply in terms of a hot or cold object, including discussing and depicting temperature as a process and as experienced by the human body. The following section investigates how the children make sense of quantitative measurements with thermometers.

Research Question 2

Research question 2 asked, "*How do the kindergarteners interpret the ECT and commercial thermometers"?*

During the second and third interviews, I asked the children to read both the ECT

and a classroom expansion thermometer, shown earlier in Figure 9 and Figure 7 respectively. In interview 2, I introduced the children to the thermometers explaining how they are used to measure temperature. While some of the children said they were familiar with thermometers, most needed an explanation of how they worked and what they measured. This introduction included saying that these were thermometers and pointing out how the displays worked. Following my introduction, the children tried the weather instruments first indoors and then outside after leaving time for them to acclimate to the colder exterior temperature. During interview 3, the children went outside to read both types of thermometers in two locations. Prior to the interview, I had placed ECTs and classroom expansion thermometers in both a shaded and full-sun spot outside the school as shown in Figure 19.



Note. Thermometers have been enlarged in the lower corners to make them more visible in this figure.

Figure 19. Full-sun and shaded locations with thermometers used in interview 3.

Overall, the children were able to approximately read the thermometers after my guidance, but they had some difficulty with the scales on both. Common mistakes included reading a number like 60 as 16 on both thermometers, reading the ECT with the

number just below the correct one, and picking a number on either scale of the expansion thermometer, °F or °C, based on whichever had a number closer to the top of the alcohol. When allowing for these errors in a correct reading, most of the children were able to read the thermometers as shown below in Table 10. In terms of thermometer preference, all but Cheyanne chose the ECT as their first choice to try out. Cheyanne did not make a choice, since I missed that question with her in interview 2.

Table 10

Acceptable Readings of the Thermometers

Thermometer type	Interview 2	Interview 3
ECT acceptable readings	5/6	6/6
Expansion thermometer acceptable readings	4/6	5/6

I note that for both thermometers there was an increase of one more person across the interviews with all six of the children being able to read the ECT. With all of these acceptable responses, children read the temperature to what they saw as the closest number displayed on the thermometers. This section is broken up into the following sub-sections: temperature scale challenges, making sense of the temperature scale, James as an illustrative example, and a summary.

Temperature Scale Challenges

This section provides examples of how the children struggled with reading thermometers due to their numeracy skills. With support, they were able to recognize how a thermometer is read from the top of liquid, but did not always know the numbers

on the scale. The text that follows deals with the procedural aspect of temperature measurement, and the next section discusses evidence of how the children demonstrated a conceptual understanding of what the thermometer was showing. As mentioned earlier, all of the children were able to eventually make acceptable readings of the thermometers with support. Acceptable readings included correctly identifying the temperature by the location on the scale, but reading the number incorrectly. This common mistake is present in 17/82 thermometer readings. For example, James, who correctly identified 4 out of 6 numbers on the numeracy assessment, reads 70 as “seventeen” in turns of talk 2078 and 2080.

2077	Ryan	Yeah? Can you read it to tell me what temperature it says it is? <pushes button on ECT, ECT displays 70°F>
2078	James	Six, seventeen
2079	Ryan	Seventeen, yeah. How did you know that?
2080	James	I actually saw the light <points to the 70°F box on ECT> and it was at seventeen, so that means it is 17 degrees outside.

This sort of transposition error, is common among 3- to 5-year-old children who have not developed composition and decomposition of multi-digit numbers (Byrge, Smith, & Mix, 2014; Macdonald, Boyce, Xu, & Wilkins, 2015). On the numeracy assessment, only Catherine correctly identified the number 14, with four of them responding with “forty” or “forty” something and one providing no answer. Since I did not expect the children to be fluent in reading numbers 1-100, a response like James saying 17 for 70 was an acceptable reading of the thermometer.

Some children (Catherine, Erica, Cheyanne) occasionally read the ECT at 10°F below the actual measurement. For example, Catherine, the only child to correctly read 6 out 6 of the numbers correctly on the numeracy assessment, reads out numbers closest to

the top and bottom of the highest illuminated box on the ECT as shown in Figure 20.

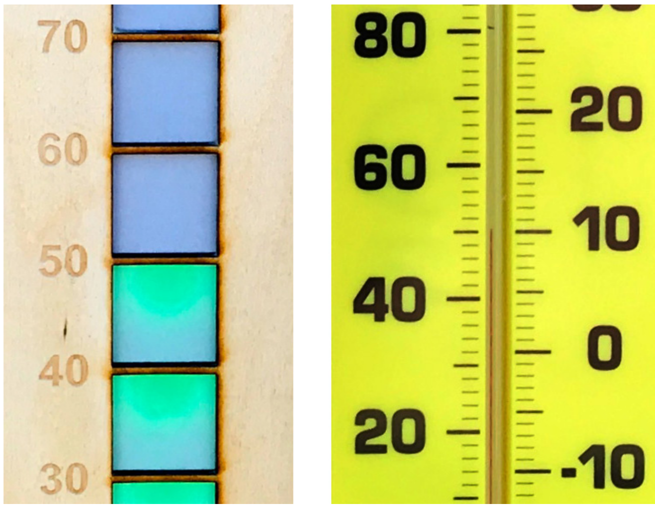


Figure 20. Closeups of ECT and classroom expansion thermometer showing 50°F.

When reading the ECT, Catherine says “50 or 40,” both numbers appearing near the top illuminated box in turns of talk 286 and 288. Looking at just the highest illuminated box in Figure 20, the 50 is at the top of the box and the 40 is at the bottom of the box.

285	Ryan	So what’s it showing you?
286	Catherine	Like 50 or 40 <touching ECT off camera>
287	Ryan	50 or 40, how did you know that?
288	Catherine	Because the square was here. <touches the 50°F box on ECT>

While this reading 10° below was unique to the ECT, another acceptable error occurred with the classroom expansion thermometer as pictured above in Figure 20. When reading the expansion thermometer, she demonstrates that she sees the top of the red line of alcohol by moving her finger across it in turn of talk 298. At first, she reads the expansion thermometer as “40” but then revises saying that it says “10” in turn of talk 302. Furthermore, she clarifies in turn of talk 304 that the expansion thermometer is

reading 10 while the ECT is reading “50 or 40,” which I interpret as her giving preference to the proximity of the 10°C mark, as opposed to being in agreement with the ECT. This may be problematic having two scales, °F and °C, on a thermometer to be used with children who have not developed a conception of temperature or numbers 1-100.

297	Ryan	And now, how about we look at this one?
298	Catherine	Yeah, now it’s this one right here <points to yellow thermometer making line back and forth at about 50°F>
299	Ryan	What temperature do you think that says?
300	Catherine	Like 40
301	Ryan	Yeah, interesting. We can take these back inside.
302	Catherine	Or 10
303	Ryan	Or ten, closer to the ten on that side?
304	Catherine	Cause the ten is right here <touches the 10°C on yellow thermometer> and 50 or 40 on this side <touches ECT>

While 5 out of the 6 children were able to make acceptable readings of the expansion thermometer, Malcolm did not. Furthermore, Malcolm needed more support to be able to read the ECT, so I provided multiple prompts to facilitate his reading of both of the thermometers. He typically pointed to the measurements on the thermometers, such as in turns of talk 1785 and 1787. Because of his tendency to point out the measurement instead of reading the number of the thermometer, I adjusted my approach to ask him to count the number of illuminated boxes in turn of talk 1790.

1784	Ryan	What’s it showing? I am just going to move the camera so it can see the thermometer and you.
1785	Malcolm	<pushes button on ECT> (ECT displays 70 °F) <touches 70°F box on ECT>
1786	Ryan	I am going to make that shadow again. How’s it look?
1787	Malcolm	<moves finger from bottom to 70°F box on ECT>
1788	Ryan	Want to hit that button again?

1789	Malcolm	<pushes button, quietly counts and touches all 12 boxes>
1790	Ryan	So how many boxes light up when you hit the button?
1791	Malcolm	<pushes button and points to the top lit box at 70°F on ECT) This box... One, two, three, four, five, six, seven <touches each box as he counts>

After my prompt in turn of talk 1790, he then touched each of the illuminated boxes as he counted them. Here the physical separations between the boxes on the ECT may have been helpful in segmenting the temperature scale to be more readable. This design feature was included to leverage the common feature of kindergarten instruction on counting objects. Over the course of all the interviews, five out of the six children touched the illuminated boxes when reading the ECT. Although they also touched the expansion thermometer, the children were less certain about the temperature readings. Such as Catherine's example earlier in turns of talk 300-304 because of the two temperature scales. For Malcolm, I was very explicit with my instructions for reading the expansion thermometer.

1796	Ryan	Great, how about this thermometer <picks up yellow thermometer and leans it against the wall> what's this one say? Can you see how high the red line is?
1797	Malcolm	To two-thousand <touches the 120°F mark on the yellow thermometer>
1798	Ryan	Two-thousand, oh boy.
1799	Malcolm	Yeah, what does this one <touches the base of the glass on yellow thermometer and moves finger to near 80°F> goes
1800	Ryan	Do you see how high that red line goes up?
1801	Malcolm	Yeah
1802	Ryan	What number does it go up to?
1803	Malcolm	Eighty
1804	Ryan	What's that?
1805	Malcolm	Eighty
1806	Ryan	Eighty, OK nice
1807	Malcolm	Eighty ... zero, eighty zero

With my explicit instructions, he was able to read the expansion thermometer at first saying “two-thousand,” then “eighty,” and finally “eighty zero.” In addition to requiring extra prompts to successfully read the thermometers, Malcolm does not appear to connect the temperature scale to the measurement of temperature. In the following section, I share examples of Malcolm’s lack of evidence for understanding what the temperature scale represents in contrast with more advanced explanations of the scale by Cheyanne and Erica.

Interpreting the Temperature Scale

In this section I present Malcolm, Cheyanne, and Erica’s interpretations of the temperature scale. They are ordered in increasing conceptual understanding towards a canonical view of the temperature scale. Malcolm did not demonstrate an understanding of the temperature scale. When I asked him to compare the sunny side of the yard to the shaded one, he never mentions anything related to one being hotter or colder. Instead after eventually saying the shaded side is “lower” in 1829, he starts comparing the rope handles on the two thermometers in turn of talk 1831.

1822	Ryan	Interesting, are these two places different, the temperature?
1823	Malcolm	Yeah
1824	Ryan	What is different about them?
1825	Malcolm	They make a different up <moves finger from zero to 40 on yellow thermometer> and a different ‘white’ <Moves hand up stack of blocks in front of ECT>
1826	Ryan	How does it feel? Does it feel different over here?
1827	Malcolm	Yeah
1828	Ryan	What’s different?
1829	Malcolm	How it, how it does, a different size, that one’s <points to sunny area> bigger and this one <points with block in hand to shaded ECT block stack> is lower
1830	Ryan	Interesting, why do you think that is? Why do you think the sizes are different?

1831	Malcolm	How, that one's different <pointing to sunny spot> is different than these two <points to ECT and Yellow in shade> because they both have, the other ones down and this one is up <points to rope handle> The rope is.

I interpret this response as indicating that Malcolm was able to read a measurement off the thermometers with support, but never showed evidence of holding conceptual knowledge of what was being measured. In contrast to Malcolm, the other five children in the study were able to demonstrate an understanding of movement on the temperature scale.

As part of the third interviews, I asked the children to make predictions after reading the first thermometers about the second thermometers. First, the children would read the ECT and expansion thermometer in either the shaded or sunny location. Next, I would ask the children to make a prediction of what they expected the thermometer on the opposite side of the yard would show. Cheyanne was able to predict and provide an explanation of why the sunny side would be hotter in turn of talk 2606, but did not say how the thermometer would look.

2603	Ryan	Great, let's go check the other one. Before we go to the other one, do you think it will be any different?
2604	Cheyanne	I think it's going to be hotter.
2605	Ryan	You think it is going to be hotter. Why?
2606	Cheyanne	Cause the sun's out on this side mostly
2607	Ryan	Oh, let's go see. What is your prediction? What do you think it's going to look like?
2608	Cheyanne	Hotter
2609	Ryan	How will the thermometer look different?
2610	Cheyanne	It wouldn't be on twenty. <points at ECT with foot>

While Cheyanne's responses "hotter" and "it wouldn't be on twenty" indicate that she is aware that the thermometer can show hotter, she does not appear to have a sense of

how the temperature scale would show it. Further evidence of this is visible when we go inside to make a picture of the sunny and shaded temperature measurements (Figure 21). In addition to reading the thermometers, she also made block-stacks with Unifix cubes record the temperatures of the ECTs in the two locations.

Figure 21. Video still of Cheyanne’s illustration of the sunny and shaded sides of the school yard with block stacks.

In turns of talk 2642 and 2644, she justifies the placement based on color instead of height. She created the block stacks correctly outside as per my instructions, but did not make the connection between the block stacks and the temperature scale when we were inside.

2639	Ryan	Can you put the blocks on the side that they go with?
2640	Cheyanne	<places yellow stack on side with yellow sun, places taller stack on side with blue patch and blue sun>
2641	Ryan	So tell me about these parts of the picture, what am I looking at?
2642	Cheyanne	The sun’s hot <lifts yellow stack on sunny side>
2643	Ryan	The sun’s hot. OK
2644	Cheyanne	And this one’s just cold so I drew it blue.

2645	Ryan	Why did you choose to do it that way?
2646	Cheyanne	Cause cold’s usually blue

Cheyanne is likely placing the blocks on the sides of the picture based on color; with the small yellow stack representing the sun and the taller stack with a blue block on top to show cold. I interpret this as Cheyanne considering color as the important attribute of the block stacks, rather than the height or number of blocks in the stack. Similarly, she uses red and blue to show hot and cold in interview 1. Cheyanne justifies why the sunny side would be hotter, but does not make connections to how that would look on the temperature scale in interview 3. While Cheyanne demonstrated that the thermometer would look different in a hotter location, she did not describe what it would look like. Once she added the block recordings of the thermometers, they no longer represented the heights of the temperature measurements. Instead she reverted to her preferred way of showing and interpreting temperature with color.

In this third example, Erica demonstrated her interpretation of the temperature scale and familiarity with thermometers. At the start of her second interview where I introduce the thermometers, Erica indicates that she knows what they are, “measurers” in turn of talk 732, and what they are for in turn of talk 738.

730	Erica	I know what these are.
731	Ryan	What are they?
732	Erica	They’re measurers
733	Ryan	Measurers, yeah. What do they measure?
734	Erica	They measure temperature and degrees.
735	Ryan	Temperature and degrees. Oh yeah, you are correct. Why do you think you might want to measure temperature
736	Erica	So I know that what degrees it is.

737	Ryan	Oh, so you know what degrees it is. OK, what is measurement? What does it mean to measure something?
738	Erica	It means to measure how cold it is or how hot it is.

Despite not knowing that they are called thermometers, she was already familiar with their function and associated terminology of temperature and degrees. She offered this information with my prompting, and continued later in the interview to explain the temperature scale of the expansion thermometer.

781	Ryan	… So with these, there is a line in them. Did you notice the line in the thermometer?
782	Erica	That's how it senses temperature. <gestures with fingers from bottom to top of the yellow thermometer>
783	Ryan	Yeah, so can you see how far the line goes up?
784	Erica	There is a little center right there and then <touches bulb and then motions all the way to the top of the yellow thermometer> It hits right here <finger at top of yellow thermometer> That's how we can tell that it is really hot, or if it hits right here it is really cold <pointing to about -40°F on yellow thermometer>
785	Ryan	OK, if it is up here it's? <points to top of yellow thermometer>
786	Erica	Really hot
787	Ryan	And if it is down here? <points to bottom of yellow thermometer>
788	Erica	It hits to really cold

Erica explained how the thermometer works in turn of talk 782, gesturing at the range of the temperature scale. When I asked her to comment on how far the red line went in the expansion thermometer, she responded in turn of talk 784 with an explanation of the scale with the top being "really hot" and the bottom being "really cold." She provided this explanation of the temperature scale on her own. This is interesting that she includes the adverb "really" on both ends indicating the extreme ends of the scale, as opposed to simply saying one end was hot and the other was cold. Since she noted the extreme values at the opposite ends of the scale, it appears she may hold a conceptual understanding of the temperature scale. That conceptual understanding may include

knowing that temperatures near the middle of the scale are what she refers to as “just the right temperature” in interview 2 turn of talk 862, and that movement in either direction get progressively hotter or colder towards the end. Together Erica’s familiarity with the temperature scale and her ability to identify the thermometers as something that can measure how hot or cold the weather is indicate that she holds an advanced conception of temperature measurement as compared to Malcolm and Cheyanne. Besides Malcolm and Cheyanne, the other four children were able to make sense of the temperature scale.

These three examples provide an overview of the range of the ways the children in the study interpreted the temperature scale on the thermometers. In the following section I provide a more detailed example with James. I include his example for his explicit way of making sense of the temperature scale throughout the course of the three interviews.

James as an Illustrative Example of Making Sense of the Temperature Scale

During interview 2, James explains the scale on the expansion thermometer after I had asked him what was the second thermometer he would like to try after picking the ECT.

2104	James	Because it looks cool and I like the color yellow <touches from the top to the bottom of the yellow> And the numbers go up really high and really low and it’s cool and I think it would be cool to see what temperature it is outside.
2105	Ryan	What would these look like if it were really hot out? Where would the numbers be?
2106	James	Up here <points to 110°F on the yellow thermometer>
2107	Ryan	How about if the temperature was really low?
2108	James	<places finger on -40 on yellow thermometer>

While he associates the top of the scale with being really hot outside in turn of

talk 2106, I made an error in my follow-up question in turn of talk 2107 saying low instead of cold possibly helping him with his answer. In addition to this instance of making sense of temperature in a linear scale, James provided a more complete explanation including high, low, and intermediate temperatures in interview 1. After I showed him an example with Unifix cubes of how some people might show cold with a short stack and hot with a taller stack, James extended the representation to show intermediate temperatures in turn of talk 2024.

2024	James	I am going to make it hot. <Makes a tall stack of orange blocks> So this one is the hot. And this one is the, this one's warm <places a smaller orange stack>, and this one is cold <places an even smaller stack of orange>
2025	Ryan	Hmm, and how are they different?
2026	James	Because they are smaller. Every time they get warmer and colder, they get smaller and bigger.
2027	Ryan	That is a nice way of showing it.
2028	James	And it kind of looks like stairs too.
2029	Ryan	It does look like stairs, let's say it got even hotter. How would you show that?
2030	James	<places both the medium and small stacks on top of the large orange stack>
2031	Ryan	How do you think that will feel?
2032	James	Really hot
2033	Ryan	Really hot, can you think of a time that you felt it was really hot?
2034	James	I was playing outside with my friends and got really hot and needed to go to my house and get some water and it kinda cooled me down a bit

James explains in turn of talk 2026 that the sizes of the block stacks represent three temperatures in relationship to each other as denoted by his use of the comparative forms of hot and cold, hotter and colder, similar to how Erica used the word "really" to modify hot and cold ends of the scale. Here he is clarifying what he said in the turn of talk 2024 with hot, warm, and cold explaining how the block stacks relate to each other. When I ask him to show an even hotter temperature, he creates an even taller stack of

blocks by combining all the shorter stacks as shown in the right of Figure 22.

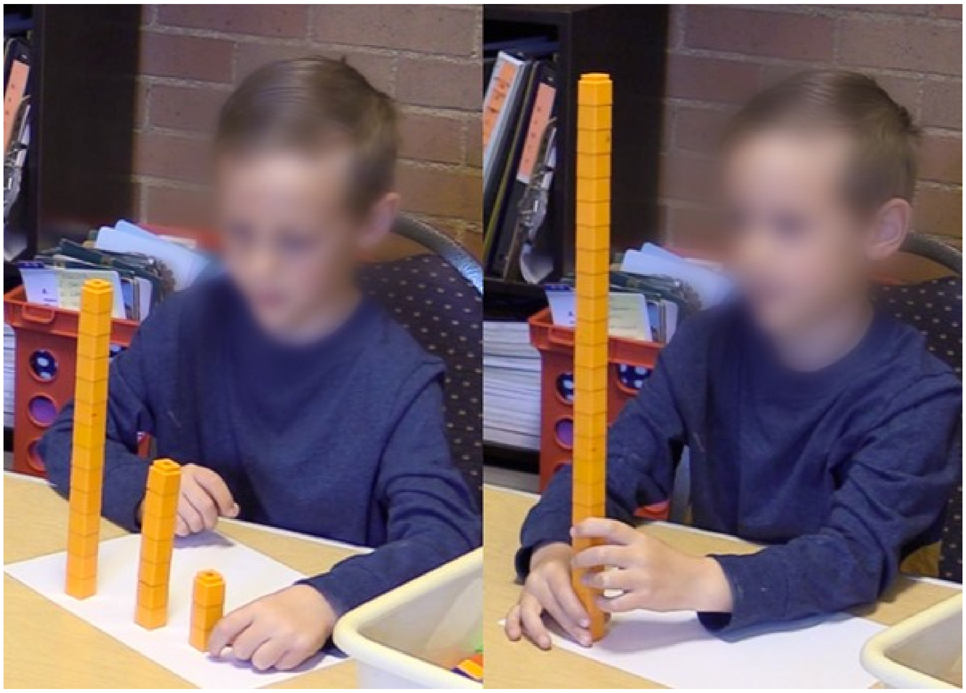


Figure 22. James showing hot, warm, and cold with blocks on the left image. On the right image, he is showing an even hotter temperature.

James answers my question about if he had ever experienced feeling really hot in turn of talk 2034 with an example of feeling really hot as he was playing outside to the point where he had to go indoors for water to cool off. Not only is James able to extend the representation consistent with his earlier one as additional height showing higher temperature, he also is able to connect the meaning of a high temperature to an experience of feeling overheated. While he appears to accept and appropriate the canonical version of the temperature scale in interviews 1 and 2, James flips his interpretation of the scale while predicting the temperature of the sunny side of the yard in interview 3.

In the following transcript excerpt, James has just finished completing a stack of

blocks to record the temperature in the shade. He made that stack with all blue blocks. When I ask him to predict what the thermometer on the sunny side will read, James indicates that it will be a different temperature from the shaded side in turn of talk 2196 and that the difference could be warmer or colder with examples of higher and lower temperatures in turns of talk 2198 and 2200. When I ask him to be more specific of what the temperature would be if it was warmer and colder, he responded that warmer would be 30 and colder would be 50 or 60 in turn of talk 2204 and 2206. This demonstrates that James interpreted higher temperature measurements as cold and lower ones as hotter.

2193	Ryan	How does it feel over here?
2194	James	Cold <compares the stack to the 40 line>
2195	Ryan	…We are going to go over to check on the other thermometer. Before we go over there, what do you think those thermometers are going to show?
2196	James	A different temperature
2197	Ryan	Why is it going to be different?
2198	James	Cause it might be colder over there or a bit warmer
2199	Ryan	What do you think?
2200	James	I think it will be 50 or 30 <shrugs shoulders>
2201	Ryan	How come?
2202	James	Because it might be warmer or colder over there. It could be either one of those, it could be 50 or 30 because it could be colder of a bit warmer, so it could be 60
2203	Ryan	If it is warmer over there what would it be?
2204	James	It might be 30
2205	Ryan	If it is colder over there, what might it be?
2206	James	50 or 60

Once James measured the temperature on the sunny side correctly with the ECT reading 70°F and the expansion thermometer reading 80°F in turn of talk 2213, he maintained his view of the higher temperature showing a colder temperature in turn of talk 2216. When I asked him how it felt in the sun, he responded, "warm, kind of" in turn

of talk 2018 and chose red blocks to record the temperature “cause it’s warm.” James did not comment on how his perception of how the temperature felt contradicted his explanation of it being colder with a higher temperature.

2211	Ryan	So what do they say?
2212	James	Seventy and eighty
2213	Ryan	Seventy and eighty, can I take a picture of that? Can you make the shadow and push the button again?
2214	James	Pushes the button
2215	Ryan	<takes picture> Great. So how are they, how do they compare to the other ones that we saw over there?
2216	James	Umm they are colder, it’s colder over here because it is a higher temperature than the other ones, it’s colder on this side than over there <points to shady side>
2217	Ryan	How does it feel over here?
2218	James	Warm, kind of
2219	Ryan	Do you mind making another stack of blocks so you can show how high the thermometer with the button is.
2220	James	Yes, I am going to make it red cause it’s warm. <builds red stack of blocks> 50 <continues stacking> 60 <continues stacking> 70 <places stack against the ECT to compare, continues stacking, compares to ECT> Seventy degrees

In Figure 23, James uses the red and dark red Unifix cubes to show how high the ECT was showing as per my instructions. Although he makes it explicit why he chose red blocks to show that it is warm in 2220, earlier on the shady side he used blue blocks to record the temperature on the ECT. Since he had just come outside from the temperature-controlled school, I interpret this selection of blue blocks to show cold. When I asked him to make a prediction of the temperature on the sunny side, he did not commit to it being colder or warmer by providing both higher and lower temperatures. His interpretation of the temperature scale placed colder temperatures with higher numbers, and he maintained this when reading the thermometer on the sunny side saying, “it’s colder over here because it is a higher temperature than the other ones,” referring to the shaded

Figure 23. James recording a temperature of 70°F off the ECT with red and dark red Unifix cubes.

thermometers. I interpret this exchange as James using color to express how he was perceiving the temperature with his skin in parallel with interpreting the temperature with the temperature scale that I had only recently introduced to him. Despite his inversion of the scale, he still recognized height as a way to measure temperature. While I wish I would have followed up more on this by asking him to try to resolve these discrepant views, it is still notable to surface these interpretations with a kindergartener.

I included this detailed examination of James because of his very explicit way of talking through his reasoning when reading the thermometers. He appears to have readily adopted the ways of measuring and representing temperature that I presented in just three meetings. His participation serves as an example of how a kindergartener could measure and make sense of quantitative temperature measurement.

RQ 2 Summary

In summary, the children were able to measure temperature with both the ECT

and the classroom expansion thermometer with varying degrees of support. Common difficulties included not being able to read double-digit numbers and issues with the temperature scales. Since much of kindergarten math deals with supporting children developing number sense and counting, it is not surprising that the children had issues with the numbers on the thermometers. The 10° increment and discrete boxes on the ECT enabled a simplified form of reading with Malcolm, where he touched and counted the number of boxes instead of reading the number scale.

The classroom expansion thermometer did not provide these affordances and also may create confusion with the dual scales. This included both Catherine and Erica reading room temperature at 20°C after first trying to read off the °F scale. These same children both read the ECT at 10°F below the actual reading. While the ECT did not ensure an accurate reading, the children were consistent with this -10°F interpretation which did not affect temperature comparisons. The mixing of the °F and °C scales with the expansion thermometer could potentially be more disruptive to temperature comparisons and learning the temperature scale.

Having accounted for the numeracy issues, the other factor for answering RQ2 of how the children interpret the ECT and commercially available thermometers comes down to how the children relate their perceptions of temperature from their senses to the canonical way of measuring temperature. In some cases, the scales mapped well to children's ideas of hot and cold. This was best for children who talked about hot and cold that included magnitude, such as James' use of the words hotter and colder when describing a series of four temperatures with blocks and Erica's volunteered explanation

of the temperature scale using really cold and really hot to describe the minimum and the maximum of the expansion thermometer's scale. While Erica consistently demonstrated a canonical understanding of the temperature scale, James flipped his interpretation of the scale from interview 2 to 3. I attribute this to him taking up the idea that temperature can be represented as height on a thermometer with one end being hotter and other being colder, but he mixed up the direction. Having only used the ECT twice, this sort of mix up could be resolved by using the tool more regularly.

Research Question 3

Research question 3 asked, "*How do kindergarteners interpret graphic representations of air temperature?*"

During interview 3 after the children had made an illustration about the temperatures on the two sides of the school yard, I asked them to interpret three temperature representations. These representations included a bar graph showing temperature over the course of a day (14 hours) in 2-hour increments, a line plot depicting continuous temperature measurement for 72 hours, and a color-coded weather map of the United States. I created the bar plot to be similar to display of the ECT with the same color scheme and box representation as shown in Figure 24. In this section I provide evidence for how color is readily interpreted in a somewhat continuous matter, but height needed to be discretely represented for the children to be able to attend to it.

In addition to the bar graph that I deliberately made to be interpreted in a similar manner to the ECT, I asked the children to interpret two canonical temperature

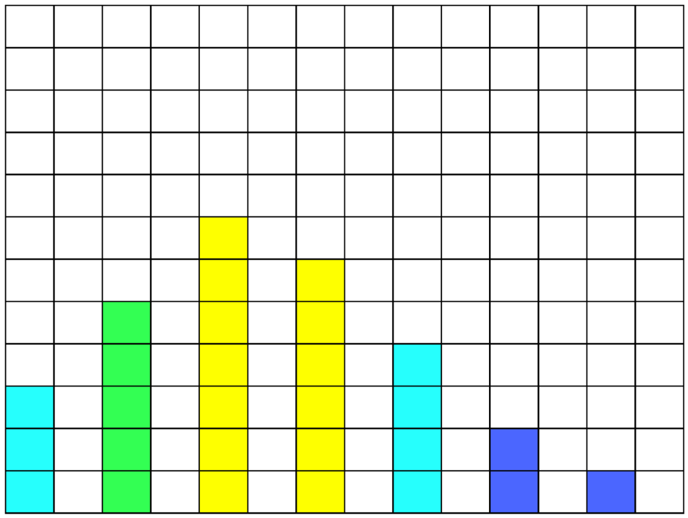


Figure 24. Bar graph showing temperature change over the course of a day using the ECT scale.

representations, a color-coded weather map and a 36-hour temperature line plot, from the National Weather Service's website weather.gov. While color coded weather maps can be seen on the morning television news and on the back page of a newspaper, the line plot is a less common way of depicting temperature. I have included both as a way to parse out the two attributes of the ECT inspired bar graph, color on the weather map and height on the line plot. By having the children interpret all three, my intention was to make comparisons as to what attribute or combination was most interpretable.

Since I created the bar graph to be similar to the ECT that the children had used a few times, it is not surprising that supposing that most of the children, 4/6, were able to interpret the bar plot as showing a range of temperatures during the day. While half of the children were able to interpret color as temperature on the weather map, not one of the children were able to explain the rise and fall of temperature in the line plot. Table 11 summarizes proficiency in interpreting the temperature representation.

Table 11

Proficiency of Making Acceptable Interpretations of Temperature Representations With 1 Representing Acceptable

Participant	Bar plot	Weather map	Line plot
Catherine	0	0	0
Malcolm	0	0	0
Erica	1	0	0
Cheyanne	1	1	0
James	1	1	0
Jonathan	1	1	0

Interpreting the ECT Inspired Bar Plot

The bar plot may have been the most interpretable plot for its parity with the ECT for its use of the color scale and bars segmented into boxes with 4/6 of the children having made a correct interpretation. Their responses fall into three categories: not interpreting the plot, interpreting the plot by either color or height, and interpreting it by both height and color. While Malcolm did not interpret the plot, Catherine incorrectly interpreted blue and green as representing the sky and grass respectively. Table 12 provides an overview of all the children's interpretations of the line plot, of which I include greater detail of three children later in the section.

In order to provide a description of the range of correct interpretations, I share Jonathan, Cheyanne, and James' interpretations below. One example is of a child interpreting the bar plot by height only, and the other two examples show children using a combination of color and height explicitly to varying degrees. It is possible that both attributes of the plot are informing all of the children's explanations, but I can only infer this when there is clear evidence in their explanations. For example, Jonathan may be

Table 12

Nature of Bar Plot Interpretations

Participant	Correct interpretation	Attends to color	Attends to height
Malcolm	0	0	0
Catherine	0	1	0
Jonathan	1	0	1
Erica	1	1	0
Cheyanne	1	1	1[a]
James	1	1	1

[a] Indicates an acceptable, but non-canonical interpretation of height.

considering color in the transcript excerpt below, but he made no mention of color as he interpreted the representation. Instead Jonathan counted each box within the bar as a degree in turn of talk 1460 below, having read the bar plot from right to left.

1460	Jonathan	1 degrees <touching 1 blue>, 0 degrees <touching blank spot in between bars>, 2 degrees <touching 2 blue>, 4 degrees <touching 4 blue>, 6 degrees <counts the blocks with finger on 6 yellow>, 7 degrees <touching 7 yellow>, 5 degrees <touching 5 green>, 3 degrees <touching 1 blue>

Jonathan's explicit counting of the boxes as "degrees" demonstrates he was attending to their height. His use of the term "degrees" shows that he applied a unit of temperature from the previous measurements with thermometers, but the graph had no unit or numerical markings. Cheyanne made a similar explicit interpretation of a single attribute with color in turn of talk 2676, but also made a more subtle interpretation of a second attribute with height in turn of talk 2674.

2674	Cheyanne	Cold <points to third blue stack>, coldest <points to second blue stack that is the tallest>, hotter <points to second yellow stack>, hotter <points to first yellow stack> and hot <points to green stack> cold a bit <points to the first blue stack>
2675	Ryan	How did you know that?
2676	Cheyanne	Cause this is blue, this is green, this is yellow, this is yellow, this is blue, this is blue, this is blue <touching each one as she says the color>

In this subtle interpretation, she appears to have considered height as magnitude of hot and cold separately. She explained the severity of hotness where she indicates that the 5 green blocks show “hot” and 6 and 7 yellow blocks as “hotter.” Although Cheyanne may have based her levels of hot by color or height, she was more explicit when describing levels of cold. For coldness, she said that 2 blue blocks were “cold,” 3 cyan blocks were “cold a bit,” and 4 cyan blocks were “coldest.” Here she considered the tallest of the cyan stacks as “coldest” while the shorter cyan and blue stacks were “cold a bit” and “cold” as seen in Figure 25.

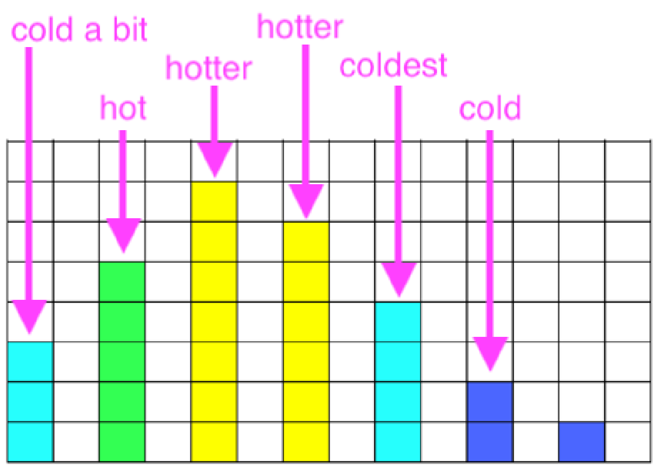


Figure 25. Annotated bar plot showing Cheyanne’s interpretation of the plot.

Cheyanne’s parsing of hot and cold as separate scales here in interview 3 is consistent with an explanation she gave in interview 2 when exploring different types of thermometers. When she was exploring two expansion thermometers containing blue and red alcohol for indicating temperature, she explained the one with a blue liquid “tells you cold” and the one with the red liquid “tells you hot.” This explanation of separate thermometers for hot and cold demonstrated Cheyanne’s view of cold and hot being

separate phenomena.

James made a similar interpretation comparing coldness, albeit in a canonical way. He referred to the stack of two blue blocks as “kind of cold” and the single blue block as “really cold.” When I asked him what the plot showed during the day, he replied by slapping the tallest yellow bar with his hand and saying “hot!” and gave “sun” as the reason. I interpret these as evidence of him considering height for calling the shortest bar “really cold” and color for referring to the sun when he described the yellow bars as shown in Figure 26.

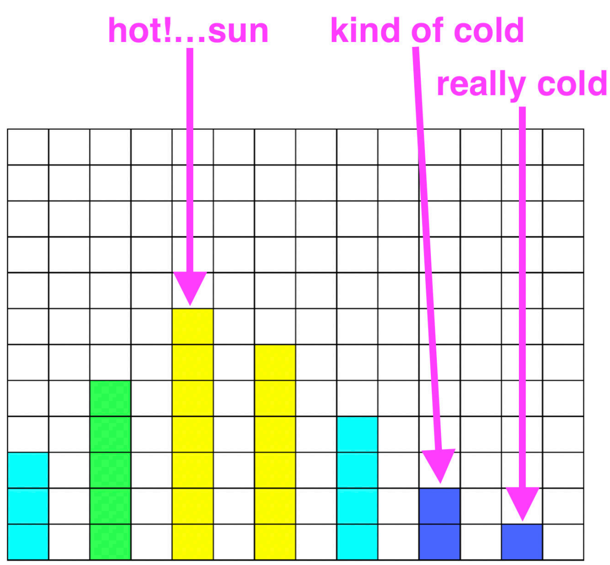


Figure 26. Annotated bar plot showing James' interpretation of the plot.

The bar plot was likely the most successfully interpreted weather presentation due to its dual attributes showing temperature, color and height via countable boxes, and its similarity to the ECT. Of all the representations, this approach may be promising for teaching young children how to record temperatures over an extended period of time.

Interpreting the Weather Map

Half of the children were able to interpret the colors on the weather map, shown in Figure 27, as depicting temperature. For two of the children who did not interpret the map correctly, Malcolm and Catherine, this was consistent with their own illustrations of temperature that did not include color as a way of showing temperature. Catherine interpreted colors more often for visual similarity, such as interpreting blue as the sky in the bar plot and earlier for a blue stack of blocks in interview 1. For the map, she accurately identifies the locations of Utah and Texas, but does not interpret it as showing temperature. Both Catherine and Malcolm interpret the map by pointing out places, such

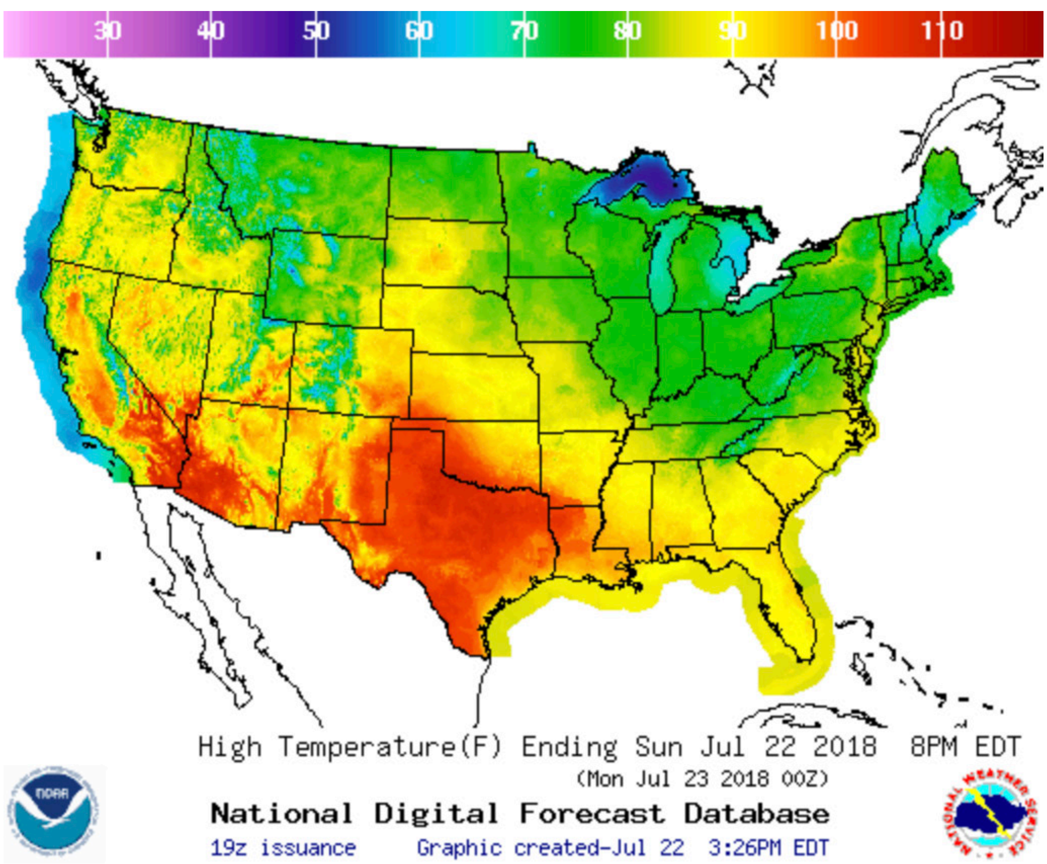


Figure 27. Color-coded weather map. Image courtesy of the National Weather Service in the public domain.

as Catherine correctly identifying Utah and Texas and Malcolm indicating where his father worked. Erica, who also did not interpret the colors on the map as temperature, indicated that red was “lava,” blue was “water,” and green was “where salt water fish live.” Unlike her own illustrations that used blue and red to show temperature, she interpreted the map as showing specific materials.

The other three children were able to successfully interpret the colors as showing temperature on the weather map. James and Cheyanne associate the colors on the map with qualities of hotness and coldness. Cheyanne readily categorized the colors on the map as “cold” and “hot.” When I asked her how she knew that, she responded just as she did with the bar plot by explaining “cause cold is blue, cold is blue, cold is also purple…hot is red and yellow is usually a little bit red.” I interpret this as Cheyanne having a pre-existing concept of what colors represent hot and cold, although green may not be part of that scheme. For the bar plot she referred to green as “hot,” but in the map it was “cold.” Cheyanne’s temperature categorization consists of a binary of hot and cold. In contrast, James made a more nuanced interpretation of the weather map by describing colors as four separate categories: “cold,” “fine,” “warm,” and “hot” in turn of talk 2335 below.

2335 James Um hot <points to red TX>, warm <points to yellow FL>, cold <points to blue CA coast>, <takes 3-4 second pause> and umm fine <points to green PA>

2336 Ryan How did you know that?

2337 James Because I can tell temperature.

2338 Ryan Yeah? What was this? <points to red TX>

2339 James Hot

2340 Ryan How did you know it’s hot?

2341 James Red makes it hot.

2342 Ryan And what did you say about over here? <points to yellow OR>

2343 James Warm

2344 Ryan Warm, how do you know that?

2345 James Cause I know hot and red and hot and yellow makes umm hot and warm makes warm.

2346 Ryan How about up here? <points to green ND>

2347 James Fine

2348 Ryan What does fine mean about the temperature?

2349 James That means the temperature is just perfect, but I don’t know what that temperature is. I just know these two these three are warm, hot, and cold. <points to CA coast and then TX>

Breaking down the time James’ took to interpret the map in turn of talk 2335, he spent a total of 12 seconds to say the entire turn of talk. In the first 6 seconds, he was able to interpret red as hot, yellow as warm, and blue as cold. In the subsequent 6 seconds he first pauses for 3.5 seconds and then interprets green as “fine.” Considering the first 6 seconds, James has made a more nuanced explanation than Cheyanne by including 3 states of temperature of “hot,” “warm,” and “cold” without a delay, may indicate that he readily associated the temperature descriptions with the colors. This may have been similar to Cheyanne’s preexisting scheme of colors since he was able to quickly interpret the first 3 colors, but he spent equal time making the last interpretation of a single color, green. I interpret this as him taking time in his three second pause to figure out where green could fit in the scheme with the other colors. This is interesting because he may have reasoned his way to the concept of room temperature through interpreting the representation, calling it “fine” in turns of talk 2335 and 2347. When I asked him to explain what he meant by “fine,” he responded “that means the temperature is just perfect, but I don’t know what that temperature is” in turn of talk 2349. Examining the first part of his answer “that means the temperature is just perfect,” I interpret this as

meaning that such a temperature would not feel hot, cold, or warm, rather it would be a lack of feeling temperature. In the second part "but I don't know what that is," he is recognizing that a "fine" temperature does not fit the ontological class that "cold," "hot," and "warm" belong to. Such an ontological class could be *the ways temperatures feel* and "fine" would not fit since it is a lack of a feeling. This may be evidence that James' conception of the temperature scale expanded. He did this by incorporating an explanation of the center of the scale in this interview when he made sense of the green area on the map as the part of the scale in between warm and cold.

I include the third successful interpretation of the weather map by Jonathan to highlight his explicit decoding of the temperature scale at the top of the weather map was pictured in Figure 27 and with his interpretations annotated in Figure 28. During this decoding, he appears to have revised his initial scheme of what colors corresponded to what temperatures. He interpreted the scale from left to right by touching the number on

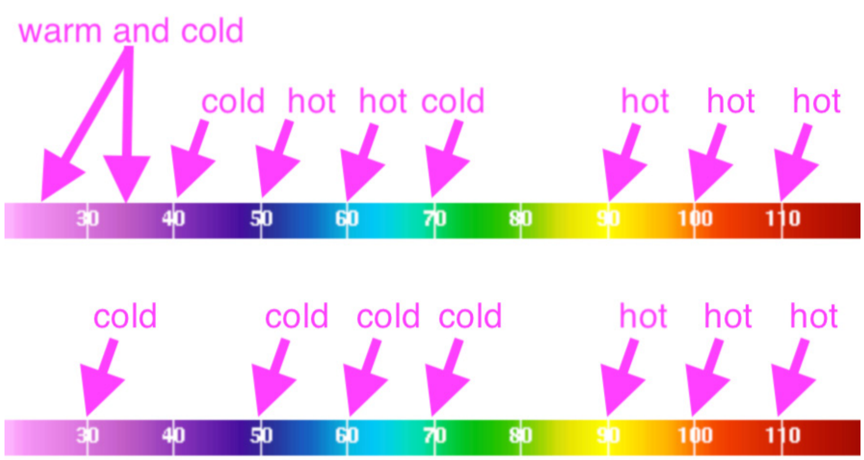


Figure 28. Annotated temperature scale from weather showing Jonathan's first (top) and second interpretation (bottom). Image courtesy of the National Weather Service in the public domain.

the scale with his finger, then saying his interpretation of the point on the scale. After making it through one interpretation of the full scale, he makes a second interpretation once again from left to right.

During the first decoding pass, Jonathan may have been making an interpretation on each color independent of its position on the scale. In his second pass, he had revised his interpretation to be consistent with the numbers on the scale. Jonathan clarified his interpretation of the scale when I asked him about it after the second interpretation by indicating that the purple through green end of the scale was “lower” and the yellow through red range was “higher” on turn of talk 1492. He continued to reference the scale by touching it before interpreting an area in the map in turn of talk 1492, using the words “colder” and “hotter” to describe each location. His use of the comparative form of cold and hot suggest he considered temperature as a continuous variable. I interpret this as a continuous reading for two reasons: his attending to the numbers on the scale by touching the numbers in both of his decoding passes and his use of the word “higher” in turn of talk 1498. Had he said hotter or hot when he pointed to the red end of the scale, it would be more likely to infer that he was considering the scale as two categories, hot and cold.

1491	Ryan	How did you know that?
1492	Jonathan	Cause these are lower <points with four fingers to purple through green> and these are higher <points with three fingers to yellow, orange, and red>
1493	Ryan	Ah, nice. What do you think that means on <points to map>? This is a map.
1494	Jonathan	<Touches green on scale and slides finger to green area on map maybe PA> Colder <touches several green spots and then blue spots> colder, colder, colder. <touches red part of scale then slides finger to TX> hotter, hotter
1495	Ryan	What was this one over here? <Points to TX red>
1496	Jonathan	Hotter
1497	Ryan	And how did you know that?
1498	Jonathan	Cause it is higher <points to red end of scale>

1499 Ryan What's higher?
1500 Jonathan The temperature.

Comparing Jonathan and Cheyanne's interpretations of the weather map, Jonathan's explicit decoding and repeated referencing of the temperature scale demonstrated a more sophisticated reading of the map beyond her categorization of colors as hot or cold. Although Jonathan did not make sense of the middle section of the temperature scale between hot and cold, it is noteworthy that he did not categorize the area near the 80-degree mark. Examining Figure 28 above, skipped interpreting 80°F in both decoding passes. Given proper facilitation, he may have been able to make sense of this part of the scale in a way similar to James. The range of successful readings of the weather map ranged from attributing certain colors as being hot or cold to being able to map the spectrum of color the temperature scale.

Interpreting the Line Plot

The line plot was the least interpretable temperature representation of the three with not a single child being able to decipher the falling and rising temperature. The responses ranged from Jonathan's lack of an interpretation to Malcolm, Erica, and James' common response that the temperature increases from left to right. Catherine interpreted the line plot, show in Figure 29, as showing the heights of tall buildings in the surrounding city's downtown area with tall buildings.

Erica, Malcolm, and Cheyanne interpreted the red line in the plot as hot for its color. James, Malcolm, and Erica interpreted the line as showing hotter temperatures moving from left to right. James read all the labeled numbers over the line, but still stated

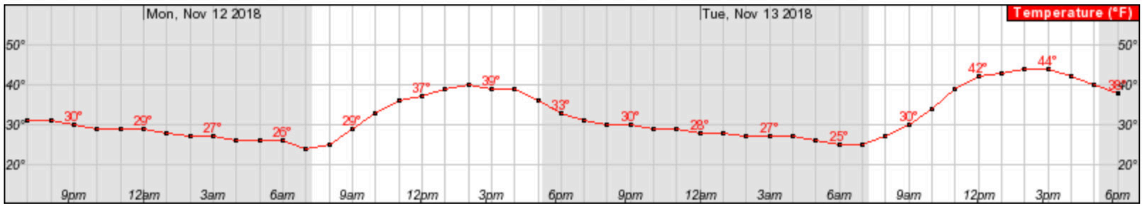


Figure 29. Line plot of continuous temperature measurement. Image courtesy of the National Weather Service in the public domain.

that the temperatures rise from left to right instead of the correct sinusoidal pattern. I interpret this as a result of the children not knowing how to parse the line into x and y dimensions. In contrast to the other representations, the line plot did not have discrete objects or sections like the individual bars in the bar plot or different colors on the weather map.

RQ 3 Summary

Of the three temperature representations, the bar graph was most successfully interpreted representation with 4/6 children making acceptable interpretations. As noted earlier, this may be due to its similarity to the ECT with discrete units and the color scale. While the bar graph used height and color to represent temperature, the other two used only one attribute at a time. Color may have been a more interpretable attribute with 3/6 acceptable interpretations of the color-coded weather map as compared to the 0/6 successful interpretations of the line plot. Although the line plot used height to show temperature, it was not in a discrete way. It is possible that children were not able to parse the x and y dimensions of the line plot.

Summary

In summary, the children demonstrated multiple ways: of representing and interpreting air temperature, of interpreting thermometers, and interpreting temperature representations. For RQ1, children used colors, symbols, and responses on a drawn human body to show air temperature. For RQ2, all but Malcolm were able to read the thermometers with some evidence of understanding the temperature scale. The ECT provided affordances of being engaging with the interactivity of the button-activated lights, a simplified scale, and discrete boxes that were often counted by touch. This is in contrast to the classroom expansion thermometer's dual scales (°F and °C), numbers with tick marks, and not as visible column as compared to the ECT's illuminated one. For RQ3, the children were most able to interpret the ECT inspired bar graph with its dual attributes for showing temperature, discrete height and color. The commercial weather representations from weather.gov were less interpretable with none of the children interpreting the line plot – possibly due to the non-discrete representation of height – and half of the children interpreting the color-coded map.

CHAPTER V

DISCUSSION

In this discussion chapter, I first present my interpretation of how the findings depicted in the previous chapter respond to the literature review chapter. My interpretations include the children's demonstrated conceptions of temperature, and how kindergarten-aged children might be supported to develop more normative views of heat and temperature. Consistencies include how young children consider hot and cold by: associating temperature with typically hot or cold objects (Albert, 1978; Erickson & Tiberghien, 1985), as separate entities (Erickson, 1979), or substances (Reiner et al., 2000; Slotta et al., 1995). The more normative temperature discussions were supported by the discrete temperature representations made with the ECT, Unifix cube method of showing temperature, and the ECT inspired bar graph. In addition to displaying temperature with discrete heights, color representations also supported the children's interpretations of temperature.

Following the conceptions of temperature section, I present the contribution of the study, implications for instruction, limitations, and conclusion.

Conceptions of Temperature

Returning to my motivation for this investigation, as a teacher I did not understand why it was so difficult for my early elementary students to interpret longitudinal temperature representations. While I was able to get my students to be proficient in the procedure of reading thermometers, I did not consider how the children

understood the concept of temperature measurement. As noted in Chapter II, this is often the case where students demonstrate procedural knowledge with measurement without holding the conceptual knowledge what is being measured (Bragg & Outhred, 2001; Smith et al., 2013). This exploratory investigation documented the ways that children expressed temperature and interpreted thermometer and temperature representations in Chapter IV. I position the following inferred conceptions of temperature in the current chapter because they are more tentative than the findings in Chapter IV.

In Figure 30, I have ordered the participants in order of diversity of conceptions of temperature with highest at the top. I consider larger diversity of temperature conceptions by seeing the themes not only by category, but also looking at how they spread across interview sessions.

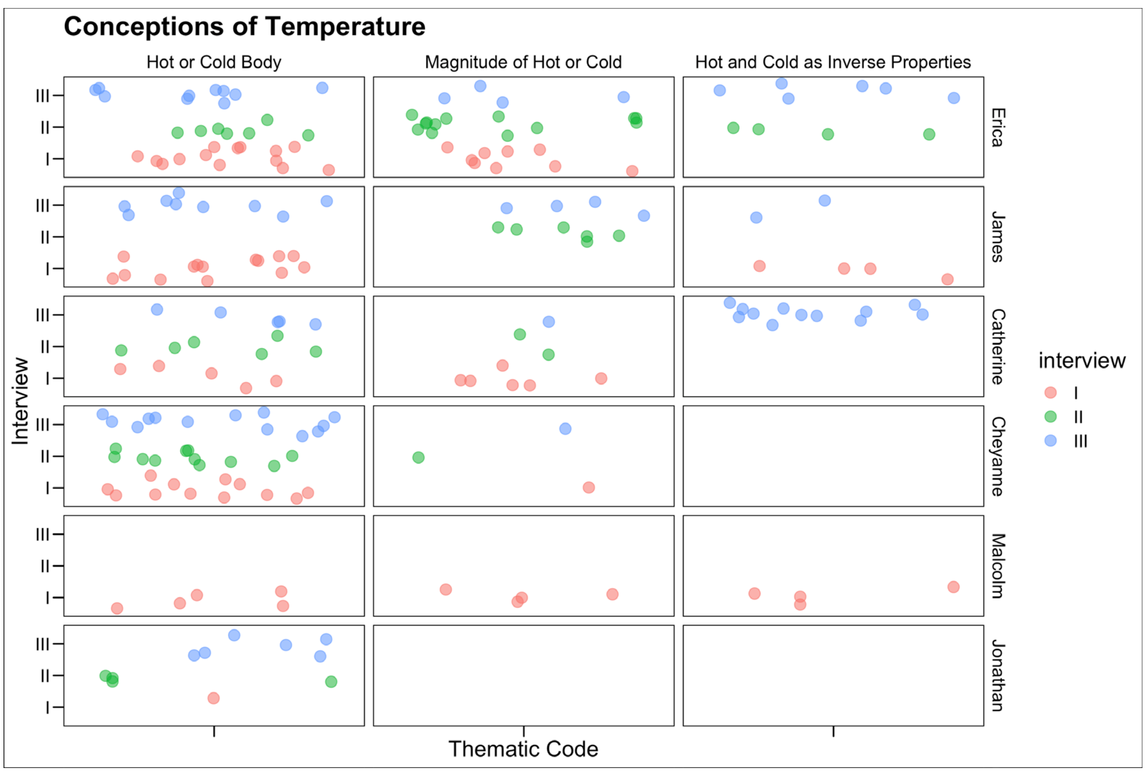


Figure 30. Distribution of thematic codes for temperature conceptions.

I discuss the coded conceptions of temperature by grouping the children into two groups, those who mostly demonstrated the *hot or cold body* conceptions consistent with the previously discussed literature (Albert, 1978; Erickson & Tiberghien, 1985), and those who demonstrated a more expansive repertoire of temperature conceptions.

Starting with the bottom half of Figure 30, Cheyanne and Jonathan mostly have codes in the *hot or cold body* conceptions column. As mentioned in the last chapter, this would include talk like Cheyanne's justification for including the moon in her picture to show cold despite the moon not being visible in the sky during the observation. I also include Malcom in the group even though he has instances of the other temperature conception codes, since overall his instances of thematic codes are limited to interview 1. In that first interview he was able to show hotter in a picture by making a bigger sun and seemed amenable to the block stacks to represent hot and cold. Once we moved into using the thermometers to represent temperature, he did not appear to see the connection of what was being measured as he made acceptable readings of the thermometers.

Considering the children on the top side of Figure 30, I coded Erica, James, and Catherine as being able to demonstrate *hot or cold body* and *magnitude of hot or cold* ways of conceptualizing temperature. Furthermore, these three children also showed evidence of interpreting the thermometers with a *hot and cold as inverse properties* which surfaced mainly when the youth were explaining how they understood the scale on the thermometers. That is, they demonstrated this conception by making sense of the range on both the ECT and the classroom expansion thermometer. I infer that the having the range of possible measurements on these thermometers allowed the children to use

the measurement tool itself as a model for constructing an understanding of temperature. This could potentially be similar to what Papert (1980) refers to as an "object to think with," but instead of gears being an object to think about proportions, the thermometer with its range of values acts as an object to think about the relation of hot and cold.

Considering the range of coded conceptions present among the six children, I view them as being on a continuum towards normative views of temperature. I view Malcolm, Cheyanne, and Jonathan as being on the left side of Figure 31, while Catherine, James, and Erica are in the center of this continuum drawn from this study. The further one moves to the left, away from the normative view, serves as holding a less normative view of temperature. At the simplest on the far left, one would only refer to hot and cold in terms of things that are usually hot or cold like fire and ice. Magnitude of hot or cold is a little more complex by associating levels of hotness and coldness, but still considering separate entities. The most complex conception of temperature demonstrated by the children was hot and cold as inverse properties. I interpret this as an intermediate step

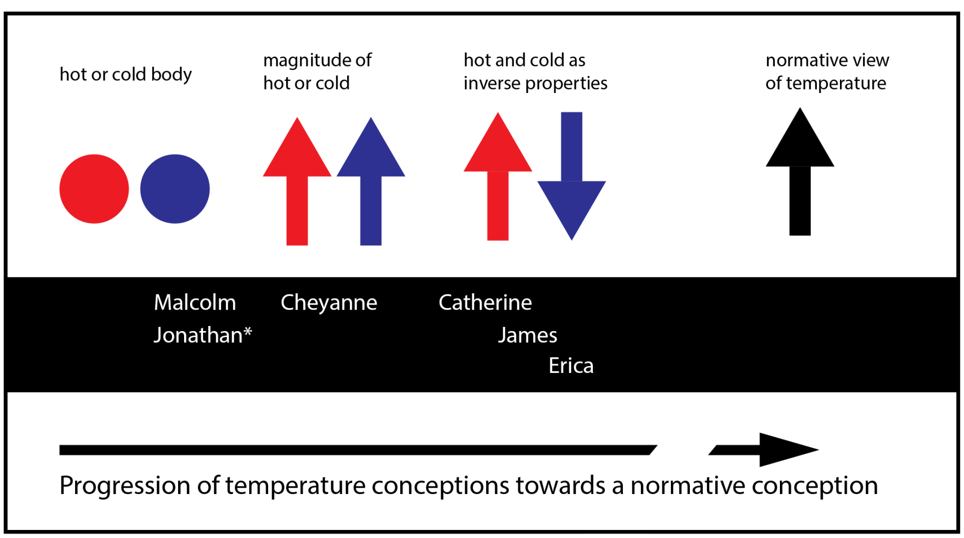


Figure 31. Temperature conception progression.

towards the normative view where hot and cold are approaching a single variable as measured by temperature.

In Figure 31, the normative view is shown as a single dimension because temperature is the singular measure of thermal energy of a substance. As opposed to the misconception of hot and cold being separate variables, they are portions of the single scale. While people may interpret parts of the temperature scale as hot or cold, those speak to a person's perception of temperature. For example, one might say both -40°F and -200°F are extremely cold, but quantitative temperature measurement allows us to compare the two with -200°F being colder as a result of having less motion at the molecular level. I have included a break in the line representing the progression of temperature conceptions to indicate the possibility of additional conceptions not observed in the current study.

Reflecting on how I utilized the *Temperature* conception thematic codes, I may have underestimated Malcolm, Cheyanne, and Jonathan's conceptions of temperature. For example, Jonathan may actually hold a more normative conception of temperature, but he often responded with one-word answers or a shrug of his shoulders. His explicit decoding of the temperature scale on the weather map demonstrated his comprehension of what the scale meant, but there was little other data like this to confirm it. Looking back on my coding, this interpretation should be coded as *hot and cold as inverse proportions.* Due to his limited speaking during the interviews, I had less turns of talk to code. This may be a limitation introduced by my method of analysis for inferring conceptions based on frequency and spread of a code over more than one interview. It is

possible that this limitation is more an artifact of my interviews' inability to elicit such conceptions. In the case of Malcolm, it is noteworthy that he does show evidence of hot and cold as inverse properties when explaining how a short stack of blocks could show cold and a taller one could show hot. In this case, I had provided the block representations for him to make sense of, which he did successfully. Similarly, Jonathan and Cheyanne may have been able to engage in discussing temperature as hot and cold as both inverse properties and separate properties with magnitude if provided the opportunity within the interviews. With this limitation noted, I inferred the children's conceptions from the evidence presented above with the caveat that Malcolm, Jonathan, and Cheyanne could have demonstrated more normative conceptions of temperature given the proper supports. The salient feature here is that at least one point in the interviews, all of the children demonstrated a conception of temperature beyond hot and cold bodies.

Even the three of children who demonstrated the hot and cold as inverse properties when explaining the range of the temperature scale, they still talked about hotness and coldness as separate things. This is not the normative view, which even trained scientists can struggle with (Linn & Songer, 1991). For example, one might demonstrate a normative conception of temperature by saying, "the high end of the temperature scale would indicate that the molecules in the air are moving faster as compared to air temperatures on the lower parts of the thermometer." While this example might be something we aspire to in later grades, it may be advantageous to first get to a *hot and cold as inverse proportion conception* as a way-point in early childhood

classrooms.

I do not present this as a learning progression (Schwarz et al., 2009); developing such a mechanism is beyond the scope of this study. However, this progression of temperature conceptions may serve as a starting point for future work to develop a learning progression of heat and temperature.

Affordances of the ECT and the Accompanying Bar Plot

The dual attributes were useful for the children's interpretation of temperature representations. Color was mostly ignored on the ECT, but was interpreted on the bar plots. Certain colors were more likely to be interpreted as hot and cold, namely blue for cold and yellow and red for hot. While some children were able to infer temperature related meanings for the other colors, some children interpreted in ways like green showing grass. This type of association of green as grass is rooted in language, as cognitive linguist Wierzbicka (1990) points out how in many languages that the word for green is related to words like grass, herbs, vegetation, and grow. Similar relationships exist especially in European languages with colors being associated with experiences universal to all humans including: red as fire, yellow as sun, and blue as sky (Wierzbicka, 1990). Since the children's interpretations of color match these universal color mappings, it makes sense that the red and yellow as hot were prominent. That being said, other colors might not be as intuitively interpreted as showing temperature. That being said, future work might examine the use of fewer colors in the scale, such as just blue and red.

The most salient feature of the ECT was the illuminated discrete scale that many

children touched as they read the temperature. All five of the children who drew the ECT included squares for the scale in their depictions. The interactive nature of the ECT, its button activation, gave the children more control when taking a measurement as compared to an expansion thermometer's constant display of temperature.

Contribution of the Study

The study makes three main contributions to the science education literature. First, it provides a more nuanced examination of how kindergartens can interpret thermometers. While previous work has found that this age group struggles with expansion thermometers (Havu-Nuutinen, 2007; Kampeza et al., 2016), I have demonstrated that all six children in the study could measure temperature procedurally with the ECT. Furthermore, three of those children demonstrated more normative conceptual understandings of temperature as measured with the ECT. Since the children in the study spent a total of less than two hours participating in the study, it is possible that more prolonged experiences with the ECT, associated data recording procedures, and classroom data discussions could support greater proportions of children constructing normative conceptions of the temperature scale. I have demonstrated that young children can be supported to make sense of quantitative measurement of temperature with tools like the ECT and accessible procedures for recording and representing such data. This included instances such as: Erica, James, Catherine, and Jonathan being able to make sense of the temperature scale, James' quick adoption of the stepped Unifix cubes to depict four different temperatures, Erica's explanation of how the metal parts of the

thermometer were taking a long time to warm up, and Jonathan's explicit decoding of the color scale on top of the weather map. Taking on such activities in early elementary could potentially alleviate difficulties with making sense of more complex data in later grades.

Second, the ECT itself is a contribution as a tool developed for supporting young children to measure and make sense of temperature. As mentioned before, I propose the ECT serves as an object-to-think-with (Papert, 1980) creating both a physical and possibly a mental representation of temperature. Common expansion thermometers may serve this same purpose for older children and adults as a model of temperature, but the ECT may be more accessible and engaging with its discrete scale counting by tens and interactive illuminated display.

Third, the study contributes empirical examples of young children talking about and illustrating temperature. As states continue to implement more ambitious science teaching in grades K-12, research is needed to determine what is possible in early elementary classrooms. As I pointed out in the literature review, the research is limited regarding heat and temperature for this age group. While the current study adds to that body of knowledge, more research is needed to better understand this age group.

Implications for Instruction

At the most basic level, procedures for recording temperature like in *Everyday Math* could be supported by making thermometers like the classroom expansion thermometer less ambiguous by covering the °C scale with a color strip. This way students will attend to °F and/or color when measuring the day's temperature. However,

as written in the Everyday Math Curriculum, this method divorces the temperature from the height attribute on the thermometer when placing a colored sticker on the month's chart. As I noted earlier, three of the children were able to make sense of the temperature scale by explaining what temperatures were like at the top and bottom of the scale. The scale on the ECT and the expansion thermometer serves as a model for thinking about temperature by depicting not only the current temperature, but also the range of possible values. One can make comparisons between temperatures when this scale is visible. An alternative approach to placing colored stickers could be to include the discrete boxes on the color strip. So instead of just recording temperature as a green sticker, it could be five green squares or blocks. This way children might make a colored bar graph, similar to the ECT inspired bar graph.

Provided there were adequate resources to provide ECTs to early elementary classrooms, these instruments could be engaging for students to use. All five[13] of the children who I asked their preference during the interviews chose the ECT as the thermometer to try.

Limitations and Suggestions for Future Research

Methodologically, there were two key limitations in the study. First, in the interview protocol for interpreting the ECT-inspired bar graph I included an explanation of time of day for each of the bars. This included pointing to a bar and saying this is when I woke up, pointing to the next saying this is when I got to school, and so forth. When I

[13] Despite working from a script for my interviews, I neglected to ask Cheyanne which thermometer she wanted to try after being shown four choices.

presented the line plot, I did not provide similar support for the children. Therefore, this was an unfair comparison of the children's interpretations of the two temperature representations. Furthermore, this occurred during a busy third interview in the sequence. In a future study, I would correct this by making the interpretation of the temperature representations its own fourth interview in the sequence and providing uniform support for each of the representations.

Second, as I mentioned earlier in this chapter, I inferred temperature conceptions based on the frequency of and distribution over multiple interviews of the temperature conception thematic codes. While my intention was to make sure that I was making claims based on adequate evidence, this may have underestimated the complexity of the children's conceptions of temperature. Children who talk less, such as Jonathan, might be miscategorized. In future studies, I will apply these conceptions of temperature codes to interview items rather than turns of talk. Furthermore, I would develop a greater number of interview items to elicit such conceptions. For example, I would have at least two ways of showing a series of three temperature scenarios with discrete quantifications. This might involve showing three pictures that I say are hot, warm, and cold with stacks of blocks and stacks of pennies to show the temperature of each image. Next, I would ask the children to show what a hotter and colder image would look like using the blocks and pennies to show temperature.

Although not a limitation as this is an exploratory study, further research is needed with a broader context of kindergarteners. Despite drawing a pool of participants with equal gender representation and a range of receptive language abilities, this was by

no means a representative sample of all kindergarteners. However, as an exploratory study, the goal was to see what might be possible when asking these 5- and 6-year-old children to make sense of quantitative measurements of air temperature. Having established that these harder ways of making weather observations can be successful with children of this age, future studies may consider examining larger samples in multiple contexts.

As this work is part of a larger design project, I will personally be pursuing full class implementations with the ECT while working with teachers to reflect on their enactments. Anonymized transcripts from this study may serve as models for the sorts of conversations the teachers might engage their students in.

Conclusion

Returning to my original dilemma that initiated my curiosity for this study: why couldn't my elementary students understand longitudinal representations of temperature? Based on the results of this dissertation, my instruction at the time focused entirely on teaching procedures for measuring and recording temperatures without attending to conceptions of what was being measured. That is, I tried improving my instruction by training young students to make and record temperature observations with canonical weather protocols. For example, this included using calibrated thermometers and observing temperature in the shade. What at the time appeared as the correct way of recording temperature, was instead the scientists' way. The ECT allowed me to implement a more age-appropriate way of observing temperature. In this dissertation, I

have shown that it is possible for young children to meaningfully engage with quantitative measurement given proper supports. These supports include the ECT, but also engaging with children's prior conceptions of heat, temperature, and temperature measurement. Returning to my theoretical orientation of prior conceptions, I present the prior conceptions surfaced in the present study.

First, prior conceptions about heat included children discussing and representing: hot and cold with objects that are typically hot or cold, magnitude of hot and cold as separate entities, and hot and cold as inverse properties. While the first view of hot/cold bodies is consistent with prior literature (Albert, 1978; Erickson & Tiberghien, 1985), hot and cold including the qualities of magnitude and inverse proportionality are new for this age group. Second, the presence of the conception of magnitude of hot and cold may have supported the children in making sense of what the thermometer was measuring. With 4/6 of the children demonstrating an understanding of the temperature scale, magnitude of hot and cold may be a naïve conception that serves as a waypoint towards developing a normative view of temperature. With 3/6 exhibiting coded conceptions of hot and cold as inverse properties, we might expect that working with the ECT over the course of an entire school year could support an entire class of young children to the way-point conception of hot and cold as inverse temperatures, and possibly further for others.

In conclusion, this dissertation is my first complete study as an independent researcher, albeit under the guidance of my committee. The results have indicated that young children can be supported to make sense of quantitative measures of temperature. Furthermore, they bring prior conceptions of temperature as resources for making sense

of temperature. The participants demonstrated this ability to reason through temperature with their ways of expressing temperature and ways of interpreting temperature representations. Although I began this inquiry with the ECT's effectiveness as being central, the more salient features of the study are the expressions and conceptions of temperature that I identified and described. The larger design project continues as I plan for a full class implementation of the measuring and interpreting temperature on a daily basis. The children's discussions of temperature documented in Chapter IV will serve as starting points for the planned implementation to show partner teachers examples of kindergarteners making sense of temperature. While this concludes this document, it begins my career as an education researcher.

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APPENDICES

Appendix A

Interview Protocols

Interview #1 Protocol

This is a one-on-one interview to be conducted with a kindergartener. The interviewer will sit at a table with the child reading each question aloud and using similar language to get the children to elaborate on their answers when needed. A video camera will record the interview making sure to capture the child's gestures.

Have the following materials at the table: colored pencils, paper, colored blocks, colored stickers

Start video camera. Say, "there are no right or wrong answers for the questions that I am going to ask you. I am trying to learn more about how kids think about temperature. We can stop at any time for any reason. Does that sound ok?" If they respond that it is ok to proceed, continue with the protocol.

1. "I have a few problems that I need your help to figure out. Does that sound ok? Do you have any questions before we begin?"

2. If they respond that it is ok to proceed, continue with the protocol and ask the questions below.

3. How hot does it feel outside right now? (provide time to respond and follow up) Is that any different than when you first came to school this morning?

4. Now we are going to feel how hot it is in two places. Let's first stand in the shade (stay for about a minute), and then we will stand in the sun (stay for about a minute).

5. Let's head back inside now to talk about and show how hot it was. Now I would like you to use the materials (colored pencils, colored blocks) to show me how hot it was outside in the shade? Can you explain what you made to me? Why did you do that?

6. Can you now make show me with the same materials that you used for the shade to show me how hot it was in the sun? How is that different from your first picture (or blocks)?

7. Now I would like you to show me how that picture or those blocks would look if it got a little hotter in the sunny spot. (Give them time to work through it, but then ask why they did what they did.) How about if it got a lot hotter?

8. Sometimes people show the temperature this way (construct an example that has a different convention for showing the temperature with the same materials, such instead of using more blocks to show hotter, use less). What do you think of showing it this way?

9. Now I want you to help me think about what happens during the day and night with how hot it is. How does how hot it is outside change during the day? How do you

know?

10. What happens to the how hot it is at night? How do you know?

11. What are some other times you can think about how hot it is? What might be some things that get hotter? Or things that get colder?

12. Say “thank you very much for talking with me today. Your answers are going to help me understand how kids think about the temperature.” Stop video camera.

Interview #2 Protocol

This is a one-on-one interview to be conducted with a kindergartener. The interviewer will sit at a table outside with the child reading each question aloud and using similar language to get the children to elaborate on their answers when needed. A location with both shade and full sun will be required. A video camera will record the interview making sure to capture the child's gestures. Have the following materials at the table: four thermometers (ECT, large classroom expansion thermometer, standard expansion thermometer, and a digital thermometer)

Start video camera. Say, "thank you for coming back to talk with me. Same as last time, there are no right or wrong answers for the questions that I am going to ask you. I am trying to learn more about how kids think about temperature. We can stop at any time for any reason. Does that sound ok?"

If they respond that it is ok to proceed, continue with the protocol.

"I have a few problems that I need your help to figure out. Does that sound ok? Do you have any questions before we begin?"

If they respond that it is ok to proceed, continue with the protocol and ask the questions below.

1. Last time we talked about how the hotness outside can change. People sometimes use tools to measure how hot it is outside. I have brought a few of these tools with me. They are called thermometers. I would like you to take a look at them before we try them out. (Give the child 3 minutes to explore the thermometers, and ask them to comment aloud what they thinking when they hold each one).

2. Now I would like to you choose one to try out. Why did you pick that one?

3. Next, we will test out the thermometer that you selected. How do you think people might use this? (After the child has a chance to talk a bit, offer to show the child the scale or readout).

4. What temperature does it say? Tell me how you figured that out.

5. If it got hotter here, what do you think the thermometer will look like?

6. Let's now try a second thermometer. How do you think people might use this? (After the child has a chance to talk a bit, offer to show the child the scale or readout).

7. What temperature does it say? Tell me how you figured that out.

8. If it got hotter here, what do you think the thermometer will look like?

9. Now let's take both thermometers outside. Thermometers take a little while to work. Let's put them in a shady spot. Let's read the thermometers and while they adjust, we will make a picture of the shady and sunny spot

10. Let's now go to a sunny spot and try the thermometers. Let's give it a minute to adjust, but while we wait I want to ask you a question. How does it feel here in the sun? Is there a difference between where we were in the shade before? Why do you think that?

11. Now that the thermometer has been in the sun for a bit, can you tell me what is says? Is there a difference between what it said when we were in the shade? Why is that?

12. If we want to remember what the thermometer showed us, how could we add that to the picture? Could you add that?

13. Which thermometer did you like using better? Why? What did you like about that one?

14. What didn't you like about the other thermometer?

15. Say "thank you very much for talking with me today. Your answers are going to help me understand how kids think about the temperature." Stop video camera.

Interview #3 Protocol

Like we did last time, we are going to measure the temperature again. This time we want to figure out a way to remember what the thermometers were showing (might need to explain record, as a way to save something so we don't forget it) what they show.

1. What materials would you like to use? (offer the paper, colored blocks, stickers, and colored pencils) Let's measure the temperature in both places and show them.

2. Let's see what it feels like in both places and make a picture at each one.

3. (Wait for the child to record both temperatures.)

4. Now, can we add the thermometer to the picture? One way might be to use the blocks to help us.

5. Go inside to finish the interview

6. What if we went to a third place that is hotter? Can you show me what that would look like?

I am going to show you what it might look like if we took the temperature in one place but kept doing it all day and night. (Use the materials the child selected to make a more longitudinal representation of temperature over the course of a day, rising throughout the day and decreasing overnight) Looking at what I made, what do you think is happening with the hotness?

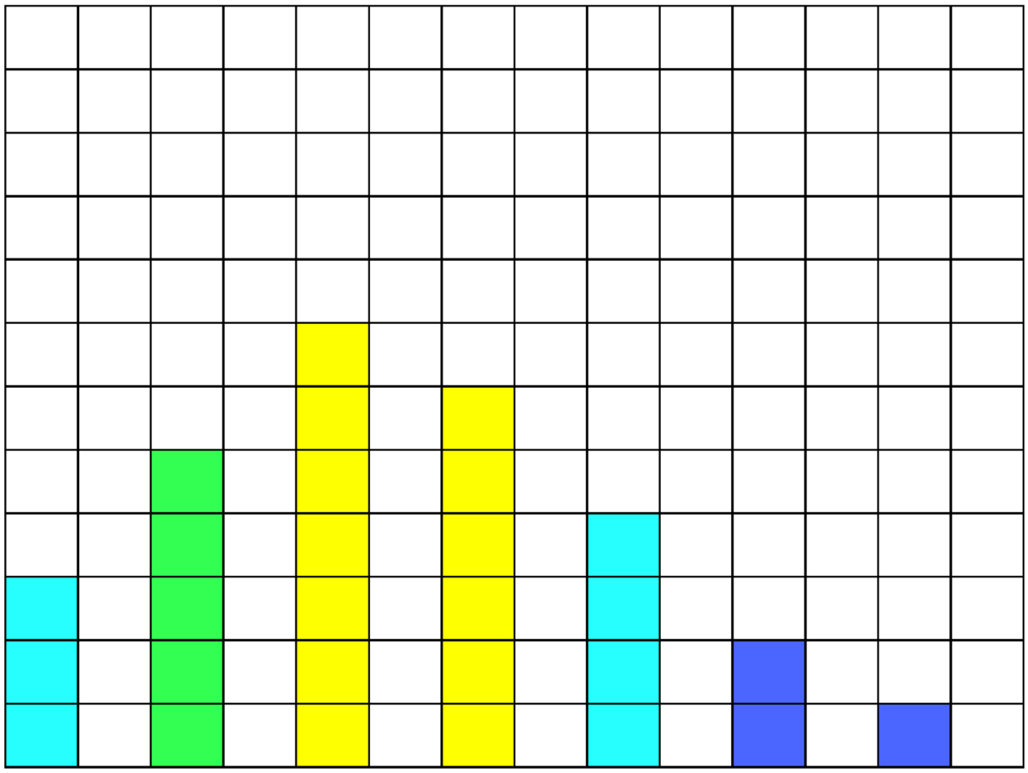
Can you tell me what these numbers are?

Show Page of Numbers 72, 80, 14, 60, 55, and 102

Ask any follow up questions for their older pictures.

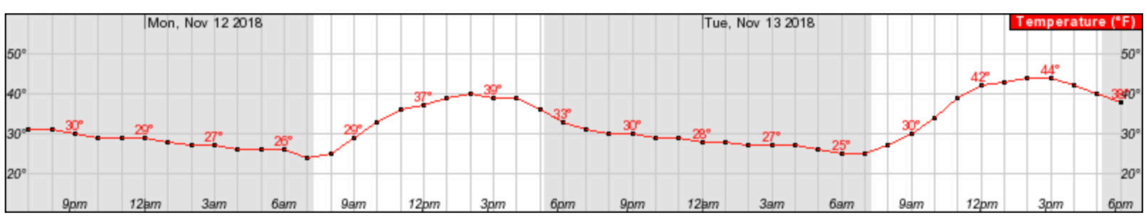
Can I show you a picture I made last week about the temperature? I wanted to remember what the thermometer said during the day, so I made this picture. This was yesterday morning (start by pointing to the first bar with 3 cyan squares and continue across the graph), this was when I was eating breakfast, this is when I was getting to school, this is when I was having lunch, etc. What do you think the picture is showing?

Bar Graph Showing Daytime Temperatures Using ECT Scale

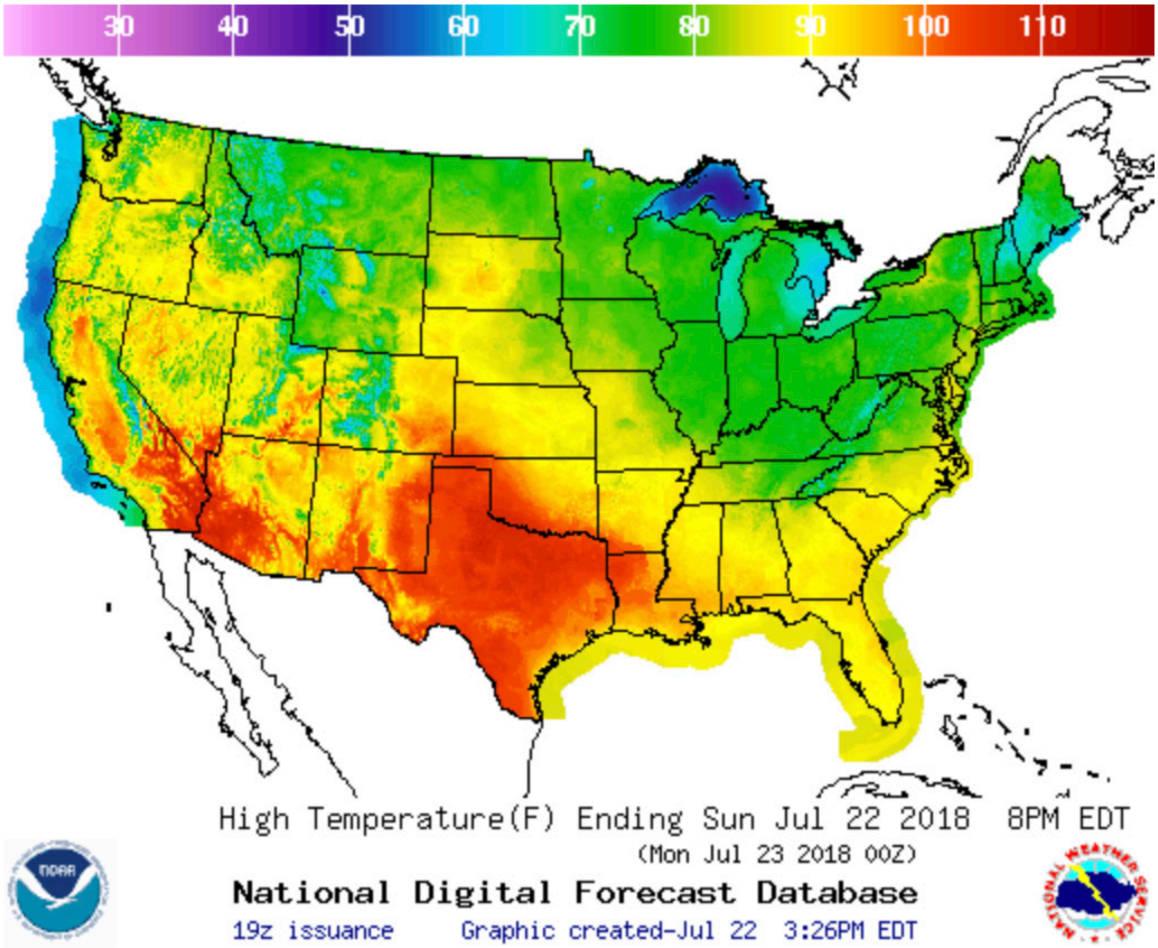


Now I want us to look at some pictures that scientists make to show how hot or cold it is. I want to tell me what you think they are showing. Ask follow up questions such as: what does the line mean? What do the colors mean? You can make your best guess and if you don't know that is ok.

Line Plot Showing 72 Hours of Continuous Temperature (weather.gov)



Weather Map Showing Daily High Temperatures with Color (weather.gov)



Once the child has interpreted all three ay "thank you very much for talking with me today. Your answers are going to help me understand how kids think about the temperature." Stop video camera.

Appendix B

Letters of Approval

Utah State University IRB Letter of Approval

aggiemail **Ryan Cain <ryan.cain@aggiemail.usu.edu>**

Approval letter from USU IRB

noreply@usu.edu <noreply@usu.edu> Tue, Oct 16, 2018 at 11:34 AM
To: victor.lee@usu.edu, ryan.cain@aggiemail.usu.edu

Institutional Review Board

USU Assurance: FWA#00003308

UtahState University
OFFICE OF RESEARCH AND GRADUATE STUDIES

Expedite #6 & #7

Full Accreditation

Letter of Approval

FROM:

Melanie Domenech Rodriguez, IRB Chair

Nicole Vouvalis, IRB Administrator

To:	Victor Lee, Ryan Cain
Date:	October 16, 2018
Protocol #:	9453
Title:	Examining Kindergarteners' Ways Of Understanding And Representing Air Temperature
Risk:	Minimal risk

Your proposal has been reviewed by the Institutional Review Board and is approved under expedite procedure #6 & #7 (based on the Department of Health and Human Services (DHHS) regulations for the protection of human research subjects, 45 CFR Part 46, as amended to include provisions of the Federal Policy for the Protection of Human Subjects, November 9, 1998):

> #6: Collection of data from voice, video, digital, or image recordings made for research purposes.
> #7: Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

This approval applies only to the proposal currently on file for the period of one year. If your study extends beyond this approval period, you must contact this office to request an annual review of this research. Any change affecting human subjects must be approved by the Board prior to implementation. Injuries or any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Institutional Review Board.

Prior to involving human subjects, properly executed informed consent must be obtained from each subject or from an authorized representative, and documentation of informed consent must be kept on file for at least three years after the project ends. Each subject must be furnished with a copy of the informed consent document for their personal records.

Ogden City School District Letter of Approval

OGDEN
SCHOOL DISTRICT
Empowering Excellence Through Education

Educational Research **October 16, 2018**

Dear Mr. Ryan Cain:

We have received your proposal to conduct the research study entitled "Examining Kindergarteners' Ways of Understanding and Representing Air Temperature."You are requesting that we grant approval to conduct your research with kindergarten students. We understand all subjects' guardians will have understand and sign informed consent forms as presented in your application and your OSD Research Request and Confidentiality Agreement on 10/9/18. This was agreed to by your Primary Investigator, Victor Lee, with his signature of attestation on the aforementioned agreement.

The Ogden School District team has reviewed your request and completed confidentiality agreement. We have also reviewed your IRB application and protocol **#9453** with USU. We have can now conclude that this research is in line with both our district mission and with appropriate IRB approved research practices for working with human subjects. WIth the aforementioned understandings to serve as guaranties, we can agree to allow this voluntary research study within our school district.

This letter is to serve as recognition of our approval for you to proceed with your research as described. Note that Ogden School District requires documentation of obtained informed consent; this should include documented verification of the procedures used, such as a statement of attestation or witness statement, dates of the disseminated informed consent documentation, and a de-identified list of all subjects with signed informed consent who will be part of your study in order to validate scope and process. Your point of contact with our school district will be Ms. Maridee Harrison. Ms. Harrison will be your resource and your first contact if any questions or concerns arise.

Please note that any data collected and presented publicly must not allow for the identification of individual participants. Any concerns about the research or the protocols employed will be handled jointly by Ogden School District and the researcher to determine appropriate response and any needed next steps, deferring to the researcher and the IRB committee for responsibility to fulfill the IRB approved processes. Further clarification and coordination will be obtained through your assigned point of contact, Ms. Maridee Harrison, harrisonm@ogdensd.org and Executive Director, Sarah Roberts.

We look forward to receiving a copy of your findings and reviewing these with you at the conclusion of your study. Upon completion, you will need to set an appointment with your Point of Contact to review the findings with members of the Ogden School District Cabinet that we might all learn from your educational research. Thank you for your efforts to further our profession.

Recruitment Script – Kindergarten Air Temperature Study

The student investigator will read the following text to students and parents just before end of day dismissal.

Hello, my name is Ryan Cain and I am a PhD candidate at Utah State University. Under the supervision of my advisor, Dr. Lee, I am conducting a study to examine how kindergarten children think about air temperature. If you and your child decide to participate, you can fill out this consent form. Since this is a small study, not everyone will be chosen to participate. I am looking to work with three boys and three girls.

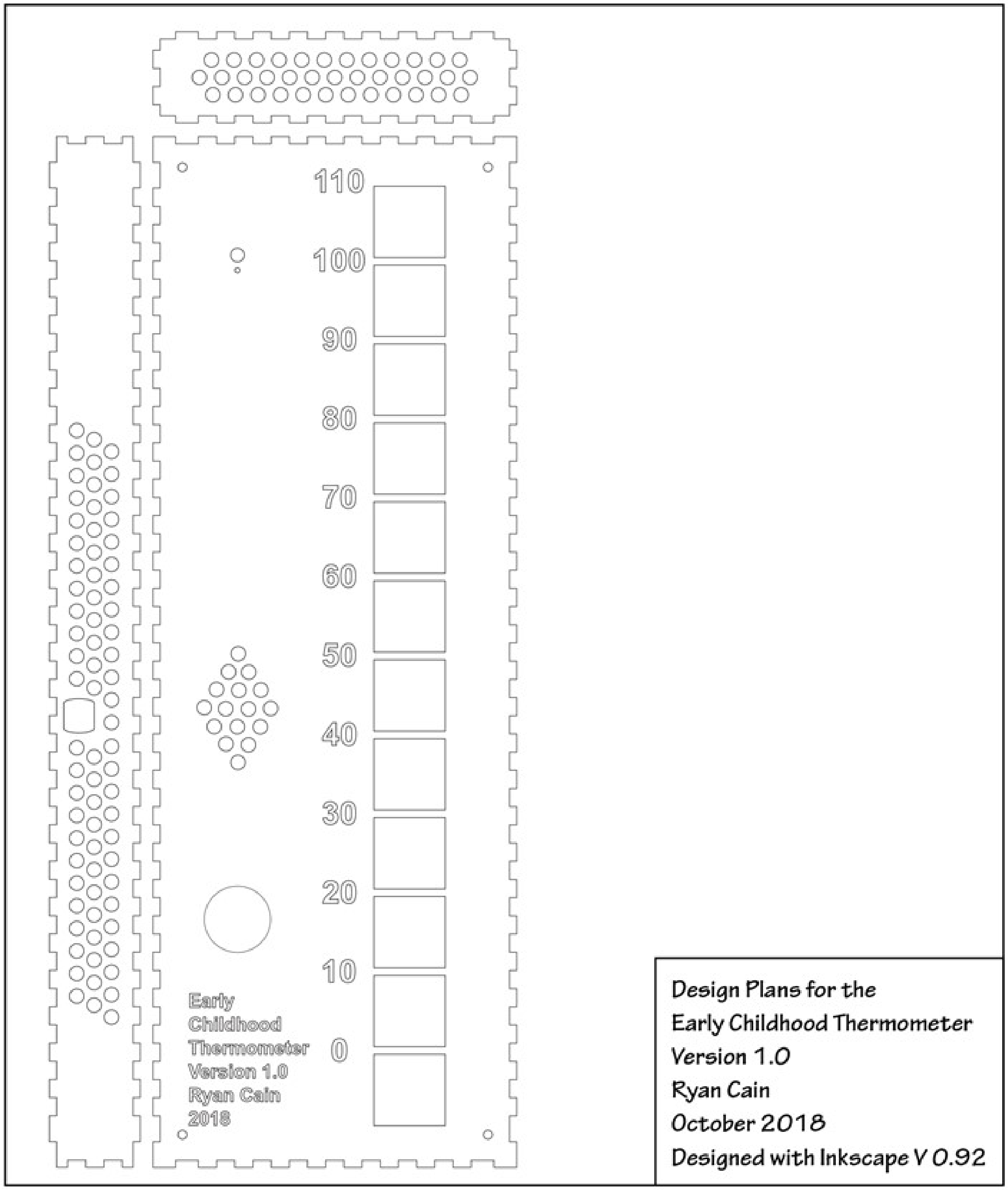
If your child is selected, they will participate in 3 video-recorded interviews lasting about 20-30 minutes each over the course of several school days. All the videos will be stored on an encrypted server that only I and my advisor, Dr. Lee, will be able to access. If I show any of the video at an education conference, I will blur your child's face to protect their privacy. In addition, I will use a pseudonym in place of their name in all my writing about them. The total time of participation will be for 60-90 minutes. During the first interview, I will be doing a vocabulary assessment with your child. This will involve asking the children to point to pictures that match the word I tell them. For the rest of the first interview and the entirety of interviews 2 and 3, I will ask questions and talk about air temperature. As a small thank your child for participating, I will be giving them two small books about weather.

Since not everyone will participate, I will also be donating copies of the books to the classroom library so you all can borrow and read them. Once all the interviews are complete, I will read one of the books in class and teach a lesson about air temperature.

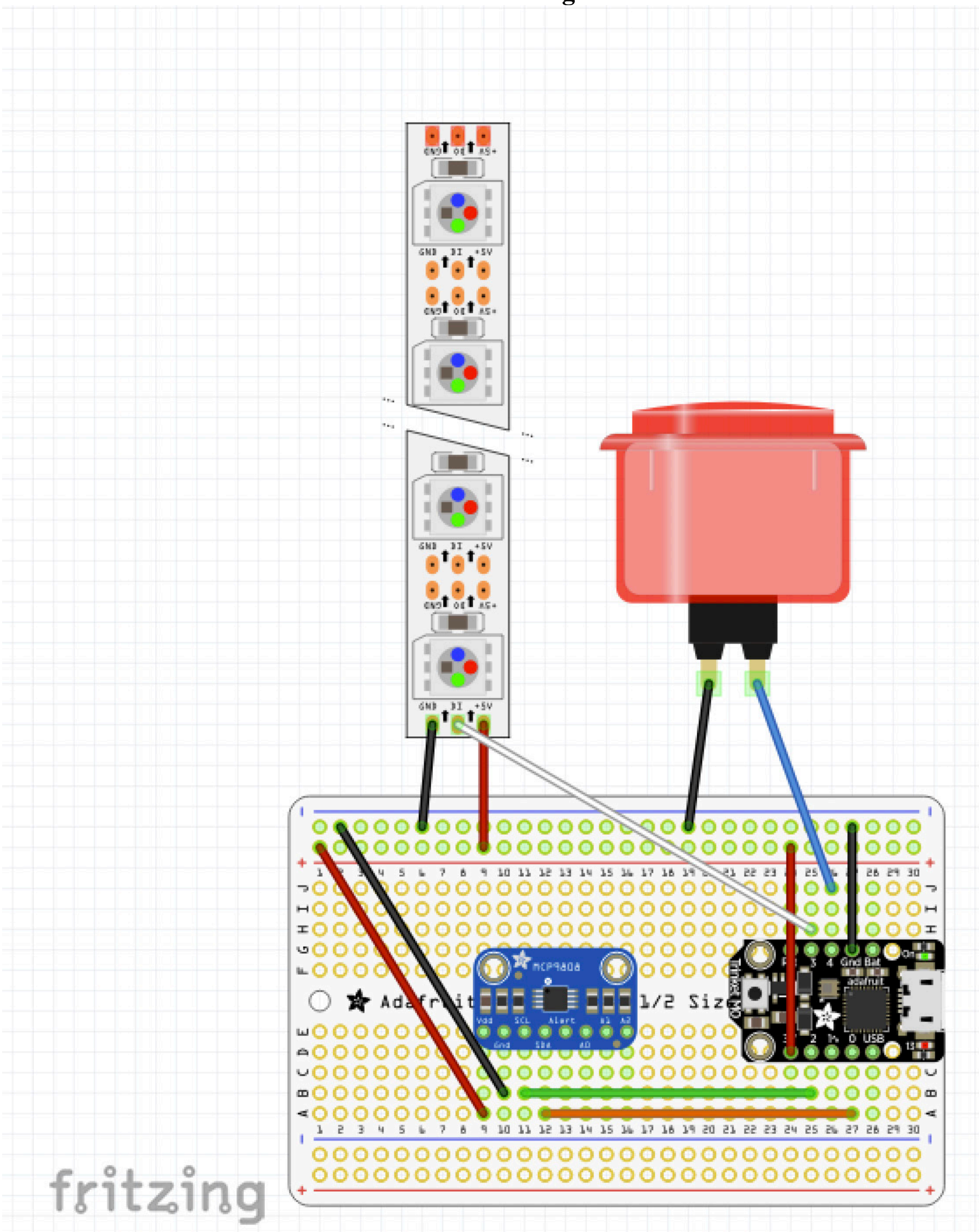
Appendix C

ECT Design Documents

ECT Enclosure Plan



ECT Circuit Diagram



ECT Software for Circuit Python Version 3

```
# Early Childhood Thermometer
# Ryan Cain
# 30 NOV 2017
# Thanks to the Adafruit Learning System and
# The Adafruit Discord Community
# Especially @tannewt @kattni @cater


import time
import board
import busio
import adafruit_mcp9808
import neopixel
from digitalio import DigitalInOut, Direction, Pull

# Helpers
i2c_bus = busio.I2C(board.SCL, board.SDA)
mcp = adafruit_mcp9808.MCP9808(i2c_bus)

NUMPIXELS = 12
NP = neopixel.NeoPixel(board.D3, NUMPIXELS, brightness=.5,
auto_write=False)
led = DigitalInOut(board.D13)  # Button LED
led.direction = Direction.OUTPUT

button = DigitalInOut(board.D4)
button.direction = Direction.INPUT
button.pull = Pull.UP

tdelay = 6
tstatus = 0

blu = (0, 0, 255)
cyn = (0, 255, 255)
grn = (0, 255, 0)
yel = (255, 255, 0)
red = (255, 0, 0)
mag = (255, 0, 255)
ooff = (0, 0, 0)

def set_thermometer_pixels(n, color):
    NP.fill(0)
    NP[0:n] = (color,)*n
    NP.show()

while True:
    tempC = mcp.temperature
    tempf = tempC * 9 / 5 + 32
```

```
print('Temperature: {} C {} F '.format(tempC, tempf))
# time.sleep(2)
if button.value:
    # NO Button press do nothing, unless time ==12:00

    led.value = False      # turn OFF LED
    set_thermometer_pixels(12, ooff)  # turn OFF neopixels

else:
    print('pressed')
    led.value = True       # turn ON LED

    if tempf > 105:
        set_thermometer_pixels(12, mag)
    elif tempf > 95:
        set_thermometer_pixels(11, mag)
    elif tempf > 85:
        set_thermometer_pixels(10, red)
    elif tempf > 75:
        set_thermometer_pixels(9, red)
    elif tempf > 65:
        set_thermometer_pixels(8, yel)
    elif tempf > 55:
        set_thermometer_pixels(7, yel)
    elif tempf > 45:
        set_thermometer_pixels(6, grn)
    elif tempf > 35:
        set_thermometer_pixels(5, grn)
    elif tempf > 25:
        set_thermometer_pixels(4, cyn)
    elif tempf > 15:
        set_thermometer_pixels(3, cyn)
    elif tempf > 5:
        set_thermometer_pixels(2, blu)
    else:
        NP[0] = blu
        NP.show()
    time.sleep(tdelay)
```

Appendix D

Process Codebook

PROCESS CODEBOOK

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Attributing cold or warmth to a source	Ways that children discussed temperature in terms of source causing hot or cold	16	68
Analogizing cold as snow	It is just like the snow	1	1
Analogizing the sun with fire.	Cause the sun is very hot, it's just like flaming fire	1	1
Associating the moon with night	The moon comes out.	1	1
Attributing cold as night	When it is dark and cold.	2	2
Attributing cold to a lack of sun	It's cause when it's cold, it's cause the sun is not shining bright enough	4	8
Attributing cold to cold air	Cause cold air	1	1
Attributing cold to shade	The reason this side was cold <taps blue side with thumb> was because there was shade.	2	3
Attributing cold to the moon	Because the moon makes us colder.	4	10
Attributing cold to the season winter	And I was thinking it was winter	4	6
Attributing cold to the wind	Cause the air blows and its cold.	9	15
Attributing temperature change to wind and sun	The wind and the sun	1	1
Attributing warmth to lack of shade	And the reason this one was hot <hods red side in right hand> was because there was no shade. <makes motion extending her arms outward>	1	1
Attributing warmth to the sun	And the sun makes us warmer	9	16
Attributing wind to trees	Um, the trees blow really hard, make a lot of wind, so it's really cold outside.	1	1

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Sun and Moon	<Points to yellow> Sun <points to gray area> Moon	1	1
Depicting cold	Ways in which children created representations of cold	14	40
Depicting cold as how the person feels it	A human getting freezed <crosses arms over chest>	1	10
Depicting cold as ice	A block of ice and it's in the shape of a square	1	2
Depicting cold as lines	In the sun it wasn't very cold. Like a little bit cold. I am going to do some lines here.	4	10
Depicting cold with blue blocks	<stacks blue blocks>	2	2
Depicting cold with the moon	<stacks blue blocks>	2	2
Depicting colder as less blocks in stack	Cause the cold is little	2	4
Depicting colder as more blocks	I would put more of <touches top of white block stack> You know white	2	2
Depicting colder as more blue stickers	It's feeling very cold, like the cold is getting bigger. <without prompting, she places more blue stickers> and colder so it gets more stickers getting cold. <places more> They are just like little scales when I bunch them like that. Can we do it any color that we want?	2	2
Depicting ice with multiple colors	I picked dark blue, orange, red, a reddish kind of color, light blue, black, brown, a white, some more dark blue, and a yellow.	1	1
Depicting snow	I would like to add me in the snow.	1	1
Depicting weather as fall	Cause the are falling <points to orange leaves> They are supposed to be up here, but they are falling. They are supposed to be up here, but they fall down to the ground <shows how the motion of the leaves falling on picture with fingers>	1	4

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Depicting for appearance	Ways that children prioritized making a representation that looked like the site of the temperature observation	15	30
Depicting with color for visual similarity	This is the grass <touches green stack> The sky <touches blue stack>	14	28
Depicting shade or sun for visual similarity	<Takes gray pencil first and traces around the edge, draws a bunch of black/gray on one side, next does a sun to the top and then some sun >	2	2
Depicting temperature	Creating a representation of temperature	20	130
Adding thermometer to the picture	Oh, that's good, now red line. I am just going to do it like this one <takes out red marker and draws line up to about 60>	7	19
Adopting introduced block representation instead of their own	I am going to make it hot. <Makes a tall stack of orange blocks> So this one is the hot. And this one is the, this one's warm <places a smaller orange stack>, and this on is cold <places an even smaller stack of orange>	1	1
Agrees with a short stack of blocks as cold and a high stack as warmer	o that means it can be cold <points to short> and warmer <points to tall stack> then just cold and it could be different.	2	3
Commenting on how to make the thermometer display a different temperature	Let's do something to get over here <points to the 110 deg box on ECT>	1	1
Depicting a progression of temperature change	Because they are smaller every time they get warmer and colder, they get smaller and bigger.	1	1
Depicting temperature as just right	We are looking at right here <touches stickers she just placed>, my skin is telling me it is just the right temperature so I putted one, two, three, four	1	1
Depicting temperature with blocks	<takes orange and blue blocks> Done <places two stacks of orange blocks (5 and 9) on one side and two stacks of blue blocks on the other side (3 and 1)	1	1

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Depicting wind	Wind, they get bigger and bigger cause that means the wind is coming slowly and faster	4	13
Depicting with color as temperature, hotness, or coldness	Cause hot would usually be red and cold would usually be blue	10	41
Depicting with written text	<grimaces face as he chooses a pencil, adds something with blue pencil> How do you spell cold?	1	1
Describing how to dress for certain temperature	Snow is cold, so you have to wear a heavy jacket.	2	2
Explaining illustration color	So this is <touches brown> warm and that's <touches red> hot, so it makes it warm in the inside	4	8
Explaining illustration form	How the weather is cold <with right index finger, circles around the picture 2-3 times> and the air is white so you can't see it	6	11
Recording temperature with blocks	Yes, I am going to make it red cause it's warm. <builds red stack of blocks> 50 <continues stacking> 60 <continues stacking> 70 <places stack against the ECT to compare, continues stacking, compares to ECT> Seventy degrees	6	25
Referencing block representation	Because they need to be the blocks to the number. <Makes side to side motion with palm flat on top of the stack>	1	2
Depicting warmth	Making a representation of hotness	18	61
Depicting even hotter as bleeding	<uses the pink to add something to r body> You are so hot you are bleeding.	1	1
Depicting heat as how it affects a person's body	the human is different than this, cause his arms are straight out <points to second picture human> and this one <points to first picture human> and this one is in	3	5
Depicting hot with the sun	This one is the sun because it was hot	6	18

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Depicting hotter by removing blue sticker	<points to blue sticker> Take this one out.	1	3
Depicting hotter with a bigger sun	<draws large sun in the middle of the top of the page, then more lines around the picture>	1	1
Depicting hotter with additional red sticker or stickers	<grabs sticker sheet and adds sixl more red stickers> When hot spots get hotter, they want to make a bigger spot. That's how it looks. <touching larger red spot.	3	7
Depicting hotter with more blocks	<Takes short stack, breaks apart and aligns with red by height (5) and (3) for the blue>	1	2
Depicting hotter with orange blocks	I am going to make it hot. <Makes a tall stack of orange blocks> So this one is the hot. And this one is the, this one's warm <places a smaller orange stack>, and this on is cold <places an even smaller stack of orange>	2	2
Depicting mixing of warm and hot with two colors	Hot and cold at the same time, so this one is inside <touches inside picture> so it's hot warm cold, so it makes it really warm in here	1	3
Depicting sun with yellow and other colors	Yes, for this one I need yellow. I might use some other colors. <builds stack of yellow blocks with one blue at the base, then brown and yellow stack> Sometimes it can't really turn into a circle, sometimes it turns into a triangle <adds third stack to complete triangle>	4	4
Depicting warmer as sweat on a person	<takes blue pencil and draws on the picture of r> Sweating	1	2
Depicting warmer with increased stack of blocks	Oh yeah, I know. I know if it hot even warmer. <takes blocks from bin> Is this like this right now <places ready made stack of four orange blocks on desk> it can get more warm <takes ready made stack of 9 orange blocks and adds on top of short orange stack on desk> 'inaudible' <adds another ready made stack of four orange blocks to the top>	3	6
Depicting weather as	So this is summer <points to red part>	1	5

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
summer			
Depicting warmer as red and brown	Yes, I can <take outs red blue, brown, and orange markers, draws blue outline, colors in with brown and red	1	1
Explaining how more blocks shows hotter part of temperature comparison	I know I only put a little bit <touching blue> and a lot <touching red>	1	1
Describing a recalled or hypothetical temperature	The ways that children discussed imagined temperatures	5	11
Describing a difference in temperature between shade and sunny spots	Cause that one with the shade <points toward the shade corner> is cold and where the sun is <moves back towards sunny corner> is warm	2	3
Describing how a hypothetical temperature would feel	I was playing outside with my friends and got really hot and needed to go to my house and get some water and it kinda cooled me down a bit	3	6
Describing recalled hot or cold observations	Like sandwiches I put in the freezer and they are cold after I take them out.	1	2
Describing cold	The ways children discussed coldness	6	12
Commenting on the temperature	I am not even that cold, not that cold.	2	4
Describes temperature at night	It gets cold.	2	2
Describing attributes of winter	Snowy	2	2
Describing temperature as dropping below	Well, when cold is just dropping down below <touching blue part of the picture> it starts like this,	1	2
Describing ice	No, but I did see some froze ground when I was walking in.	1	2
Describing shade or full sun	The ways children discussed shadiness and direct sunlight	2	5

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Commenting about shadiness	Yeah, if I stand right here it makes more shadow.	1	1
Commenting about sunniness	There is more sun over here.	1	1
Depicting shade as a mix of hot and cold	Shadow, it was sunny <touches sun> and cold <touches wavy lines> mixed together <slaps open right palm on clenched left fist>.	2	3
Describing thermometer	The ways in which the children talked about the thermometers	11	80
Asking questions about thermometry	Why are there boxes on this?	1	1
Choosing thermometer to try	I want to try this one <pushes button on ECT>	1	2
Describing attribute of a thermometer	Because it has lights	3	10
Describing how the thermometer works	t changed colors <touches each of the boxes on the ECT from 0 to 50 deg>	2	3
Describing low end of thermometer as cold	It hits to really cold	1	1
Describing temp increase shown as higher line in thermometer	It would get more higher <touches top of green illuminated ECT and motions up to the top> this one	3	4
Describing temp increase shown as lower line in thermometer	I think more lower <motions to the bottom>	1	1
Explaining illustration of thermometer	This thermometer <touches thermometer on short stack side> isn't on because I didn't press the button and this one is on <circle finger around black/brown oval shape on tall stack side>	2	3
Explaining what a thermometer does	So this one tell you hot <points to yellow thermometer> and this one tells you cold <points to blue thermometer>	3	6

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Exploring the thermometer	Well, this you see <hits ECT button> It tells. If it is all the way up here. <touches top of ECT> That's one hundred fifty degrees	3	14
Expressing opinion about a thermometer	Cause, I like those the most cause you can change the temperature. You can make it, when you press a button, it can act on its own.	6	15
Expressing preference of thermometer	Because it has lights and it's really cool. That what you think too huh?	6	14
Identifies thermometer	Fermometer for the coldness and hotness	3	4
Justifying preference of thermometer	Because inside is squares and outside is circles (referring to how the ECT illumination looks like circles in bright light)	1	1
Describing Warmth	The ways the children discussed hotness	2	2
Expressing preference for a sunniness	I like the sun. I want to stay in the sun	1	1
Describing sun	Cause it is hot and heated <crosses arms over chest>	1	1
Describing temperature as up	The hot is up full degrees it goes to all the way up here <points to the top of the red part of the picture>	1	1
Describing wind	The ways children discussed wind or air	2	4
Describing air	Cause it's white and nobody can see it.	1	1
wind	For like wind <draws short lines above and below the people he just drew> There	1	1
Explaining temperature	The ways children discussed temperature	16	71
Explaining a change in temperature	It goed colder.	2	6
Explaining a difference between shade and sunny thermometers	I don't know, because the shadow is cold.	1	4

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Explaining a hypothetical temperature display	Up here <points to 110 deg on the yellow thermometer>	2	4
Explaining a mixing of hotness and coldness	Mixing happening right here. <points to border between red and brown and dashed lines picture from earlier interview>	2	4
Explaining cause of a hypothetical temperature	The suns not here. <points with index finger towards the door that is also the direction of the sun (east)>	1	2
Explaining cause or causes for the current temperature	Because the sun is barely out and more clouds are covering it.	1	4
Explaining change in temperature measurement	Because the green one <touches green 50 box on ECT> was here <touches 60 box on ECT> and now it is here <touches 50 ECT box	2	3
Explaining color choice with justification from literature	You know that the yellow and the orange fight because, <holds up orange pencil> I want to be in the sun!, No I want to be in the sun! <Big smile>	1	7
Explaining difference between shade sunny spots	Lighter and darker <touches yellow side after saying lighter with left hand, touches black side with right hand after saying darker>	1	1
Explaining heat	So heat is a kind of velour, So I meant develops in a very certain way by the sun. The sun makes the heat from its hot flaming burn. And when you touch the sun, Bam! You get a burn.	2	9
Explaining how her senses can help her make an observation	Cause the temperature is touching my skin and that is how I know	1	4
Explaining the addition of the thermometer in the picture	It would like up <moves finger up from the bottom of drawn thermometer>, three steps would light up	2	4
Making a temperature comparison	Umm they are colder, it's colder over here because it is a higher temperature than the other ones, it's colder on	7	17

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
	this side than over there <points to shady side>		
Opposites	Away in its home <reaches out to his left> and the sun bumps up <makes upward motion with right hand as if holding a ball>	1	2
Extraneous	These were some extra codes to be able to indicate the interview number and	0	2627
Evaluating the interviewer	Do you even know how to work the camera?	1	1
Humor	Because sometimes I can read scientist.	1	1
Interview 1		6	632
Interview 2		7	857
Interview 3		10	1136
Feeling temperature	How the children discussed thermal sensation	20	268
Describing how the thermometer feels (temperature)	Well this is starting to get warm <touches the yellow thermometer> It's still pretty cold. And on the <touches ECT> the metal is still pretty cold even though it's not outside. I was very surprised.	1	4
Feeling a breeze	Oooh, I can feel the breeze	1	1
Feeling a just right temperature	Yeah, it feels just the right temperature so I would say I will take the stickers and then it will be one, two, three, four. <places one sticker for each number> So this is how it feels now. It feels just like this. <touches the stickers she just placed>	1	1
Feeling cold	Cold	19	35
Feeling colder and warmer	Colder and warmer	1	1
Feeling hot	Now hot	4	4
Feeling hot and cold	Now hot and a little bit cold	3	3

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Feeling shade	A little bit in the shade	1	1
Feeling warm	Well it feels warm.	5	6
Feeling warmer	It feels a lot warmer	2	2
Feeling wind	Yes <nods head up and down>	2	2
Interpreting temperature representations	The ways children made sense of the temperature representations	19	246
Appears to mix up inside and outside	This is the warm <puts hand over outside picture> ... this is the cold one <points to inside picture> 8	1	1
Appears to mix up sun and shade spots	Yeah, this one is warmer <points to the side with the short stack> and this one is colder <taps finger on tall stack side of picture>	1	2
Does not take up block representation	<looks for a bit, then shrugs shoulders>	1	1
Indicating temperature measurement change	Umm, this one changed. <picks up yellow thermometer> Because it was on 60 I think and now it is on 10	3	4
Indicating the color on the ECT	Because the green one <touches green 50 box on ECT> was here	3	4
Investigating the difference in temperature	<walks towards the sunny part of the yard> but when I go out into the sun, <runs back towards the shaded thermometer> let's see, let's bring the thermometer out <carries the shaded ECT into the sun> Let's see, what were we in the sun. <pushes button a few times>	1	1
Making sense of line plot	Then I think it is like the big, the buildings. <traces red line with finger>	5	16
Making sense of line	Hot	2	2

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
plot, color as indicator of temperature			
Making sense of map	I think here is where we live. <makes circular motion with finger around Utah> Like Utah <Points to TX> This is Texas, I just said it a little bit in Spanish	3	5
Making sense of map, blue as cold	Cold, cold, cold, cold, cold, cold <touches blue and green areas from CA to VA>	2	3
Making sense of map, color key	Cause these are lower <points with four fingers to purple through green> and these are higher <points with three fingers to yellow, orange, and red>	1	3
Making sense of map, green and blue as cold	<Touches green on scale and slides finger to green area on map maybe PA> Colder <touches several green spots and then blue spots> colder, colder colder.	1	1
Making sense of map, green as fine	That means the temperature is just perfect, but I don't know what that temperature is.	1	2
Making sense of map, red and yellow as hot	Red makes it hot.	3	7
Making sense of map, yellow as warm	yellow makes umm hot and warm makes warm.	1	3
Making sense of plot, pointing out geographic locations	It's showing all the different states. Like we live in Utah. And I am lucky cause I get to walk right across the street.	2	3
Making sense of the time ordered plot, color as an indicator as temperature	Cold <points to third blue stack> , coldest <points to second blue stack that is the tallest>, hotter <points to second yellow stack>, hotter <points to first yellow stack> and hot <points to green stack> cold a bit <points to the first blue stack>	1	2
Making sense of time ordered plot, color meaning for visual similarity	The sky <touches the blue stack she built for the first blue> I think	2	2

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
Making sense of time ordered plot, comparing heights	It changes sizes <touching individual bars of graph> and changes biggest <touching biggest> and changes smallest <touching second blue>	2	4
Making sense of time ordered plot, counting boxes	1 degrees <touching one blue>, 0 degrees <touching blank spot in between bars>, 2 degrees <touching two blue>, 4 degrees <touching 4 blue>, 6 degrees <counts the blocks with finger on 6 yellow>, 7 degrees <touching 7 yellow>, 5 degrees <touching green 5>, 3 degrees <touching blue>	2	2
Making sense of time ordered plot, higher mean higher temp	Higher <touches the top of the paper above the highest bar 7 yellow>	2	6
Making sense of time ordered plot, talking about events	Getting ready for bed <pointing to third blue>, go to sleep <points to last blue>	1	3
Making sense of time ordered plot, talking about parents	Because I know in the night my parents always tell it gets cold outside because of the tree	1	1
Making sense of time ordered plot, touching plot	This one is little <traces first blue> and this one is bigger <traces first yellow>. This one has three <points to the first blue> and this one <touches base of first yellow> has eight or seven	4	8
Making sense of time ordered plot, using blocks	I don't know. I am just broking it to do the same thing. <breaking up stack of blocks to make matching stacks to the picture>	1	2
Not taking up block stack temperature representation	<grimaces and shakes head left to right>	1	1
Noticing a change in temperature	No. It was 50 or 60, but now it is 50 or 40	1	3
Noticing an inconsistency or mix-up	No that has to be the shady side, cause the sun was shady. (Ryan's shadow is visible in the picture)	2	4
Predicting what the	I think it's going to be hotter.	6	19

Codes	Description for Categories of Process Codes and Examples for Individual Process Codes	Count of Files	Count of Instances
thermometer will read			
Reading numeracy assessment	Seven two, eighty, fourty one, sixty, fifty five, one hundred	6	12
Reading thermometer	I think it is 40 (ECT displays 50)	14	117
Thermometers for hot and for cold	So this one tell you hot <points to yellow thermometer> and this one tells you cold <points to blue thermometer>	1	2

Appendix E

Analytic Memos

Overview of Analytic Memos

Refinement and Use of Codes Over Time

In the following sections, I document my iterative process for answering my three research questions that are presented in Chapter IV and inferences drawn about the children's temperature conceptions in Chapter V. Later in this appendix, I include an analytic memo for each participant, but first I explain the process that necessitated the memos. The overall process involved a round of process coding, a round of thematic coding, categorization and refinement of the thematic codes, re-examining the process codes with the transcripts, and finally drafting the chapters.

I established the initial thematic codes for the things that stood out to me while examining the entire data corpus. These codes included: *Corporal, Depicting with visual similarity, Wind/air, Season, Cultural, Hot or cold body, Magnitude of hot or cold, Hot and cold as inverse properties, Normative temperature explanation*. In deciding how to proceed with my analysis, I realized that these codes did not necessarily align with my research questions. While *Corporal, Depicting with visual similarity, Wind/air, Season, Cultural, and Hot or cold body* began to address RQ 1, *Magnitude of hot or cold, Hot and cold as inverse properties, and Normative temperature explanation* were more interpretations of how the children were conceptualizing temperature. Additionally, RQ 2 and RQ 3 were not addressed in these thematic codes. To better address all three research questions, I developed analytic memos for each of the participants to systematically answer each research questions.

To begin the memos, I first categorized each of the process codes for a possible

connection to each of the research questions. In some cases, some of the research questions could apply to RQ 1 and RQ 2, but for the most part the process codes related to a single research question. This allowed me to list each process code presence for each research question by participant. Next, I examined the frequencies of counts looking for codes that were more frequent than 1 instance. Process codes with greater frequencies were then used to locate accompanying transcript segments that were then inserted into the memos. Based on the codes and the transcript segment, I then wrote explanation of how I made sense of the children's responses to the interviews.

For RQ1, this led to the identification of the themes for representing temperature as *symbols*, *colors*, and *effects on the human body*. Examples included Catherine using a symbol of the sun show that it was hot inside, Cheyanne's use of the color red to show hot because lava is red, and James's way of showing hotter with my body's response of sweating. Also, for RQ1, I developed themes of *Temperature Talk* as *Hot/cold body* and as *Process.*

For RQ2 and RQ 3, the process codes served more as markers for locating the parts of the interviews where the children interpreted the thermometers and temperature representations. The portions of the memos related to these research questions served as a place to evaluate the children's responses. In addition to the memos, I also summarized the responses into tables quantifying acceptable interpretations of the thermometers and representations found in Chapter IV.

The rest of this appendix contains the individual analytic memos for each participant.

Catherine

Research Question 1

How do kindergartners represent and talk about air temperature?

Looking at the codes below, I focus on the commenting, depicting, and explaining process codes to begin to answer RQ1.

Illustrations of Temperature

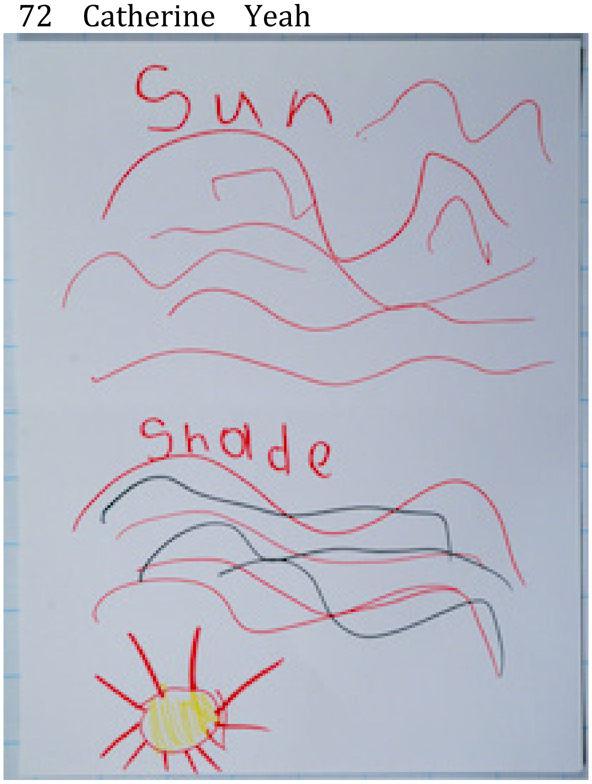
Catherine represents cold in her drawings with lines and warmth with the sun (see Figures 1, 2, and 3 below). This can be seen in the in the 8 instances of process code 31 : Depicting cold as lines and the 13 instances of process code 37 : Depicting hot with the sun below.

Process Code	Number of Instances
1 : Adding thermometer to the picture	6
20 : Commenting about shadiness	1
21 : Commenting about sunniness	1
22 : Commenting on the temperature	3
31 : Depicting cold as lines	8
34 : Depicting colder as less blocks in stack	1
35 : Depicting colder as more blocks	1
37 : Depicting hot with the sun	13
44 : Depicting shade as a mix of hot and cold	3
49 : Depicting warmer with increased stack of blocks	3
53 : Depicting with color as temperature, hotness, or coldness	5
54 : Depicting with color for visual similarity	5
63 : Describing how a hypothetical temperature would feel	1
75 : Explaining a difference between shade and sunny thermometers	4
81 : Explaining color choice with justification from literature	7
86 : Explaining illustration color	1
87 : Explaining illustration form	5
90 : Expressing preference for a sunniness	1
91 : Feeling temperature	6
94 : Feeling cold	2
96 : Feeling hot	2
97 : Feeling hot and cold	1
98 : Feeling shade	1

99 : Feeling warm	1
127 : Noticing a change in temperature	3

In interview 1 she indicates the lines represent cold.

X	Spkr	Transcript
61	Ryan	Do you mind if we *pushes paper flat on table* since I am videoing and I just want to be able to see. Can you point to me? Can you tell me about this top picture *points to top sunny picture* What's happening in this one?
62	Catherine	This is cold
63	Ryan	It's cold
64	Catherine	Yeah
65	Ryan	And can you tell me about the shade picture?
66	Catherine	Cold *points to wavy lines* and sunny *touches sun* mix together *moves both hands on picture in circular motion*
67	Ryan	Cold and sunny mix together?
68	Catherine	Yeah
69	Ryan	Which one do you think was warmer?
70	Catherine	*points to shade picture and taps it*
71	Ryan	This one in the shade
72	Catherine	Yeah

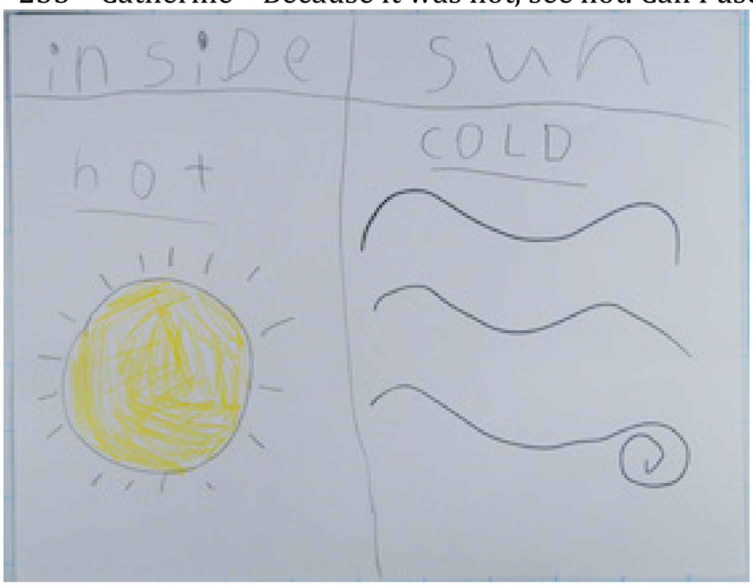


Interview 1 Illustration

In interview 2, she again shows cold with wavy lines and this time is more

explicit about how the sun represents warmth.

X	Spkr	Transcript
249	Catherine	It was hot here a little bit. I am going to spell hot. I know hot is H O T. I am going to put a sun for hot.
250	Ryan	Great
251	Catherine	You know, what are the lines on the sun for?
252	Ryan	I am not really sure. What do you think?
253	Catherine	I think because it is shining or something
254	Ryan	Yeah, and why did you pick to put a sun there?
255	Catherine	Because it was hot, see hot. Can I use a colored pencil?



Interview 2 Illustration

Interview 3 Illustration

Block and Color Representations of Temperature

In interview 1, Catherine readily adopts the stacking block method for showing warmth and cold. She uses orange and red blocks for representing warmth or hotness, and later suggests that yellow could also be “a hotter one.” She adds more blocks to show more warmth, as captured in three instances of code 49 : Depicting warmer with increased stack of blocks. This can be seen in the transcript. When it comes to the color of the blocks, she picks certain colors to represent certain things, such as the red, orange, yellow, and white as mentioned above, and green to represent grass and blue to represent sky. These are noted in codes 53 : Depicting with color as temperature, hotness, or coldness and 54 : Depicting with color for visual similarity.

X	Spkr	Transcript
83	Ryan	That’s ok. Sometimes people show temperature, can I show you a way? *grabs some blocks on floor*
84	Catherine	Oh yeah, I know. I know if it hot even warmer. *takes blocks from*

		bin Is this like this right now *places ready made stack of four orange blocks on desk* it can get more warm *takes ready made stack of 9 orange blocks and adds on top of short orange stack on desk* 'inaudible' *adds another ready made stack of four orange blocks to the top*
85	Ryan	So tell me what you just did to show me, you said it got more warmer. What did you do with the blocks?
86	Catherine	I put it taller and get pieces of orange.

She also uses the blocks to represent cold, choosing white ones.

X	Spkr	Transcript
107	Ryan	So which one is cold?
108	Catherine	Like, the white ones. *takes white blocks*
121	Ryan	Oh, OK. Anything else about cold or night?
122	Catherine	When it's night, it is really really cold
123	Ryan	Really really cold
124	Catherine	I would put more of *touches top of white block stack* You know white

Talking About Temperature

Catherine makes other connections in the discussion about air temperature, namely to how her mother told her that it gets very cold at night and how her color choices for depicting the sun are based in a children's book as noted in the code 81 : Explaining color choice with justification from literature.

X	Spkr	Transcript
452	Catherine	Oh *labels top of left side sun, draws sun in yellow* This one is the sun because it was hot *colors in sun with yellow pencil* You know why I am using yellow?
453	Ryan	How come?
454	Catherine	I am going to mix it with orange *colors in sun with orange pencil*
455	Ryan	How come you used that one?
456	Catherine	You know that the yellow and the orange fight because, *holds up orange pencil* I want to be in the sun!, No I want to be in the sun! *Big smile*
457	Ryan	Is that in the book The Day the Crayons Quit ?
458	Catherine	Yeah
459	Ryan	With Duncan
460	Catherine	Yeah, they were fighting like I wanna be in the sun, no I wanna be in the sun, I wanna be in the sun
461	Ryan	But you worked it out, you had a compromise there.
462	Catherine	Yeah, I did it a mix from yellow and orange, so they cannot fight

Research Question 2

How do kindergartners interpret the ECT as compared to commercially available thermometers?

Process Code	Number of Instances
1 : Adding thermometer to the picture	6
70 : Describing temp increase shown as higher line in thermometer	2
71 : Describing temp increase shown as lower line in thermometer	1
75 : Explaining a difference between shade and sunny thermometers	4
76 : Explaining a hypothetical temperature display	3
80 : Explaining change in temperature measurement	2
89 : Explaining the addition of the thermometer in the picture	3
103 : Indicating the color on the ECT	1
131 : Predicting what the thermometer will read	4
132 : Probing about color change on thermometer	1
133 : Reading numeracy assessment	1
134 : Recording temperature with blocks	5
135 : Referencing block representation	2
139 : Choosing thermometer to try	2
140 : Commenting on how to make the thermometer display a different temperature	1
141 : Describing attribute of a thermometer	6
147 : Expressing opinion about a thermometer	4
148 : Expressing preference of thermometer	4
150 : Indicating temperature measurement change	2
151 : Justifying preference of thermometer	1
152 : Reading thermometer	23

Fluency with Numbers and Thermometers

Catherine fluently reads thermometers. She was the only participant to read all of the six numbers on the numeracy assessment correctly. In addition, she was able to read all of the thermometers. These included the ECT, the classroom expansion thermometer, the pocket-sized thermometer, and the digital thermometer. She demonstrates an

understanding of how thermometers work after initiating a conversation of what it would take for the thermometer to be at the top of its scale. This is demonstrated in the code 76 : Explaining a hypothetical temperature display. In the transcript below, she explains how the temperature would be both at the highest and lowest parts of the temperature scale.

X	Spkr	Transcript
416	Catherine	And now it is to 30. *presses ECT button to confirm that her blocks stack is the same height as the display* Let's do something to get over here *points to the 110 deg box on ECT*
417	Ryan	What do you think we would have to do to get it over there?
418	Catherine	I don't know, get lots of blocks?
419	Ryan	Lot's of blocks? What would that mean if it was all the way up to there?
420	Catherine	That it is more hotter *places foot at top of block stack and motions up to the top off the ECT* but if it's more colder like more down *with palm facing down motions from the top of the thermometer down to the top of the block stack*
421	Ryan	How would that feel?
422	Catherine	Like really cold

Although Catherine might not need the ECT with her ability to read all the thermometers, she still expresses a preference for using it over the other thermometers. This is captured in the 4 instances of the 148 : Expressing preference of thermometer code and the 1 instance of the 151 : Justifying preference of thermometer code. Reasons for her preference include the ECT's size, that it's cool, and its lights.

X	Spkr	Transcript
194	Ryan	So which one did you say you would try if we put it right outside the door?
195	Catherine	I want to try this one *pushes button on ECT*
196	Ryan	How come?
197	Catherine	Because this one is really cool. I want to have one like this one.

Research Question 3

How do kindergartners interpret graphic representations of air temperature in

relation to the ECT?

Process Code	Number of Instances
105 : Making sense of line plot	5
107 : Making sense of map	3
116 : Making sense of time ordered plot, color meaning for visual similarity	1
117 : Making sense of time ordered plot, comparing heights	2
120 : Making sense of time ordered plot, talking about events	3
122 : Making sense of time ordered plot, touching plot	3
123 : Making sense of time ordered plot, using blocks	2
125 : Making a temperature comparison	2

After Ryan tries to compare the bar graph to how we recorded temperatures with the blocks and the ECT, Catherine does not make the connection to height representing the temperatures. Instead she interprets the 4 squares of blue by recreating it with blocks and saying it represents the sky. This is consistent with how she responded in interview one representing the sky, where both of these instances were coded as 54 : Depicting with color for visual similarity.

X	Spkr	Transcript
541	Ryan	Matching it, so if this is how we matched it with the thermometer outside, what do you think is happening here?
542	Catherine	When you woke up
543	Ryan	What was it like when I woke up?
544	Catherine	The sky *touches the blue stack she built for the first blue* I think
545	Ryan	How is when I woke up different from *points to first yellow* the afternoon?
546	Catherine	This one is little *traces first blue* and this one is bigger *traces first yellow*. This one has three *points to the first blue* and this one *touches base of first yellow* has eight or seven
547	Ryan	Yeah? And if those are showing temperature, how do you think it feels? Does it feel different at those times?
548	Catherine	Yeah
549	Ryan	How is it different?
550	Catherine	I don't know. I don't know how it is different.

While she notices the differences in heights (line 546), she does not make the connection with their representation of temperature when prompted. Said another way, the features of the graph are observable to her, but they do not represent temperature values. She has a potentially similar interpretation when looking at the line plot as visually similar to the tall buildings in the city.

X	Spkr	Transcript
553	Ryan	So here is one of them that scientists make. *shows temp line plot* What do you think that is showing about temperature?
554	Catherine	I don't know
555	Ryan	What do you think that line might mean?
556	Catherine	Like to another city.
557	Ryan	So this is for Ogden, this is for our city.
558	Catherine	Then I think it is like the big, the buildings. *traces red line with finger*

When looking at the weather map, she mainly attends to how is a map showing where we live. When prompted to attend to scale at the top by Ryan, she notices that the scale is the same as one on the ECT and verifies with the ECT and map on table.

Participant Summary

Catherine is able to recognize all the numbers displayed by thermometers and can accurately read all of them. She represents cold with lines (for wind) and warmth with the sun. She uses the sun to represent warmth even when representing an indoor observation. She has a preference for the ECT because it looks cool. She refers to shade a mix of sun and cold. She also makes an accurate prediction when going over the shade, predicting the exact number. When illustrating the sun, she justifies her choice of yellow and orange in reference to a dispute between the two crayons as to who is the true color of the sun in the children's book The Day the Crayons Quit (Daywalt & Jeffers, 2013).

Cheyanne

Research Question Process Codes

In this section of the memo, I have listed the codes that occurred for Cheyanne by research question. In some cases, codes may apply to more than one research question. These process codes were developed and applied in January and February of 2019.

Research Question 1

How do kindergartners represent and talk about air temperature?

Representing Temperature

Cheyanne represents coldness and hotness with the colors and symbols. She justifies her color choices for visual similarity to things objects that are usually hot or cold. Colors include blue, red, orange, and yellow. These are captured in the in the 9 instances of code 53 : Depicting with color as temperature, hotness, or coldness and the 10 instances of code 54 : Depicting with color for visual similarity. In addition, Cheyanne represents warmth with the sun and the moon for cold with a justification the the sun makes us warm and the moon makes us cold. This can be seen in few instances of the codes 37 : Depicting hot with the sun and 33 : Depicting cold with the moon.

Process Code	Number of Instances
1 : Adding thermometer to the picture	2
10 : Attributing cold to a lack of sun	5
13 : Attributing cold to the moon	9
14 : Attributing cold to the season winter	1
15 : Attributing cold to the wind	2
18 : Attributing warmth to the sun	3
32 : Depicting cold with blue blocks	1
33 : Depicting cold with the moon	1
35 : Depicting colder as more blocks	1
37 : Depicting hot with the sun	2
38 : Depicting hotter by removing blue sticker	3
40 : Depicting hotter with adititional red sticker or stickers	2
41 : Depicting hotter with orange blocks	1

48 : Depicting temperature with blocks	1
53 : Depicting with color as temperature, hotness, or coldness	9
54 : Depicting with color for visual similarity	10
60 : Describing a differnece in temperature between shade and sunny spots	1
63 : Describing how a hypothetical temperature would feel	3
68 : Describing wind	2
79 : Explaining cause or causes for the current temperature	4
91 : Feeling temperature	11
94 : Feeling cold	8
97 : Feeling hot and cold	2
100 : Feeling warmer	1
128 : Noticing an inconsitency or mixup	2

During interview 1 she explains the color choices of blue and red as representing water and fire. While the Image 1 below contains two red stickers, this was the final state of asking her to what it would look like if it were to get hotter and even hotter. At first, she removed the blue sticker, and then added a second red to show it even hotter.

X	Spkr	Transcript
2388	Cheyanne	*points to the red sticker then the blue sticker* Hot and water makes, fire and water makes cold and hot
2389	Ryan	Fire and water makes cold and hot, OK. Can you tell me which one is the water?
2390	Cheyanne	*places right index finger on blue sticker*
2391	Ryan	OK, the blue one. What does the red one mean?
2392	Cheyanne	*touches red one with index finger* Fire

Interview 1 Illustration

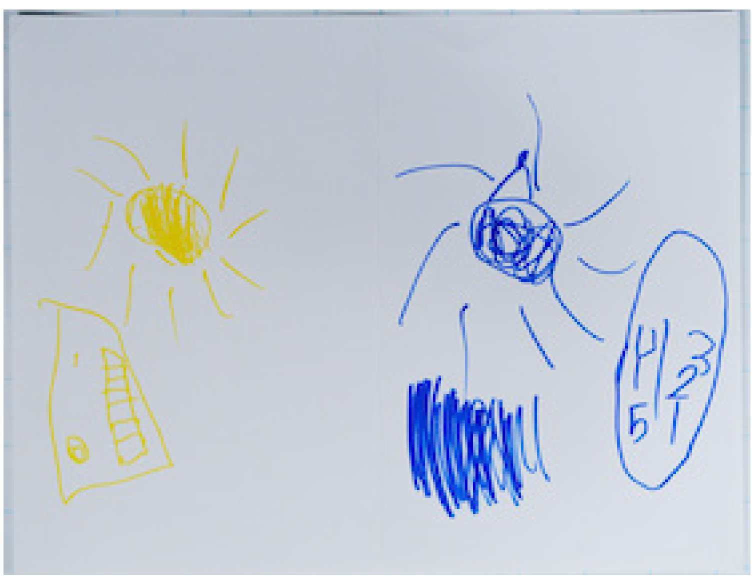
Later in interview 1, she uses orange and blue blocks for representing the difference between an area outside in the shade and an area in the sun.

X	Spkr	Transcript
2468	Ryan	So tell me what you are showing.
2469	Cheyanne	It's hotter *points to orange block side* than cold *points to the blue block side*
2470	Ryan	OK, Why? Why did you choose to use the blocks that you used? Tell me about what the difference is between the blocks.
2471	Cheyanne	Cold would usually be just ice which is blue
2472	Ryan	Oh OK, yeah. How about the other side?
2473	Cheyanne	*places hand on mouth and then opens eyes wide* Lava is orange *places index finger on orange blocks* and lava is hot

During interview 2 she represents how the temperature feels by drawing the moon. Unfortunately I lost her drawing, so it is shared as screen grab from the video of the interview below.

Interview 2 Illustration

In interview 3, she draws the sunny side of the yard with a yellow sun and the shady side of the yard with a blue sun. In addition to the illustration, she had stacks of blocks that we used outside to record what the thermometers were showing. These are discussed further under RQ 2.



Interview 3 Illustration

X	Spkr	Transcript
2641	Ryan	So tell me about these parts of the picture, what am I looking at?
2642	Cheyanne	The suns hot *lifts yellow stack on sunny side*
2643	Ryan	The suns hot. OK
2644	Cheyanne	And this one's just cold so I drew it blue.

2645	Ryan	Why did you choose to do it that way?
2646	Cheyanne	Cause cold's usually blue

Temperature Talk

When discussing how the temperature feels, Cheyanne attributes warmth to the sun and cold to the moon and wind. This appears as follows in the process codes: 9 instances of 13 : Attributing cold to the moon 9, 5 instances of 10 : Attributing cold to a lack of sun 5, 3 instances of 18 : Attributing warmth to the sun, 2 instances of 15 : Attributing cold to the wind, and 1 instance of 14 : Attributing cold to the season winter. At the start of interview 1, Cheyanne indicates that it is cold because the sun is being blocked.

X	Spkr	Transcript
2365	Ryan	How does it feel out here?
2366	Cheyanne	Cold hot
2367	Ryan	Cold and what else?
2368	Cheyanne	Hot
2369	Ryan	Cold and hot. Tell me how come?
2370	Cheyanne	Because the sun is barely out and more clouds are covering it.

Several of the codes can be seen in the except of the transcript from interview 2.

X	Spkr	Transcript
2479	Ryan	Yeah, we went outside. Do you remember how it felt out there?
2480	Cheyanne	*nods head up and down* Cold and hot
2481	Ryan	Cold and hot, do you remember what made it cold and what made it hot?
2482	Cheyanne	It is almost winter and the wind blows. And the sun makes us warmer

Line 2482 is packed with three notable temperature talk items. She is associating the coldness with the approaching season of winter and the wind that is blowing, but also that that there is some warmth provided by the sun. In both of the above excerpts Cheyanne talks about temperature as a combination of hot and cold, or in her words from

line 2366, “cold hot.” This hot and cold continues into RQ 2.

Research Question 2

How do kindergartners interpret the ECT as compared to commercially available thermometers?

The process codes for this question mainly reflect the interview questions. While I did review the transcript for codes 78, 79, 131, 145, and 149, these are direct responses to my interview questions not contributing to answering RQ 2. Instead I share transcript excerpts that better speak to the research question.

Process Code	Number of Instances
1 : Adding thermometer to the picture	2
78 : Explaining cause of a hypothetical temperature	2
79 : Explaining cause or causes for the current temperature	4
103 : Indicating the color on the ECT	2
131 : Predicting what the thermometer will read	3
133 : Reading numeracy assessment	1
134 : Recording temperature with blocks	2
138 : Asking questions about thermomer	1
141 : Describing attribute of a themometer	2
145 : Explaining what a thermometer does	2
149 : Identifies themometer	2
152 : Reading thermometer	12
153 : Thermometers for hot and for cold	2

Fluency with Numbers and Thermometers

Cheyanne is able to approximately read the ECT with only being instructed to hit the button. She was able to correctly read 58% of the numbers correctly on the numeracy assessment putting her near the average for the study of 59.5%. Upon looking at the thermometers, she identifies them as “fermometers” after I told her they are used for measuring how hot it is outside. Although she does not read the numbers correctly on the scale of the ECT, she does identify how far the line is illuminated by the number below the highest box on line 2513.

When I showed her the Classroom (yellow) and pocket (blue) thermometers, she

expected them to measure hot and cold separately because of the color of the liquid inside of them, red and blue respectively, line 2516. This color association is consistent with her earlier responses analyzed for RQ1.

Cheyanne is unable to read the Classroom thermometer during interview 2, expecting it to have a button like the ECT. When I asked her how far the red the red line went in the Classroom thermometer, she pointed to the top at about 100°F on line 2525. In interview 3, she is able to read the Classroom thermometer when it is at 0°C on line 2602.

X	Spkr	Transcript
2513	Cheyanne	*hit button* (ECT displays 70) *points to 60* sixteen
2514	Ryan	Sixteen, how about this thermometer? *points to yellow thermometer* Is that telling you the temperature right now?
2515	Cheyanne	*shakes head left to right*
2516	Ryan	No? So the way these two thermometers work, they have a little line in them. *picks up both yellow and blue thermometers* This one has a red line in it. *yellow* This one has a blue line in it.
2517	Cheyanne	So this one tell you hot *points to yellow thermometer* and this one tells you cold *points to blue thermometer*
2518	Ryan	Why do you think that?
2519	Cheyanne	Cause hot would usually be red and cold would usually be blue
2520	Ryan	So this has the blue line *holds up blue thermometer* and this has the red line *holds up the yellow thermometer* So they both can tell us hot and cold. Do you know how they do that?
2521	Cheyanne	*nods head up and down*
2522	Ryan	Can you tell me?
2523	Cheyanne	You press this. *presses bottom circle at the base of the yellow thermometer*
2524	Ryan	So this one it is not a button, but that is where it senses the temperature. Can you see how far that red line is?
2525	Cheyanne	*points toward the top 100 degrees* (yellow thermometer reads around 70)

X	Spkr	Transcript
2601	Ryan	Perfect, we are going to save this so we know how to make our picture when we go inside. What does the temperature say on the yellow one? *Touches yellow thermometer*

2602	Cheyanne	Zero, points to thermometer

Recording Values From the ECT

In interview 3, Cheyanne mixes up the block stacks when attempts to place them on the illustration of taking the temperature in the sun and in the shade. Instead of placing the taller stack on the sunny side of the illustration, she chose to go for visual similarity. That is, the short stack was yellow so it goes on the side with the yellow colored sun and the tall stack goes on the blue side with the blue colored sun, as seen in the image and transcript excerpt below.

Interview 3 Illustration with Block Representations

X	Spkr	Transcript
2639	Ryan	Can you put the blocks on the side that they go with?
2640	Cheyanne	*places yellow stack on side with yellow sun, places taller stack on side with blue patch and blue sun*
2641	Ryan	So tell me about these parts of the picture, what am I looking at?
2642	Cheyanne	The suns hot *lifts yellow stack on sunny side*
2643	Ryan	The suns hot. OK
2644	Cheyanne	And this one's just cold so I drew it blue.
2645	Ryan	Why did you choose to do it that way?
2646	Cheyanne	Cause cold's usually blue

Research Question 3

How do kindergartners interpret graphic representations of air temperature in relation to the ECT?

Cheyanne interprets all three of the temperature representations (bar graph, line

plot, and weather map) according to color. This can be seen in the codes above, 106, 108, 112, and 115.

Process Code	Number of Instances
106 : Making sense of line plot, color as indicator of temperature	1
108 : Making sense of map, blue as cold	1
112 : Making sense of map, red and yellow as hot	1
115 : Making sense of the time ordered plot, color as an indicator as temperature	2
122 : Making sense of time ordered plot, touching plot	1
125 : Making a temperature comparison	1
126 : Not taking up block stack temperature representation	1

When interpreting the bar graph, she touches each bar indicating hotness or coldness.

X	Spkr	Transcript
2674	Cheyanne	Cold *points to third blue stack*, coldest *points to second blue stack that is the tallest*, hotter *points to second yellow stack*, hotter *points to first yellow stack* and hot *points to green stack* cold a bit *points to the first blue stack*
2675	Ryan	How did you know that?
2676	Cheyanne	Cause this is blue, this is green, this is yellow, this is yellow, this is blue, this is blue, this is blue *touching each one as she says the color*

She responds in a similar fashion with the line plot indicating that it is hot since the line itself is red.

X	Spkr	Transcript
2683	Ryan	OK, My next questions is, sometimes scientists make pictures to show the temperature. So I want to show you two pictures that scientists make. And I want you to tell me if these pictures tell you anything? *shows temperature plot*
2684	Cheyanne	*rolls eyes and then shakes head left to right*
2685	Ryan	No, do you know what that line might be showing?
2686	Cheyanne	Hot
2687	Ryan	Hot, how come? How did you know that?
2688	Cheyanne	It’s red

And again for the weather map, but this time commenting on green as cold.

X	Spkr	Transcript
2689	Ryan	Ohhh, how about this picture? *shows temperature map* This is a map.
2690	Cheyanne	States.
2691	Ryan	States, yeah. Can you tell me, and this is also a way scientists show temperature, can you tell me anything about the temperature in that picture?
2692	Cheyanne	Cold, cold, cold, cold, cold, cold *touches blue and green areas from CA to VA* hot, hot *touches red TX and yellow to the east of TX*
2693	Ryan	How did you know that?
2694	Cheyanne	Cause cold is blue, cold is blue, cold is also purple.
2695	Ryan	And how about the other areas that you pointed too?
2696	Cheyanne	Hot is red and yellow is usually a little bit red

<u>Outside RQ Codes</u>

What are some noteworthy instances outside of the research questions?

Process Code	Number of Instances
73 : Evaluating the interviewer	1

This is interesting because it captures her skepticism of me.

X	Spkr	Transcript
2358	Cheyanne	Do you even know how to work the camera?

Participant Summary

Cheyanne talks about temperature in terms of hot and cold bodies, representing hot as red and blue as cold. She justifies this color choice as red representing fire and blue representing water. When visualizing the shade and sunny spots in interview 1, she placed a single blue sticker for the shaded area and a single red for the sunny area. When asked to how to show warmer, she removed the single blue sticker and added a second red to show even hotter. When presented with stacks of blocks as a way to show increasing temperature, she does not take it up in conversation. Other references to hot and cold objects include referring to proximity to the dessert, the sun, and the moon. She

often refers to the sun when talking about hot and the moon when talking about cold. These ways of talking about contrasting temperatures persist despite the moon not being visible during any of the observations. In terms of color, she picks justifies choices with visual similarity. This includes using orange blocks for warmth being similar to lava and blues ones for looking like ice. She is able to read the yellow thermometer and the ECT, making errors with reading the double-digit numbers and referring to the ECT measure 10 degrees below the actual (the bottom of the box as opposed to the top). In interview 3 she mixes up the block stacks, possibly due to the fact the yellow small stack is visually similar to the yellow sun she drew on the warm side.

Erica

Erica demonstrated exhibited the widest range of codes as compared to the other participants. This may be indicative of her inclination to engage in conversation.

Research Question 1

How do kindergartners understand, talk about, and show air temperature?

Representing Temperature

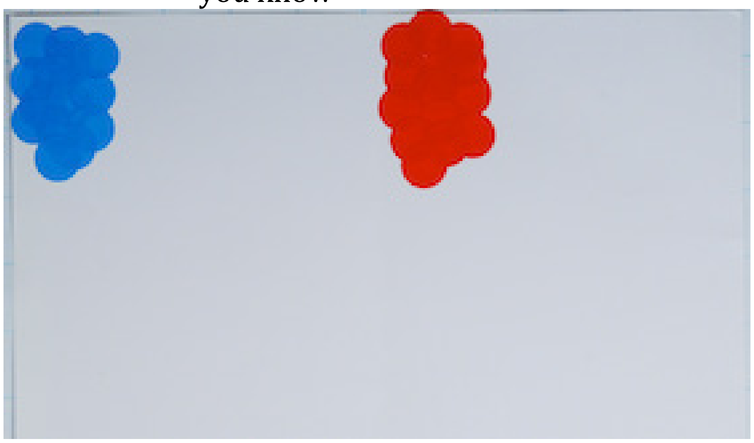
Process Code	Number of Instances
1 : Adding thermometer to the picture	5
4 : Anologizing cold as snow	1
5 : Anologizing the sun with fire.	1
9 : Attributing cold as night	1
10 : Attributing cold to a lack of sun	3
12 : Attributing cold to shade	2
14 : Attributing cold to the season winter	3
17 : Attributing warmth to lack of shade	1
18 : Attributing warmth to the sun	5
22 : Commenting on the temperature	1
23 : Corpreal	5
28 : Depicing hotter with more blocks	2
34 : Depicting colder as less blocks in stack	3
36 : Depicting colder as more blue stickers	2
40 : Depicting hotter with aditional red sticker or stickers	5

45 : Depicting snow	1
47 : Depicting temperature as just right	1
49 : Depicting warmer with increased stack of blocks	1
50 : Depicting weather as fall	4
51 : Depicting weather as summer	5
53 : Depicting with color as temperature, hotness, or coldness	14
54 : Depicting with color for visual similarity	1
58 : Descibing how to dress for certain temperature	1
60 : Describing a differnece in temperature between shade and sunny spots	2
66 : Describing temperature as dropping below	2
67 : Describing temperature as up	1
69 : Descriping ice	2
74 : Explaining a change in temperature	1
83 : Explaining heat	9
84 : Explaining how her senses can help her make an observation	4
91 : Feeling temperature	10
92 : Feeling a breeze	1
93 : Feeling a just right temperature	1
94 : Feeling cold	6
99 : Feeling warm	1
100 : Feeling warmer	1
128 : Noticing an inconsitency or mixup	2

Erica represents air temperature with the colors blue and red using colored stickers and markers. This stands out with 14 instances of the code 53: Depicting with color as temperature, hotness, or coldness. She represents a colder with more blue stickers and hotter with more red stickers as captured in the codes 36: Depicting colder as more blue stickers and 40: Depicting hotter with additional red sticker or stickers.

X	Spkr	Transcript
668	Ryan	Alright, yeah. Let’s pretend we went back outside after lunch, and it got hotter in the sun. How would you show that the sunny spot got higher?
669	Erica	*grabs sticker sheet and adds sixl more red stickers* When hot spots get hotter, they want to make a bigger spot. That’s how it looks. *touching larger red spot.
670	Ryan	That’s how it looks?

671 Erica That's how it looks when it's getting even hotter.
672 Ryan Now what if it got even hotter than that?
673 Erica That will allow even more *adds four more red stickers* sun and heat
674 Ryan Tell me more, what is sun and what is heat?
675 Erica Well the temperature of the heat means that it is getting bigger *makes gesture with both hands with fingers spread out* and warmer, you know



Interview 1 Illustration

In addition to the stickers, Erica uses colors to represent seasons and pairs them with the colors she deems appropriate. In the image below, green represents the leaves in summer and is next to the red drawing. She also puts orange for the leaves in fall next to the blue. This is picked up in the codes 50: Depicting weather as fall, 51: Depicting weather as summer, and 54: Depicting with color for visual similarity.

Interview 2 Illustration

X	Spkr	Transcript
837	Erica	Well, *continues to draw with the blue* when temperature is up high with the hots *opens red marker and begins drawing* I know, my skin is telling me that it is daytime
838	Ryan	Daytime
839	Erica	And it's not fall or it's not winter, or fall, but it's summer.
840	Ryan	So is that summer in that part of the picture?
841	Erica	Yeah
842	Ryan	Anything else I should know about your picture?
843	Erica	Well, when cold is just dropping down below *touching blue part of the picture* it starts like this, but when *touching red part of picture* the hot is up full degrees it goes to all the way up here *points to the top of the red part of the picture*
844	Ryan	Oh so is that, so what are you drawing there?
845	Erica	So I know weather, that's the time that the leafs are there *starts coloring with green marker* and the trees and the time when the leaves are falling, they come in reds, browns or orange. This is how you know the weather. *draws some orange dots over the blue par of the picture* You see how the leaves are dropping? That's how I can tell weather.

Here I start to notice how Erica's talk about seasons, daytime, and temperature may suggest that her conception of time is a bit more fluid with overlapping scales (months for season, daytime and nighttime).

In her final interview she depicted the sunny side with red as the hot side and with blue for the shady side showing that it was cold. After being asked to add the thermometers, she adds a expansion thermometer to the hot side that is all the way to the top and an ECT on the shady side with only 4 boxes.

It is interesting to note here that when the she drew the expansion thermometer, she drew the line with tick marks, but with the ECT she drew the boxes. This is consistent with all of the participants. For James, it is not visible in the artifact, but you can see him adding it in the video

Interview 3 Illustration

X	Spkr	Transcript
1058	Erica	I would show with this thermometer, *draws in dots hot thermometer* that it is all the way up, that's how I would show it *puts line in on hot thermometer
1059	Ryan	How would you show the other one?
1060	Erica	I would show it *draws with red on the cold thermometer* like that
1061	Ryan	Can you compare those two thermometers? Can you tell me what they are both saying?
1062	Erica	I have to get back to class.
1063	Ryan	Is it OK if you stay with me a little longer, I have a few more questions?
1064	Erica	Yeah, I would just worry they would leave me
1065	Ryan	They are not going to leave. We will make sure to take you if they leave. So could you compare the two thermometers for me?
1066	Erica	This one is in the cold *drawing with a colored pencil on the cold thermometer*
1067	Ryan	And what's it showing us?
1068	Erica	That it's cold.
1069	Ryan	And how does it do that?
1070	Erica	Like, how it is showing 4 *points to cold* and this one *points to hot* is showing all the way up

Temperature Talk

When talking about temperature, Erica demonstrates a variety of discussing temperature. These include references to: day/night and seasons temperature differences, temperatures dropping and going up, what clothing to wear for certain weather, how her skin senses temperature, and how heat is a process. These are captured across many codes and demonstrate a the most varied repertoire of temperature talk amongst the participants.

When describing how room temperature feels after returning from the cold outdoors indicates that she is feeling a just right temperature. This is interesting because she comes to the definition of room temperature on her own. From Wikipedia, "Colloquially, room temperature is the range of air temperatures that most people prefer for indoor settings, which feel comfortable when wearing typical indoor clothing." This is one example of Erica's redundancy to engage in thoughtful and reflective conversation about the temperature.

X	Spkr	Transcript
861	Ryan	Does it feel different now that we are inside?
862	Erica	Yeah, it feels just the right temperature so I would say I will take the stickers and then it will will be one, two, three, four. *places one sticker for each number* So this is how it feels now. It feels just like this. *touches the stickers she just placed*

In another instance where Erica talks about temperature in terms how it feels, she is more explicit about how her skin senses temperature.

X	Spkr	Transcript
724	Erica	When the sun is shining, I know that it is hot. When the sun is not shining, I know that it is cold.
725	Ryan	How did you know that?
726	Erica	Well, I know weathers
727	Ryan	How did you learn the weather?
728	Erica	Well, when I feel the snow on my hands. My hands tell me an observation. And that means, and that is how I know, that's how I can know that it is cold. When the sun is shining, it heat gathers onto

my skin and that's how I know it is hot.

Also of interest in this quote on line 728, where Erica starts to explain heat. Here she talks about heat gathering on her skin. As heat was central to this study, I encouraged her during the interviews to explain heat. This is one of 9 instances of the code 83 : Explaining heat. Consistent with the above instance, she describes heat with actions: getting bigger, develops, forms, and getting hotter.

X	Spkr	Transcript
677	Erica	Well, when you see that this side is still cold and the same temperature *makes circular motion with finger on blue spot*, and this side is even hotter *makes circular motion on red spot with two fingers*
678	Ryan	It's even hotter. So what is heat?
679	Erica	So heat is a kind of velour, So I meant develops in a very certain way by the sun. The sun makes the heat from its hot flaming burn. And when you touch the sun, Bam! You get a burn.
680	Ryan	Yeah, what are some other things that have heat? Can you think of other things?
681	Erica	Well, like when the sun shines down on something, like that forms heat, the sun develops to make more more heat. *makes expanding motion with both hands* Like, isn't that cool?

Research Question 2

How do kindergartners interpret the ECT as compared to commercially available thermometers?

Erica recognizes the thermometers as measurers for determining how cold or how hot it is. She is able to read all of the thermometers, including the ECT within 10 degrees (reads the number below the highest box) the Classroom, pocket metric, and digital thermometers.

The process codes show how Erica not only recognizes the function of thermometers with codes and 149 : Identifies thermometer, 145 : Explaining what a thermometer does, but also is familiar with what the scale represents on the ECT and Classroom thermometer appearing in codes: 67 : Describing temperature as up, 67 :

Describing temperature as up, 70 : Describing temp increase shown as higher line in thermometer, 142 : Describing how the thermometer works, and 144 : Describing low end of thermometer as cold.

Process Code	Number of Instances
1 : Adding thermometer to the picture	5
66 : Describing temperature as dropping below	2
67 : Describing temperature as up	1
70 : Describing temp increase shown as higher line in thermometer	1
74 : Explaining a change in temperature	1
85 : Explaining how more blocks shows hotter part of temperature comparison	1
88 : Explaining illustration of thermometer	2
133 : Reading numeracy assessment	1
134 : Recording temperature with blocks	6
142 : Describing how the thermometer works	1
143 : Describing how the thermometer feels (temperature)	4
144 : Describing low end of thermometer as cold	1
145 : Explaining what a thermometer does	2
146 : Exploring the thermometer	4
147 : Expressing opinion about a thermometer	3
148 : Expressing preference of thermometer	4
149 : Identifies thermometer	1
152 : Reading thermometer	32

The following section of transcript demonstrates her identification and explanation of thermometers.

X	Spkr	Transcript
730	Erica	I know what these are.
731	Ryan	What are they?
732	Erica	They're measurers
733	Ryan	Measurers, yeah. What do they measure?
734	Erica	They measure temperature and degrees.
734	Erica	They measure temperature and degrees.
735	Ryan	Temperature and degrees. Oh yeah, you are correct. Why do you think you might want to measure temperature
736	Erica	So I know that what degrees it is.
737	Ryan	Oh, so you know what degrees it is. OK, what is measurement? What does it mean to measure something?

738	Erica	It means to measure how cold it is or how hot it is.

This excerpt shows how she understands the range of the thermometer.

X	Spkr	Transcript
784	Erica	There is a little center right there and then *touches bulb and then motions all the way to the top of the yellow thermometer* It hits right here *finger at top of yellow thermometer* That's how we can tell that it is really hot, or if it hits right here it is really cold *pointing to about -40 deg on yellow thermometer*
784	Erica	There is a little center right there and then *touches bulb and then motions all the way to the top of the yellow thermometer* It hits right here *finger at top of yellow thermometer* That's how we can tell that it is really hot, or if it hits right here it is really cold *pointing to about -40 deg on yellow thermometer*
785	Ryan	OK, if it is up here its? *points to top of yellow thermometer*
786	Erica	Really hot
787	Ryan	And if it is down here? *points to bottom of yellow thermometer*
788	Erica	It hits to really cold

Research Question 3

How do kindergartners interpret graphic representations of air temperature in relation to the ECT?

For the bar graph, Erica interprets blue and yellow colors as temperature, but does not make sense of the line plot or the weather map in terms of temperature. For the line plot, she reads one of the temperatures that is labeled, but then talks about how it goes to South America. For the weather map, she mainly points out her ideas of geographic locations. After I asked her to compare two areas of the map, she indicates that the blue areas are water and that red represents lava.

Process Code	Number of Instances
105 : Making sense of line plot	2
114 : Making sense of plot, pointing out geographic locations	2
118 : Making sense of time ordered plot, counting boxes	1
119 : Making sense of time ordered plot, higher mean higher temp	3
124 : Investigating the difference in temperature	1

125 : Making a temperature comparison	6

Here is an excerpt of Erica making sense of the weather map after being explicitly prompted to discuss temperature.

X	Spkr	Transcript
1137	Erica	This is actually self of the United States, and it's cold. *pointing to US-Canada border* Utah of the America and that's where alligators used to live back with the dinosaurs
1138	Ryan	How about are the colors showing us anything?
1139	Erica	This is water *points to blue off the coast of CA* This is lava *points to red TX*
1140	Ryan	Why do you say it's lava?
1141	Erica	Cause it is red and actually red is my favorite color.
1142	Ryan	How about up here? *points to PA*
1143	Erica	It's showing us that salt water fish live there.
1144	Ryan	How come you say that?
1145	Erica	Cause I know that salt water fish live there and I have caught salt water crayfish there. I have caught an enormous one.

James

Research Question 1

How do kindergartners show and talk about air temperature?

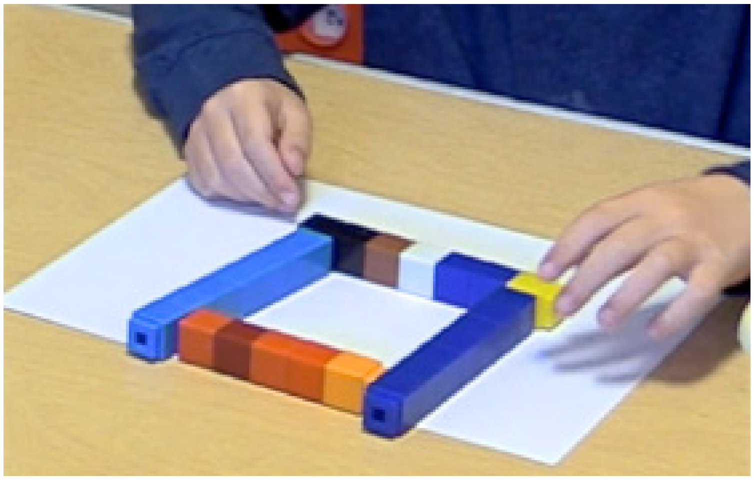
Representing Temperature

James depicts temperature with colors that are visually similar to things such as ice as blue and the sun as yellow. This appears in the process codes 30 through 57 on the list below. During the process coding, I created a more inclusive code that captures depicting with color as temperature, hotness or, coldness, for which James has 13 instances of depicting with color as temperature, hotness, or coldness.

Process Code	Number of Instances
1 : Adding thermometer to the picture	3
2 : Agrees with a short stack of blocks as cold and a high stack as warmer	1
3 : Adopting introduced block representation instead of thier own	1
11 : Attributing cold to cold air	1

12 : Attributing cold to shade	1
14 : Attributing cold to the season winter	2
15 : Attributing cold to the wind	4
18 : Attributing warmth to the sun	6
19 : Attributing wind to trees	1
29 : Depicting a progression of temperature change	1
30 : Depicting cold as ice	2
32 : Depicting cold with blue blocks	1
37 : Depicting hot with the sun	1
41 : Depicting hotter with orange blocks	1
42 : Depicting ice with multiple colors	1
43 : Depicting mixing of warm and hot with two colors	3
46 : Depicting sun with yellow and other colors	2
49 : Depicting warmer with increased stack of blocks	2
52 : Depicting wind	2
53 : Depicting with color as temperature, hotness, or coldness	13
54 : Depicting with color for visual similarity	4
57 : Depicting warmer as red and brown	1
59 : Describes temperature at night	1
62 : Describing attributes of winter	2
63 : Describing how a hypothetical temperature would feel	2
64 : Describing recalled hot or cold observations	2
77 : Explaining a mixing of hotness and coldness	4
86 : Explaining illustration color	5
91 : Feeling temperature	10
94 : Feeling cold	8
99 : Feeling warm	1
101 : Feeling wind	1
154 : wind	1

During interview 1, James decided to use blocks to represent how it felt outside. He creates a block of ice using blue blocks for two of the four sides as seen in the screen-capture from the video below.



Interview 1a Illustration

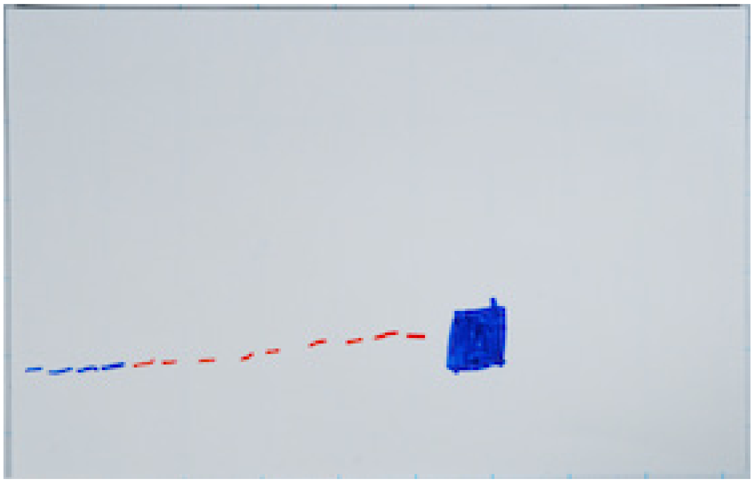
When I asked him how he could change his representation to show if it were to get warmer outside, he decided to make a sun.

X	Spkr	Transcript
1983	Ryan	How about during the day today, it starts to warm up. How could we change your picture to show it's getting warmer?
1984	James	I'll make the sun.
1985	Ryan	And how will you make the sun?
1986	James	A circle, some stripes on the outside, and a little yellow on the inside.

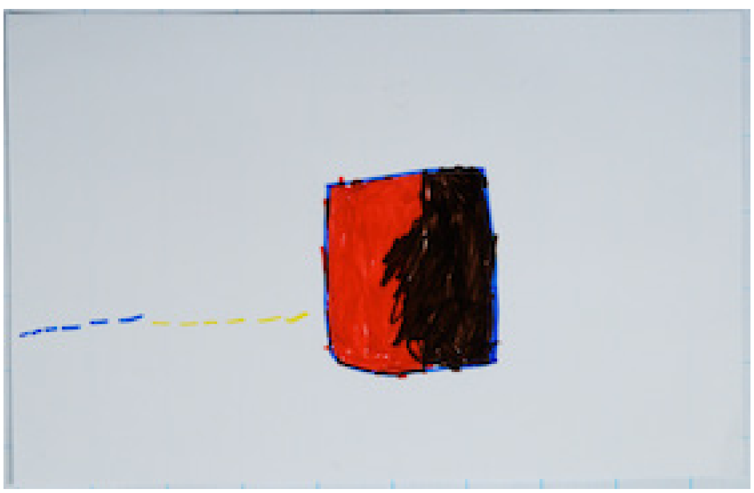
Noting the limitations of the blocks for making a sun, he makes a triangle shape with yellow, orange, brown, and blue blocks.

Interview 1b Illustration

In interview 2, James makes two pictures to compare the temperature outside to temperature inside the school. He draws a blue box to show cold and red and brown box to show a mix of hot and warm.



Interview 2a Illustration



Interview 2b Illustration

X	Spkr	Transcript
2132	Ryan	This should be a picture of outside, of what the temperature feels like outside.
2133	James	OK *draws with blue marker, then looks at r*
2134	Ryan	Can you tell me about your picture?
2135	James	It's a square full of the air outside or how cold it is, and actually makes it really cold outside, so it feels like it's winter and it's almost winter time, so it feels like it's winter outside.
2136	Ryan	And what's winter like?

2137	James	Cold
2138	Ryan	How about if I gave you another paper and we say it's inside. Can you show me what it's like inside, the temperature?
2139	James	Yes, I can *take outs red blue, brown, and orange markers, draws blue outline, colors in with brown and red
2140	Ryan	What can you tell me about that?
2141	James	So this is a giant square, showing how warm and hot it is in here at the same time in here, so it shows how hot and warm it is at all times.
2142	Ryan	Can you show me and tell me about the parts of that picture?
2143	James	So this is *touches brown* warm and that's *touches red* hot, so it makes it warm in the inside

In interview 3, James represents the shaded side of the yard with lines showing wind, a yellow sun, and blue people (Ryan and James). For the sunny side of the yard, he includes the yellow sun but the people are red.

Interview 3 Illustration

In the below transcript excerpt, I have removed a few lines where James talks about who the people are in the picture for brevity.

X	Spkr	Transcript
2249	James	*Draws blue people on blue stack side* There
2250	Ryan	Nice, so what it this side? *points to the blue people*
2251	James	Cold

2252	Ryan	And are you going to make a picture on the other side?
2253	James	I need to make a bit of lines on this side too
2254	Ryan	Sure
2255	James	For like wind *draws short lines above and below the people he just drew* There
2256	Ryan	What do those lines mean?
2257	James	Wind, they get bigger and bigger cause that means the wind is coming slowly and faster
2258	Ryan	And what does the wind do to you?
2259	James	It makes you cold
2271	James	And I am making me like I am hot, and I am hot outside *works on people with red marker* There *looks at r*
2272	Ryan	So what is different about these two pictures?
2273	James	Because it's blue and red for cold and hot
2274	Ryan	Why did you pick those?
2275	James	Because that is the color of cold and hot.
2276	Ryan	Which one is the one for cold?
2277	James	*places marker on blue drawing*
2278	Ryan	What color?
2279	James	Blue
2280	Ryan	And for red is?
2281	James	*hits red picture with marker* Hot

While outside measuring the temperature, he used blue blocks to record the temperature off the ECT in the shade and red in the sunny location. These two block stacks served as a starting point for the image above.


Interview 3 Illustration Process

In addition to making the representations in interview 1 for the the block of ice and the sun, James readily took up the convention of representing temperatures with stacks of blocks. After I showed him two stacks of blocks of different heights and told him the taller one was hot and the shorter one was cold, he used this approach to show me the depiction of what his sun looked like instead of the triangle. It is noteworthy that he shows three temperatures as compared to my one, and then shows a forth one being even hotter when prompted.

X	Spkr	Transcript
2024	James	I am going to make it hot. *Makes a tall stack of orange blocks* So this one is the hot. And this one is the, this one's warm *places a smaller orange stack*, and this on is cold *places an even smaller stack of orange*
2025	Ryan	Hmm, and how are they different?
2026	James	Because they are smaller every time they get warmer and colder, they get smaller and bigger.
2027	Ryan	That is a nice way of showing it.
2028	James	And it kind of looks like stairs too.
2029	Ryan	It does look like stairs, let's say it got even hotter. How would you show that?
2030	James	*places both the medium and small stacks on top of the large orange stack*
2031	Ryan	How do you think that will feel?
2032	James	Really hot
2033	Ryan	Really hot, can you think of a time that you felt it was really hot?
2034	James	I was playing outside with my friends and got really hot and needed to go to my house and get some water and it kinda cooled me down a bit

Temperature Talk

When discussing temperature, James associates coldness with winter, ice, and wind. For hotness, he talks about the sun and about being very hot when playing outside. In the transcript above on lines 2024-2028, James talks about how the steps represent hot, warm, and cold. This is interesting because all of the blocks are orange. I interpret this

talk to show that he is thinking about temperature on a single scale as opposed to his other representations where cold and hot were blue and red respectively. Although this was only present in interview 1, it may indicate that he is amenable to this way of showing temperature.

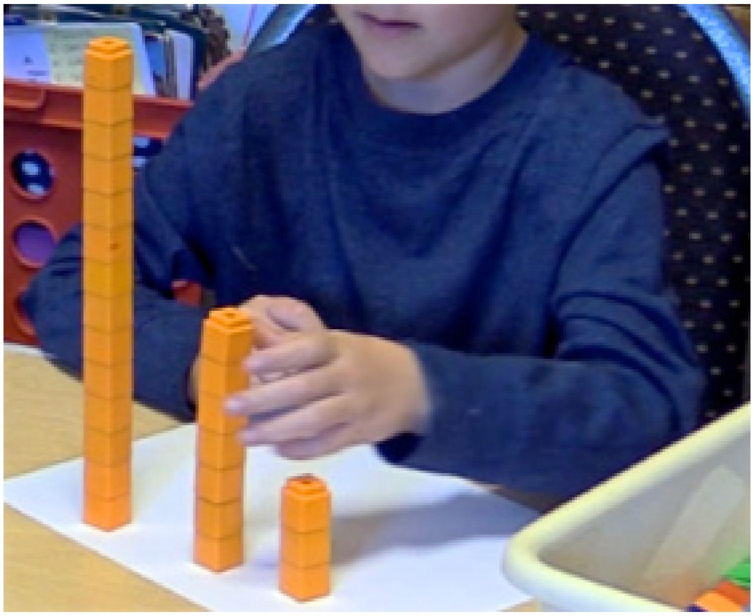
James talks about room temperature as a mix of warm and hot as he explains the Illustration 2b and line 2143 above.

When asked about what happens to the temperature at night in interview 1, James responds that it gets cold due to the wind.

X	Spkr	Transcript
2007	Ryan	What happens at night?
2008	James	It gets cold.
2009	Ryan	Why does it get cold?
2010	James	Because it starts to get windy out in the nighttime.
2011	Ryan	Oh, the night it gets windy. Anything else?
2012	James	Um, the trees blow really hard, make a lot of wind, so it's really cold outside.

He returns to this idea of trees causing wind that make it cold at night in interview 3, this time adding that his parents told him about this.

X	Spkr	Transcript
2307	James	Because I know in the night my parents always tell it gets cold outside because of the tree
2308	Ryan	What does the tree do?
2309	James	It blows with wind and makes more wind and then it get's cold in the night.



Interview 1 Illustration C

Research Question 2

How do kindergartners interpret the ECT as compared to commercially available thermometers?

Process Code	Number of Instances
1 : Adding thermometer to the picture	3
70 : Describing temp increase shown as higher line in thermometer	1
76 : Explaining a hypothetical temperature display	1
80 : Explaining change in temperature measurement	1
131 : Predicting what the thermometer will read	8
133 : Reading numeracy assessment	1
134 : Recording temperature with blocks	4
146 : Exploring the thermometer	2
147 : Expressing opinion about a thermometer	3
148 : Expressing preference of thermometer	3
149 : Identifies thermometer	1
152 : Reading thermometer	15

James is able to read all of the thermometers, although he reads the numbers as sixteen and seventeen instead of 60 and 70 respectively. The following excerpt from

interview 2 demonstrates his mostly correct reading of all four thermometers.

X	Spkr	Transcript
2074	James	Yeah *pushes button on ECT* (ECT display 70 deg* That's cool.
2075	Ryan	What do you think it is showing you?
2076	James	It is showing the temperature *points to box below what the ECT was just displaying*
2077	Ryan	Yeah? Can you read it to tell me what temperature it says it is? *pushes button on ECT*
2078	James	Six, seventeen
2079	Ryan	Seventeen, yeah. How did you know that?
2080	James	I actually saw the light *points to the 70 deg box on ECT* and it was at seventeen, so that means it is 17 degrees outside
2081	Ryan	And these thermometers, since we have these inside they are telling us the temperature in here. If we bring them outside it will tell us the temperature outside
2082	James	Mmmm, that's cool.
2083	Ryan	How about this one? *touches the yellow thermometer* Can you see what this one is telling us what the temperature is?
2084	James	It's telling us that it is sixteen. *points to 60 on yellow thermometer*
2085	Ryan	Sixteen, how did you know that?
2086	James	I see the red line and it stops at sixteen, so that means it is 16 degrees in here.
2087	Ryan	How about this one? If you hit these buttons what do they?
2088	James	It turns it on.
2089	Ryan	Turns it on, yeah. And do you see those number in there? *lifts gray thermometer* What those numbers say?
2090	James	They the degrees that are in here.
2091	Ryan	Do you know what those number say?
2092	James	Um , 65 to 67
2093	Ryan	How about this one? *lifts blue thermometer*

In addition to properly reading the thermometers, he exhibits a correct interpretation of the temperature scale. His answer is clear for the hot end, but unfortunately I provide the answer for cold by saying low instead of cold. This appears in the process codes 70 : Describing temp increase shown as higher line in thermometer and 76 : Explaining a hypothetical temperature display. Below is one example from the interview.

X	Spkr	Transcript
2100	James	Because I want to see what it will show outside? Cause I haven't tested this one out outside.
2101	Ryan	And if you took another with you, which would be the other one you would take?
2102	James	I would say it would be this one. *points to yellow thermometer*
2103	Ryan	How come?
2104	James	Because it looks cool and I like the color yellow *touches from the top to the bottom of the yellow* And the numbers go up really high and really low and it's cool and I think it would be cool to see what temperature it is outside.
2105	Ryan	What would these look like if it were really hot out? Where would the numbers be?
2106	James	Up here *points to 110 deg on the yellow thermometer*
2107	Ryan	How about it the temperature was really low?
2108	James	*places finger on -40 on yellow thermometer*

Although he makes the correct interpretation of the high end in the above example, he mixes up the number scale when making a prediction of a sunny location just after reading the temperature in the shade.

X	Spkr	Transcript
2195	Ryan	We are going to hold onto this, so we'll save this. I am going to leave this here for right now. *places the blue stack of blocks against the ECT* We are going to come back in a moment to get that. We are going to go over to check on the other thermometer. Before we go over there, what do you think those thermometers are going to show?
2196	James	A different temperature
2197	Ryan	Why is it going to be different?
2198	James	Cause it might be colder over there or a bit warmer
2199	Ryan	What do you think?
2200	James	I think it will be 50 or 30 *shrugs shoulders*
2201	Ryan	How come?
2202	James	Because it might be warmer or colder over there. It could be either one of those, it could be 50 or 30 because it could be colder of a bit warmer, so it could be 60
2203	Ryan	If it is warmer over there what would it be?
2204	James	It might be 30
2205	Ryan	If it is colder over there, what might it be?
2206	James	50 or 60

It is interesting that he predicts both a lower and higher value after noting that it

could be warmer or colder. When I follow on lines 2203 and 2205 about what it would look like for each, he indicates that colder would be a higher number and hotter would be a lower number. While this is incorrect, it still might show that he is temperature as a single scale, just inverted.

When he takes the actual reading on the ECT and the Classroom thermometer, he reads them as 70 and 80 and correctly indicates that the measurement with a higher number represents a warmer temperature in the sun as compared to the shaded thermometers.

X	Spkr	Transcript
2208	James	*pushes button, but it does not illuminate. Flips switch on and then presses button again* Seventy *touches the number 70 on the ECT* (ECT displays 70)
2209	Ryan	70, how does that compare to the other side?
2210	James	Eighty
2211	Ryan	So what do they say?
2212	James	Seventy and eighty
2213	Ryan	Seventy and eighty, can I take a picture of that? Can you make the shadow and push the button again?
2214	James	Pushes the button
2215	Ryan	*takes picture* Great. So how are they, how do they compare to the other ones that we saw over there?
2216	James	Umm they are colder, it's colder over here because it is a higher temperature than the other ones, it's colder on this side than over there *points to shady side*
2217	Ryan	How does it feel over here?
2218	James	Warm, kind of
2219	Ryan	Do you mind making another stack of blocks so you can show you can show how high thermometer with the button is.
2220	James	Yes, I am going to make it red cause it's warm. *builds red stack of blocks* 50 *continues stacking* 60 *continues stacking* 70 *places stack against the ECT to compare, continues stacking, compares to ECT* Seventy degrees
2221	Ryan	Do you want to hit the button one more time?
2222	James	*pushes ECT button, leans over looking at ECT*
2223	Ryan	How does that look?
2224	James	To the perfect size.

2225	Ryan	Looks good to me. Hit the button one more time and I'll take a picture. And can you leave your blocks there too?
2226	James	Yes *places stack*
2227	Ryan	Let's go grab the thermometer over here, and we will take this. How does it feel when we come over here?
2228	James	Cold
2229	Ryan	Cold, why do you think it feels cold over here?
2230	James	Because in the in the shade it could be cold, in the sun it could be hot
2231	Ryan	Why do you think that is?
2232	James	Because in the shade the trees are kind of blowing and it blows and makes wind in the shade. And when you are in like hot (points to the sunny area), it can still be cold sometimes but it is warm mostly most of the time.
2233	Ryan	Do you feel wind over here?
2234	James	Yes *nods head up and down*
2235	Ryan	Did you feel wind over in the sunny spot?
2236	James	No *shakes head left to right*

The above transcript section extends past where James corrects his comparison of temperatures to include his explanation of why the two places were different temperatures.

Thermometer Preference

James chooses the ECT as his first choice.

Research Question 3

How do kindergartners interpret graphic representations of air temperature in relation to the ECT?

Process Code	Number of Instances
2 : Agrees with a short stack of blocks as cold and a high stack as warmer	1
3 : Adopting introduced block representation instead of their own	1
105 : Making sense of line plot	7
106 : Making sense of line plot, color as indicator of temperature	1
108 : Making sense of map, blue as cold	2
111 : Making sense of map, green as fine	2

112 : Making sense of map, red and yellow as hot	4
113 : Making sense of map, yellow as warm	3
116 : Making sense of time ordered plot, color meaning for visual similarity	1
121 : Making sense of time ordered plot, talking about parents	1
122 : Making sense of time ordered plot, touching plot	2
125 : Making a temperature comparison	1

James interprets the bar graph by saying that the fourth blue (last item in the plot and shortest stack) and the yellow stacks are hot. It is possible that he is saying sun for the color, but it could just be in relation to occurring during the day.

X	Spkr	Transcript
2298	Ryan	Looking at the picture. What do you think the temperature does?
2299	James	Makes it hot and cold outside and inside
2300	Ryan	Can you show me where? And this is all outside. This is all the temperature outside of my house.
2301	James	It is?
2302	Ryan	Yeah. So what happens to the temperature? So this is morning, afternoon, evening, night *pointing across the picture as time passes in those phrases*
2303	James	*points to the fourth blue, lowest temp, and looks at r*
2304	Ryan	What happens?
2305	James	That one is really cold *pointing to 4th blue* that one is kind of cold *points to 3rd blue*
2306	Ryan	How do you know?
2307	James	Because I know in the night my parents always tell it gets cold outside because of the tree
2308	Ryan	What does the tree do?
2309	James	It blows with wind and makes more wind and then it get's cold in the night.
2310	Ryan	How about during the day?
2311	James	*slaps the two yellow columns* Hot!
2312	Ryan	How did you know that?
2313	James	Sun
2314	Ryan	Yeah, what does the sun do?
2315	James	Make it hot.

Despite not being clear on why the yellow columns represent the sun and being hot, it seems that he picked the last blue block based on its height since he compares it to

the one next to it that is taller in line 2305, saying the taller is kind of cold while the shortest one is really cold.

When interpreting the temperature line plot, James indicates that is showing hot. When asked to explain that he conveys that the plot shows increasing temperatures from left to right, but the plot actually shows the decreases and increases over the course of a 48 hour period. He reads all of the labels on the plot correctly and moves his finger up and down with the plot, but does not indicate any decreases in temperature. It does not appear that he is attending to the changes in height of the plot, and might be suggesting it is hot because it the line is red.

X	Spkr	Transcript
2318	Ryan	That's OK, you told me a lot of good things about that picture. That was a picture I made. Sometimes scientists make pictures of the temperature. I am going to show you two of their pictures. What do you think of this one? *places line plot of temperature* Can you tell me what that tells us about the temperature?
2319	James	Hot
2320	Ryan	How do you know?
2321	James	Because sometimes I can read scientist.
2322	Ryan	Where is it showing it is hot?
2323	James	*touches red line at the end of the first gray box*
2324	Ryan	OK, how did you know it was hot?
2325	James	Because I can tell right here *points to red line just after first gray box* from the numbers it gets hotter and hotter *traces temperature line up and down while going left to right on plot* This is way too hot *pointing to end of plot* so we go down to here *points to the end of gray box* it's only supposed to be that hot during a day
2326	Ryan	Oh, and where does it get hotter?
2327	James	*Points to the last white box of plot and traces line, pointing at very end*
2328	Ryan	What's that line doing?
2329	James	The lines showing all these numbers of the temperature
2330	Ryan	Can you read any of those numbers?
2331	James	Thirty, 29, 27, 26, 29, 37, 39 , 33, 30, 28, 27, 25, 30, 42, 44
2332	Ryan	And what is happening with those numbers?
2333	James	It get's hotter and hotter, if you go back *points from end tracing*

back to start of plot it gets colder and colder

When interpreting the weather map, James sees red as hot, yellow as warm, blue as cold, but more importantly green as fine.

X	Spkr	Transcript
2335	James	Hot *points to red Texas*, warm *points to yellow FL*, cold *points to blue CA coast*, and umm find *points to green PA*
2336	Ryan	How did you know that?
2337	James	Because I can tell temperature.
2338	Ryan	Yeah, what was this? *points to red TX*
2339	James	Hot
2340	Ryan	How did you know it's hot?
2341	James	Red makes it hot.
2342	Ryan	And what did you say about over here? *points to yellow OR*
2343	James	Warm
2344	Ryan	Warm, how do you know that?
2345	James	Cause I know hot and red and hot and yellow makes umm hot and warm makes warm.
2346	Ryan	How about up here? *points to green ND*
2347	James	Fine
2348	Ryan	What does fine mean about the temperature?
2349	James	That means the temperature is just perfect, but I don't know what that temperature is. I just know these two these three are warm, hot, and cold. *points to CA coast and then TX*

Participant Summary

James demonstrates a sophisticated conception of air temperature while being able to use all the thermometers, make representations depicting more than two temperatures, and is able to decipher the range of temperatures on the weather map. When presented with stacks of blocks of differing heights showing hot and cold, he extends this representation to show hot, warm, and cold. This is consistent with his drawing of air indoors with a mix of red for hot and brown for warm. He is the only participant that interprets the weather map scale with hot, warm, fine, and cold. Like Erica, it appears he might be arriving at the idea of room temperature with fine.

Jonathan

Jonathan as the Pilot Participant

Jonathan was the first participant to go through each of these interviews, so he served as the test case for the interview protocols. While he was not highly talkative, I made sure to ask more follow up questions to the other five participants. On multiple occasions he responds with "I don't know" or shakes his head from left to right.

In his interview 3, I only had him make a stack of blocks to record the temperature one of the two locations outside. Afterwards, I did have him make a stack from a photograph that I took. In addition, for this block recording of the temperature I was explicit about counting the boxes to figure out how many blocks to stack. After the interview, I revised the protocol to simply ask the children to use the blocks to show how high the temperature was. This decision was meant to avoid imposing a one-to-one representation as kindergarteners may still be developing the math practice of one-to-one correspondence.

<u>Research Question 1</u>

How do the kindergartners talk about and show air temperature?

Illustrations of Temperature

Jonathan makes detailed illustrations attending to making realistic looking representations. This appears in codes in the 4 instances of code 54 : Depicting with color for visual similarity and the 2 instances of code 55 : Depicting shade or sun for visual similarity. When showing depicting temperature, he draws wind, the sun, the moon, and how the human body might react noted in codes 25, 27, 31, and 33.

Process Code	Number of Instances
1 : Adding thermometer to the picture	2
8 : Associating the moon with night	1

9 : Attributing cold as night	1
13 : Attributing cold to the moon	1
15 : Attributing cold to the wind	3
16 : Attributing temperature change to wind and sun	1
23 : Corporal	3
25 : Depicting even hotter as bleeding	1
27 : Depicting warmer as sweat on a person	2
31 : Depicting cold as lines	2
33 : Depicting cold with the moon	1
52 : Depicting wind	1
54 : Depicting with color for visual similarity	4
55 : Depicting shade or sun for visual similarity	2
56 : Depicting with written text	1
59 : Describes temperature at night	1
68 : Describing wind	2
74 : Explaining a change in temperature	5
82 : Explaining difference between shade sunny spots	1
86 : Explaining illustration color	2
87 : Explaining illustration form	1
91 : Feeling temperature	12
94 : Feeling cold	5
95 : Feeling colder and warmer	1
96 : Feeling hot	2
99 : Feeling warm	3
101 : Feeling wind	1
136 : Sun and Moon	1

For example, during interview one Jonathan includes: me (accurately showing me with a blue shirt, brown pants, and blue sneakers), the corners of the building where we made the observations, and the shade and sun with black and yellow. In the transcript below on line 1192, he indicates that the shady side is cold and the sunny side is warm. His picture at this point shows what the warm and cold sides look like without necessarily depicting hotness or coldness. When I ask him how it would look if it got warmer, he first shows sweat on me and blood to show even hotter.

Interview 1 Illustration

X	Spkr	Transcript
1188	Ryan	Very cool. So tell me which side is this in the picture *r points to the side with the yellow*
1189	Jonathan	Light *points to yellow* Dark *points to the side with gray/black shading*
1190	Ryan	You talked about how it felt. How did the different sides feel?
1191	Ryan	Which one was cold?
1192	Jonathan	Cold *touches the one with gray/black* Warm *touches the yellow one*
1193	Jonathan	Cold and warm?
1194	Ryan	Now let's pretend that I was outside and it started to get hotter, how can you change the picture to show that. Let's say it is getting later in the day.
1195	Jonathan	*takes blue pencil and draws on the picture of r* Sweating
1196	Ryan	What is that?
1197	Jonathan	Sweating
1198	Ryan	That I am sweating, yeah that would be a good, a really good way to show it. How about if it got even hotter?
1199	Jonathan	*touches hair and looks at paper,*
1200	Ryan	Is there a color that you need that I don't have with the markers? What do you need?
1201	Jonathan	I need pink
1202	Ryan	pink
1203	Jonathan	*uses the pink to add something to r body* You are so hot you are bleeding.

In interview 2, James makes a picture of wind after noting that it is cold outside as

compared to inside. He creates this drawing while outside in the cold.

Interview 2 Illustration A

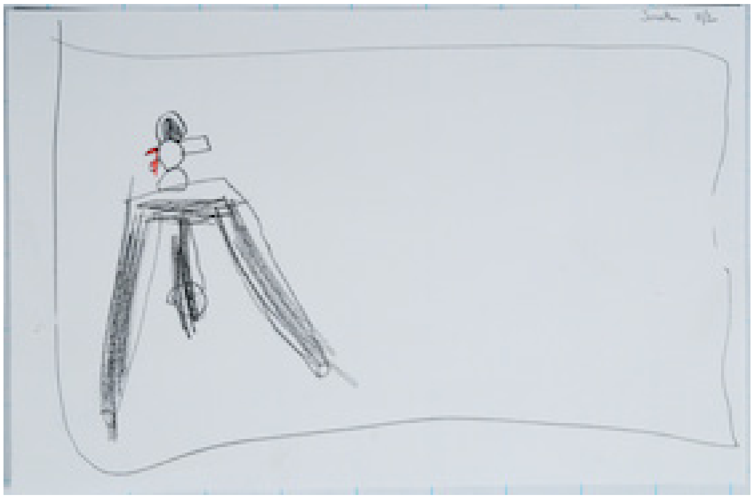
Upon entering the building, he creates a second drawing similar to the one from interview one with two corners. This time he puts the sun on one side and the moon and a star on the darker side. The dark side is colored with black pencil and includes the word cold. While he indicates that both sides of this drawing below are outside, there did not appear to be a sunny and shady part in the video as it all appeared to be not in direct sunlight.

Interview 2 Illustration B

X	Spkr	Transcript
1288	Ryan	It feels a little different to me. This picture was outside. What

		were these lines? What did you put there?
1289	Jonathan	Wind
1290	Ryan	Wind. Would there be anything you might add to the picture inside?
1291	Jonathan	*grimaces face as he chooses a pencil, adds something with blue pencil* How do you spell cold?
1292	Ryan	C O L D
1293	Jonathan	*Takes black pencil and adds a bunch of black lines, puts pencil down and looks at r*
1294	Ryan	Tell me which picture is showing what.
1295	Jonathan	*takes yellow pencil and draws*
1296	Ryan	Is there anything else you want to add?
1297	Ryan	Can you explain to me what in the picture?
1298	Jonathan	*points to picture and shakes head side to side*
1299	Jonathan	*Points to yellow* Sun *points to gray area* Moon
1300	Ryan	The moon in the….
1301	Jonathan	The dark
1302	Ryan	Is that? *points to dark side of picture* Can you tell me where at school this is?
1303	Jonathan	*points outside, where we went with the thermometer*
1304	Ryan	So you are pointing to…? What is that out there?
1305	Jonathan	That, uh, I don't know
1306	Ryan	This is outside, you are pointing to outside.
1307	Jonathan	*nods up and down*
1308	Ryan	How about this one? *points to yellow side of paper* Where is that?
1309	Jonathan	Right where we were *points out the window again*
1310	Ryan	Oh that's were we were standing. So this is all outside?
1311	Jonathan	*nods head up and down*

Looking at the transcript above, I note that this interview took a bit more effort to get Jonathan to talk than the other participants. This can be seen in lines 1298 and 1305. After completing this picture with the COLD written, I ask Jonathan to make a picture of the inside. His picture is a detailed illustration of the tripod and camera without anything showing temperature.



Interview 2 Illustration C

For interview 3, James illustrates what was visible outside, direct sun, shade, grass, the ECTs and the Classroom thermometers. Details on the thermometers include the boxes and button on the ECT and a yellow body with red line for the Classroom thermometer. Besides adding the thermometers upon my request, he does not show hot or cold.

Interview 3 Illustration C

Temperature Talk

Jonathan's talk about temperature includes incomplete sentences. For example,

when asked to compare the sunny and shady spots he says cold, warm.

X	Spkr	Transcript
1190	Ryan	You talked about how it felt. How did the different sides feel?
1191	Ryan	Which one was cold?
1192	Jonathan	Cold *touches the one with gray/black* Warm *touches the yellow one*
1193	Jonathan	Cold and warm?

Block Representation

Jonathan shrugged his shoulders when I showed him the tall and short stack of blocks to represent the warm and cold corners in interview 1.

Research Question 2

How do the kindergartners interpret the ECT as compared to commercially available thermometers?

Process Code	Number of Instances
1 : Adding thermometer to the picture	2
74 : Explaining a change in temperature	5
131 : Predicting what the thermometer will read	2
133 : Reading numeracy assessment	6
134 : Recording temperature with blocks	5
145 : Explaining what a thermometer does	2
147 : Expressing opinion about a thermometer	1
148 : Expressing preference of thermometer	1
150 : Indicating temperature measurement change	2
152 : Reading thermometer	12

Jonathan is able to read both of the ECT and the Classroom thermometers. In interview 2, he notices the change in temperature from inside to outside and in his words, “went colder.”

X	Spkr	Transcript
1325	Jonathan	*pushes button* (ECT displays 60 degrees)
1326	Ryan	Any different?
1327	Jonathan	It is down one *touches the 70 box and then moves finger down to the 60 box while the ECT is not lit*
1328	Ryan	It what, what happened to it?
1329	Jonathan	It goes down
1330	Ryan	It went down, so what do you think that means?

1331	Jonathan	It goed colder.

In interview 3 he reads both the ECT and Classroom thermometers correctly (note, the ECT may be displaying a lower temperature since the sensor is shielded from the sun unlike the glass on the Classroom thermometer).

X	Spkr	Transcript
1348	Ryan	Alright j, we are going to have you look at both thermometers, both sides. Which one do you want to start with. *walks with j over to the sunny side of the yard* Alright j, can you tell me what that thermometer says?
1349	Jonathan	*pushes button on ECT* (ECT displays 50 degrees) 50
1350	Ryan	50, maybe hit it one more time so I can take a picture.
1351	Jonathan	*pushes ECT button*
1352	Ryan	How about the yellow thermometer?
1353	Jonathan	60

Thermometer Preference

Jonathan chooses the ECT as his first choice “because it looks cool.” (line 1242)

Research Question 3

How do the kindergartners interpret graphic representations of air temperature in relation to the ECT?

Process Code	Number of Instances
72 : Does not take up block representation	1
105 : Making sense of line plot	1
107 : Making sense of map	1
109 : Making sense of map, color key	3
110 : Making sense of map, green and blue as cold	1
112 : Making sense of map, red and yellow as hot	2
118 : Making sense of time ordered plot, counting boxes	1
119 : Making sense of time ordered plot, higher mean higher temp	3
122 : Making sense of time ordered plot, touching plot	2
125 : Making a temperature comparison	2

Jonathan interprets the bar graph by counting each of the squares calling them degrees. He says the temperature gets higher during the day and points to the highest stack.

X	Spkr	Transcript
1457	Ryan	Nice detail. Let's see. I am going to show you a picture that I made. This is what the thermometer looked like all day and into the night. I want to see if you could tell me what you think this picture might mean. What do you think that might mean? *places time ordered bar plot* That's what the thermometer was telling me. … So this was the morning *points to first bar depicting 3 blue*
1458	Jonathan	What's this one? *points to the second bar with 5 green*
1459	Ryan	That's a little later in the day, this is going home, this is going to bed. *moves finger across the bottom of the plot while saying this*
1460	Jonathan	1 degrees *touching one blue*, 0 degrees *touching blank spot in between bars*, 2 degrees *touching two blue*, 4 degrees *touching 4 blue*, 6 degrees *counts the blocks with finger on 6 yellow*, 7 degrees *touching 7 yellow*, 5 degrees *touching green 5*, 3 degrees *touching blue*
1461	Ryan	Yeah, you took all those temperatures. That is great. How about, what would you say happens to the temperature during the day?
1462	Jonathan	Higher *touches the top of the paper above the highest bar 7 yellow*
1463	Ryan	Higher, can you show me how you knew that?
1464	Jonathan	*touches from the bottom to top of the 7 yellow bar and repeats tracing it's length, then also traces the empty space above the 7 yellow bar*
1465	Ryan	So during the day the temperature…
1466	Jonathan	Gets higher *still touching the 7 yellow bar*
1467	Ryan	Gets higher, OK and what happens at night?
1468	Jonathan	Gets lower
1469	Ryan	Gets lower. Why do you think that is?
1470	Jonathan	*shrugs shoulders* 'sounds like I don't know but does not open mouth'

When asked to interpret the line plot, Jonathan shrugs his shoulders and shakes his head after I made two requests. For the weather map, he interprets the colors on the temperature scale at the top of the map first.

X	Spkr	Transcript
1489	Ryan	No, it's OK. I have another picture that scientists make. How about this picture. *places temperature map* What do you think that means?
1490	Jonathan	*places right index finger on yellow part near FL or GA. Points*

		finger in scale at top starting on Magenta That's warm and cold. *slides finger to purple* cold *slides finger to purple-blue* cold *slides finger to blue* hot.. hot *slides finger to green* cold *slides finger to yellow* hot, *slides finger to orange* hot, *slides finger to red* hot. *lifts finger back to the magenta end of the scale, taps purple* cold *taps blue* cold *touches green* cold, *touches yellow* hot, *touches orange* hot, *touches red* hot.
1491	Ryan	How did you know that?
1492	Jonathan	Cause these are lower *points with four fingers to purple through green* and these are higher *points with three fingers to yellow, orange, and red*
1493	Ryan	Ahh, nice. What do you think that means on *points to map*? This is a map.
1494	Jonathan	*Touches green on scale and slides finger to green area on map maybe PA* Colder *touches several green spots and then blue spots* colder, colder, colder. *touches red part of scale then slides finger to TX* hotter, hotter
1495	Ryan	What was this one over here? *Points to TX red*
1496	Ryan	What was this one over here? *points to red or orange TX*
1497	Jonathan	Hotter
1498	Ryan	And how did you know that?
1499	Jonathan	Cause it is higher *points to red end of scale*
1500	Ryan	What's higher?
1501	Jonathan	The temperature.

Participant Summary

Although Jonathan did not talk as much as the other participants about temperature, he was able to read all of the thermometers and interpret two out of the three temperature plots. His illustrations included many details of the way each location looked, such as the corners of the building, direct sun or shade, and the clothing that I was wearing. After being prompted, he showed an increase of temperature as a reaction from the body (sweat and blood). Other representations included lines for wind and the sun, moon, and a star.

Malcolm

Research Question 1

How do kindergartners understand, talk about, and show air temperature?

Malcolm mostly shows and talks about temperature in ways that a person experiences it. This can be seen in the 10 instances of code 24: Depicting cold as how the person feels it and 5 instances of code 26: Depicting heat as how it affects a person's body. Although he points out the air is not visible, so you can't show it on the paper, he does draw some yellow air and wind in some of the pictures. He usually adds details to make the picture appear accurate, such as grass, dirt, himself and me.

Process Code	Number of Instances
1 : Adding thermometer to the picture	1
2 : Agrees with a short stack of blocks as cold and a high stack as warmer	2
6 : Appears to mix up inside and outside	1
7 : Appears to mix up sun and shade spots	2
15 : Attributing cold to the wind	6
18 : Attributing warmth to the sun	2
23 : Corpreal	15
24 : Depicting cold as how the person feels it	10
26 : Depicting heat as how it affects a person's body	5
37 : Depicting hot with the sun	2
39 : Depicting hotter with a bigger sun	1
46 : Depicting sun with yellow and other colors	2
52 : Depicting wind	10
54 : Depicting with color for visual similarity	4
58 : Descibing how to dress for certain temperature	1
61 : Describing air	1
65 : Describing sun	1
87 : Explaining illustration form	5
91 : Feeling temperature	6
94 : Feeling cold	6
129 : Opposites	2

Illustrations of Temperature

X	Spkr	Transcript
1545	Ryan	Tell me what is on the paper. *points to picture* What are the

		different part of your picture?
1546	Malcolm	A human getting freezed *crosses arms over chest* and some yellow air *points to yellow part with pencil* and some grass and some dirt and some flowers
1547	Ryan	Some grass, some dirt, and some flower, a human. And what was the human doing?
1548	Malcolm	Freezing *crosses arms over chest*
1549	Ryan	Oh, freezing, show me that again *points to m's arms*
1550	Malcolm	*crosses arms over chest and shrugs shoulders* Freezing
1551	Ryan	What does that *crosses arms over chest* mean?
1552	Malcolm	You're cold
1553	Ryan	You're cold, oh. And I noticed you shook your head a little bit, how come you shook your head?
1554	Malcolm	Cause, how you're *crosses arms over chest and shrugs shoulders* fr sickle
1555	Ryan	Oh, interesting. And tell me what was this over here *points to yellow part of drawing*?
1556	Malcolm	Yellow air
1557	Ryan	Yellow air, why did you show the air yellow?
1558	Malcolm	So you can see the air *crosses arms over chest* is so blows on the human
1559	Ryan	Can you say that a little louder, I didn't hear.
1560	Malcolm	The yellow air is so you can see it blows on the human
1561	Ryan	It blows on the human, can you tell what does that mean, blows on the human?
1562	Malcolm	Cause the air is cold *with fingers spread apart touches fingertips to each other* it goes forward not backwards *hold pencil parallel to table moving back an forth* and pushes the human *makes gesture with three fingers spread out*
1563	Ryan	So the air, it blows on the human and it, what did you say it does?
1564	Malcolm	It blows, it pushed him sickles *crosses arms over chest*
1565	Ryan	It pushes him
1566	Malcolm	And sickles him
1567	Ryan	And sickles him, yeah, interesting. I really like all the details you included in that picture. Can you remind me, what was this part over here? *points to orange drawing in upper right of picture*
1568	Malcolm	The grass that's getting blowed away

In interview 1, Malcolm draws a picture of what it feels like outside after stepping back inside. He draws a person with yellow air blowing on the person. It is important to note the arms on the person are drawn in an oval shape to show that they are crossed over

the chest. Malcolm gestures this arm position in in line 1548 after saying “freezing.” After I follow up on this, he indicates that the aroums over chest means “you’re cold.”

Interview 1 Illustration A

In addition to talking about what the wind does to the human, he also points out that it blows the grass away. After this I asked him to make a warmer picture. In this second illustration below, he now includes the sun and a person with arms outstretched. Although he later points out the arms are out, when he explains how the sun is warming the person he crosses his arms.

Interview 1 Illustration B

X	Spkr	Transcript
1589	Ryan	Tell me about this picture.
1590	Malcolm	How the sun *touches orange roundish shape in upper left corner* is warming up the flowers and growing the flowers and the human is warm *crosses arms over chest*
1591	Ryan	The humans warm. And tell me the different parts. What is this over here? *points to roundish orange shape in the upper left hand corner*
1592	Malcolm	The sun *points to the round shape* shines *moves down from round shape* on the flowers and the human and keeps them warm.
1593	Ryan	Oh, how does the sun do that?
1594	Malcolm	Cause it is hot and heated *crosses arms over chest*
1595	Ryan	It is hot and heated. How does the person feel there?
1596	Malcolm	*Crosses arms over chest* good and hot
1597	Ryan	Good and hot. How could you change this picture if it got even hotter, if it got really hot?
1598	Malcolm	*draws large sun in the middle of the top of the page, then more lines around the picture*
1599	Ryan	Tell me what you did?
1600	Malcolm	The sun is bigger than this sun *points to sun in upper left corner* cause how it is heated and hot *crosses arms above shoulders* it heated more then it heats the humans so hot that its dying
1601	Ryan	Oh, the human is dying?
1602	Malcolm	Yeah, cause it is so hot.
1603	Ryan	Show me where the sun is?
1604	Malcolm	*points with pencil to center of top of page*
1605	Ryan	How is this sun *points to small sun* different from this sun *points to big sun*
1606	Malcolm	Cause it is smaller and this one is bigger.

When I ask him to show how the picture would change if it was even warmer, he draws a larger sun in line 1598 and later indicates that it is so hot that the human is dying.

X	Spkr	Transcript
1607	Ryan	Interesting, is there anything else you want to tell me about that picture?
1608	Malcolm	Well, yeah. This *might point to small sun* the moon is smaller than the sun cause how the sun is really bigger *spreads arms out to the sides* and it's bigger than this sun *points to small sun*, and this sun is bigger *points to big sun* and this part is different *points to human flower area in second picture* the human is different than this, cause his arms are straight out *points to second picture human* and this one *points to first picture human*

		and this one is in
1609	Ryan	Oh they are in. Can you show me with your arms what this human looks like? *points to first picture human*
1610	Malcolm	*crosses arms over chest*
1611	Ryan	Can you show me what this human looks like? *points to human in second picture*
1612	Malcolm	*extends arms straight out level with shoulders*
1613	Ryan	Why is it different?
1614	Malcolm	Cause this one is hot *points to second picture* and this one is cold *points to first picture*

Here he explains that the arms are crossed in the cold and extended in the hot picture.

In interview 2 he draws a picture showing cold, but this time the people have their arms extended. When describing his illustration, he points out that weather is cold and that the air is not visible while moving his finger around the picture in line 1709. In addition, he makes the gesture of crossing his arms while saying cold in line 1713.

Interview 2 Illustration A

X	Spkr	Transcript
1708	Ryan	Can you tell me about the picture? What am I looking at?
1709	Malcolm	How the weather is cold *with right index finger, circles around the picture 2-3 times* and the air is white so you can't see it and

		there is dirt *points to brown arch* so the grass can grow in it. *makes zig-zag motion on green area*
1710	Ryan	Nice details, what did you tell me about the air?
1711	Malcolm	Cause it's white and nobody can see it.
1712	Ryan	Yeah, you can't see it. And how did it feel out there?
1713	Malcolm	Cold *crosses arms over chest*

Extraneous Objects

Malcolm adds items into his illustrations that to me appear unrelated as they were not present during the interviews. These include flowers (1 and 3), a girl walking around without shoes on (3), and a non-working car (3).

Block Representation

When I present the block representation with a short stack for the cold picture and a tall one for the hot one, he seems amenable to the representation.

Research Question 2

How do the kindergartners interpret the ECT as compared to commercially available thermometers?

Process Code	Number of Instances
1 : Adding thermometer to the picture	1
88 : Explaining illustration of thermometer	1
89 : Explaining the addition of the thermometer in the picture	1
103 : Indicating the color on the ECT	1
131 : Predicting what the thermometer will read	2
133 : Reading numeracy assessment	2
134 : Recording temperature with blocks	3
141 : Describing attribute of a thermometer	2
142 : Describing how the thermometer works	2
146 : Exploring the thermometer	8
147 : Expressing opinion about a thermometer	4
148 : Expressing preference of thermometer	2
152 : Reading thermometer	23

During interview 2, Malcolm does not read any values off the thermometers. When using the ECT, he indicates that the color is green, when it actually is yellow. After leaving the thermometer outside for some time, he pushes the button again an says it is

still green (when it is green this time). He does notice a difference in the way the illumination looks like a square indoors, but a circle outside. This is due to the ECT being viewed with much brighter ambient light outside. Malcolm touches each of the illuminated boxes on line 1743.

X	Spkr	Transcript
1729	Malcolm	There it goes. (ECT displays 50 deg green)
1730	Ryan	What's it doing?
1731	Malcolm	It's turning green again *touches the lower boxes on the ECT*
1732	Ryan	Yeah, turning green again?
1733	Malcolm	Mmhum, but not all the way green
1734	Ryan	Not all the way green? What do you mean?
1735	Malcolm	Cause it's just circles of green in the middle
1736	Ryan	Oh, just circles. Good observation. How about this one? *picks up blue thermometer* Does this one look any different?
1737	Malcolm	*holding blue thermometer* That turned, the color in there *pointing to line in blue thermometer* turned this color *pointing to the blue plastic on the outside of the blue thermometer*
1738	Ryan	Interesting, do you want to take these back to the table?
1739	Malcolm	Yeah *walks to table and places both thermometer on the table*
1740	Ryan	You want to hit the button again?
1741	Malcolm	*pushes ECT button* (ECT displays 50 deg green)
1742	Ryan	So what did you say about it?
1743	Malcolm	It had two circles *makes circular motion with finger on each illuminated box* and it turned to squares right now. *touches switch on ECT*

During interview 3, Malcolm is able to read the ECT and the Classroom thermometer with my help. Once again, he uses his finger to count by touching each illuminated box on the ECT.

X	Spkr	Transcript
1785	Malcolm	*pushes button on ECT* (ECT displays 70 deg) *touches 70 deg box on ECT*
1786	Ryan	I am going to make that shadow again. How's it look?
1787	Malcolm	*moves finger from bottom to 70 box on ECT*
1788	Ryan	Want to hit that button again?
1789	Malcolm	*pushes button, quietly counts and touches all 12 boxes*
1790	Ryan	So how many boxes light up when you hit the button?

1791	Malcolm	*pushes button and points to the top lit box at 70 deg on ECT) This box… One, two, three, four, five, six, seven* touches each box as he counts*
1792	Ryan	Seven, OK. Could you make a stack of blocks to show that? So that we can remember what the temperature was, you said it was seven squares high.
1793	Malcolm	See *pushes button and touches 70 deg box on ECT* That one… seven 'inaudible' *works on making stack of blocks* I see my brother, he just ruined down the hill (stack is more than 7 blocks) *places stack against ECT display)
1794	Ryan	You can hit the button again.
1795	Malcolm	*pushes button* Let's see *leans stack against ECT display* just need one more *adds one more to the stack and leans against ECT* (stack is just over the bottom of the 70 deg box on ECT) There!
1796	Ryan	Great, how about this thermometer *picks up yellow thermometer and leans it against the wall* what's this one say? Can you see how high the red line is?
1797	Malcolm	To two-thousand *touches the 120 deg mark on the yellow thermometer*
1798	Ryan	Two-thousand, oh boy.
1799	Malcolm	Yeah, what does this one *touches the base of the glass on yellow thermometer and moves finger to near 80 deg* goes
1800	Ryan	Do you see how high that red line goes up?
1801	Malcolm	Yeah
1802	Ryan	What number does it go up to?
1803	Malcolm	Eighty

After taking the temperature on the sunny side of the yard, Malcolm takes the temperature on the shaded side. While he is able to notice the difference in temperature measurement heights, it does not appear that he notices the difference in temperature. At the end of the following excerpt he starts to point out a difference of the handles on the thermometers.

X	Spkr	Transcript
1815	Malcolm	*flips switch on ECT, pushes button* (ECT displays 40 deg) Oh it's forty *touches the 40 block on ECT* zero
1816	Ryan	What is the temperature over here?
1817	Malcolm	Forty zero
1818	Ryan	Forty zero, can you show that with blocks?
1819	Malcolm	*already started stacking blocks, pushes button and compares to*

		ECT display, keeps adding until the stack is just about at the top of the 40 deg block, then looks at r
1820	Ryan	Nice, how about the yellow one?
1821	Malcolm	Up to forty zero again?
1822	Ryan	Interesting, are these two places different, the temperature?
1823	Malcolm	Yeah
1824	Ryan	What is different about them?
1825	Malcolm	They make a different up *moves finger from zero to 40 on yellow thermometer* and a different 'white' *Moves hand up stack of blocks in front of ECT*
1826	Ryan	How does it feel? Does it feel different over here?
1827	Malcolm	Yeah
1828	Ryan	What's different?
1829	Malcolm	How it, how it does, a different size, that one's *points to sunny area* bigger and this one *points with block in hand to shaded ECT block stack* is lower
1830	Ryan	Interesting, why do you think that is? Why do you think the sizes are different?
1831	Malcolm	How, that one's different *pointing to sunny spot* is different than these two *points to ECT and Yellow in shade* because they both have, the other ones down and this one is up *points to rope handle* The rope is

Thermometer Preference

X	Spkr	Transcript
1680	Ryan	Green, so if we were to pick two thermometers to use, which one, or pick one, which one would you want to use?
1681	Malcolm	*places hands on each side of ECT and pats it*
1682	Ryan	That one, why?
1683	Malcolm	*picks up ECT* Cause I like it
1684	Ryan	I am going to have you say that again just because the toilet flushed. Why would you use that one?
1685	Malcolm	Cause I like it how it changes colors. *moving fingers up and down on the ECT display*

Research Question 3

How do kindergartners interpret graphic representations of air temperature in relation to the ECT?

Process Code	Number of Instances
2 : Agrees with a short stack of blocks as cold and a high stack as warmer	2
105 : Making sense of line plot	1

107 : Making sense of map	1
114 : Making sense of plot, pointing out geographic locations	1
117 : Making sense of time ordered plot, comparing heights	2
125 : Making a temperature comparison	5

Malcolm interprets the bar graph and the line plot by height, noting that the height changes without making references to changes in hot or cold.

X	Spkr	Transcript
1901	Ryan	So this is when I got up and had breakfast *touches first blue* , this is when I went to school *touches green*, this was in the afternoon after lunch *touches first yellow*, this is towards the end of the school day like now *touches the second yellow*, this might be getting ready for dinner *touches second blue*, this might be getting ready for bed *touches third blue*, and this might be sleeping *touches 4th blue*. So what do you think the temperatures are like then?
1902	Malcolm	Different sizes
1903	Ryan	I have some numbers that I want to show you and see if you could tell me what these numbers are. What's this number? *points to 72*
1904	Malcolm	Seventeen
1905	Ryan	Seventeen *points to 80*
1906	Malcolm	Eighteen, fourteen, forty two, seventy, sixteen six
1907	Ryan	OK, sometimes scientists make pictures that show the temperature too. I want to show you what their pictures look like and see if you can tell me anything about them. So here is one picture from this week for the temperature. Can you tell me what that might mean? *places temperature line plot on table*
1908	Malcolm	How high it's doing. *moves finger along the red line showing temp*
1909	Ryan	Yeah, how high it is. That's very good. Anything else you want to tell me about it?
1910	Malcolm	*cough* It goes higher and higher and higher. *makes zig zag motion with finger over plot*
1911	Ryan	Higher and higher and higher, thank you. I am going to show you another one.

For the weather map, he interprets it for locations.

X	Spkr	Transcript
1913	Ryan	This one is a map and it is showing temperature. Can you tell me what that is showing?
1914	Malcolm	These ones are the littlest *points to lower end of scale at top of*

		page this color and this color, and there are different colors 'inaudible' This on is mount four *points to Buffalo*, and this one's needa *points to Montanna*, and this one is my dad's work *points to SD* cause that looks like it, and this one is Utah *points to OK*
1915	Ryan	Can you tell me anything about the temperatures on this, on here?
1916	Malcolm	The earth how it shows *swirling motion with finger on map* momemters *makes earth rotating gesture maybe with arms* in the world, that how you know.
1917	Ryan	Anything about the colors?
1918	Malcolm	Colors, in this? *points to map*
1919	Ryan	Yeah
1920	Malcolm	How they are different colors and the same?
1921	Ryan	Yeah, what might those different colors mean?
1922	Malcolm	How the different colors in the same, they change colors cause the storm's wind *makes big gestures with arms*

Participant Summary

Malcolm makes sense of temperatures using gestures to show how the body experiences temperature. When showing an increase of temperature, he makes a larger sun. Although he is able to read and notice differences on the thermometers, I do not see evidence of him knowing how temperature relates to hotness and coldness.

CURRICULUM VITAE

RYAN FRANCIS CAIN

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ACADEMIC EMPLOYMENT

2018–Present Instructor of Educational Technology
Department of Teacher Education
Weber State University

EDUCATION

2019 Ph.D., Instructional Technology and Learning Sciences
Utah State University
Major advisor: Dr. Victor R. Lee

2006 M.A.T., Childhood Education
Queens College, City University of New York

2001 B.A., Fine Art Photography
University at Buffalo

PUBLICATIONS

Lee, V.R., Fischback, L., & **Cain, R.** (2019) A wearables-based approach to detect and identify momentary engagement in afterschool makerspace programs. *Contemporary Educational Psychology,* doi: https://doi.org/10.1016/j.cedpsych.2019.101789.

Cain, R., Phillips, A., & Lee, V.R. (2017) Making her way, One youth's path to well-developed interest in digital fabrication *In proceedings of the Learning Sciences Graduate Student Conference, Expanding Apprenticeship*. Bloomington, IN

Drake, J. R., **Cain, R.**, & Lee, V. R. (2017). From Wearing to Wondering: Treating Wearable Activity Trackers as Objects of Inquiry. In D. Tsybulsky & I. Levin, *Digital Tools and Solutions for Inquiry-Based STEM Learning*. IGI Global.

Cain, R. & Lee, V.R. (2016). Measuring electrodermal activity to capture engagement in an afterschool maker program. *In proceedings of FabLearn 2016: Conference on*

Creativity and Fabrication. ACM.

Lee, V.R. & **Cain, R.** (2016) Wearing their feelings on their sleeves? Wearable technology and the capture of student engagement with Maker activities. In Azevedo, F. (chair), Ahn, J., Mann, M., Dorph, R., Cannady, M., Lee, V.R., & Cain, R. Moving ahead in the study of STEM interests and interest development: A new research agenda. In *Proceedings of the International Conference of the Learning Sciences*. Singapore: International Society of the Learning Sciences.

Lee, V. R., Drake, J., **Cain, R.**, & Thayne, J. (2015). Opportunistic uses of the traditional school day through student examination of fitbit activity tracker data. In *Proceedings of the 14th International Conference on Interaction Design and Children* (pp. 273-276). ACM.

Nadelson, L. S., **Cain, R.**, Cromwell, M., Edgington, J., Furse, J., Hofmannova, A., Lund, E., Matyi, J., Morris, S., Sais, C., & Xie, T. (2015). A world of information at their fingertips: College students' motivations and practices in their self-determined information seeking. *International Journal of Higher Education*, 5(1), 220.

Crismond, D., Soobyiah, M., & **Cain, R.** (2013). Taking engineering design out for a spin. *Science and Children,* 50(5), 52.

Crismond, D., Gellert, L., **Cain, R.**, & Wright, S. (2013). Minding design missteps. *Science and Children*, *51*(2), 80.

Suescun-Florez, E. A., **Cain, R.**, Kapila, V., & Iskander, M. G. (2013). Bringing soil mechanics to elementary schools. *In proceedings of the 120th Annual Conference and Exposition*, *Engineering Education: Frankly, We Do Give a D*mn*. Atlanta :American Society for Engineering Education

Suescun-Florez, E., Iskander, M., **Cain, R.**, & Kapila, V. (2013). Delivering geotechnical engineering to elementary school children. *Geo-Strata—Geo Institute of ASCE*, *14*(2), 44-48.

Suescun-Florez, E., Iskander, M., Kapila, V., & **Cain, R.** (2013). Geotechnical engineering in US elementary schools. *European Journal of Engineering Education*, *38*(3), 300-315.

PRESENTATIONS

Cain, R., & Rasmussen, C. (2019). No experience required, Online teaching tools to make your instruction more effective. Workshop presented at the 50th Annual Meeting of the International Society for Exploring Teaching and Learning,

Charlotte, NC.

Lee, V.R., Fischback, L., Chandel, A., & **Cain, R.** (2018). Looking at aggregate arousal levels across youth in afterschool makerspace activities. Poster presented at the American Educational Research Association Meeting, New York.

Cain, R., Phillips, A., & Lee, V.R. (2018). Making her way, One youth's path to well-developed interest in digital fabrication. Stand-alone paper presented at the NARST Annual International Conference, Atlanta, GA.

Cain, R., & Phillips, A. (2017). From participant to mentor, A case study of youth interest development in a makerspace. Poster presented at Student Research Symposium at Utah State University in Logan, UT.

Cain, R. (2016). An educator's perspective of the classroom support needed for children with hearing loss. Invited lecture presented to the graduate-level Listening and Spoken Language Interdisciplinary Seminar, Department of Communicative Disorders and Deaf Education, Utah State University, Logan, UT.

Lee, V. R., & **Cain, R.** (2016). Using wearables to capture features of engagement in youth makerspaces. Paper presented at the aWear 2016: Wearable technologies, knowledge development, and learning Stanford, CA.

Cain, R. (2016). Electrodermal activity used as a proxy for engagement in a makerspace. Presentation at Student Research Symposium, Utah State University, Logan, UT.

Lee, V.R. & **Cain, R.** (2016). Does a jump count as a step? A case of a productive disciplinary engagement with recess activities. Paper presented at the American Educational Research Association Meeting, Washington, DC.

Lee, V. R., Drake, J., Thayne, J., & **Cain, R.** (2016). From using wearable technology to improving with statistical reasoning. Poster presented at the American Educational Research Association Meeting, Washington, DC.

Lee, V. R., King, W.L., & **Cain, R.** (2015). Grassroots or returning to one's roots? Unpacking the inception of a youth-focused community makerspace. Paper presented at FabLearn 2015, Stanford, CA.

Cain, R. (2015). 3D printing and modeling in an elementary science classroom. Presentation at Making Innovation Makerspace Conference 2015, Utah State University, Logan, UT.

Dec, J., Burker, J., **Cain, R.**, Rudzitis, T., Tiffin, J., Wheeler, S. (2014). Making in the classroom: Reports from the front lines. World Maker Faire, Flushing, NY.

Baker, A., Amu, Y., Chavez, R., & **Cain, R.** (2012). Sustainable school gardens and community building. Brooklyn Food Conference, Brooklyn, NY.

TEACHING EXPERIENCE

University Level Coursework

Weber State University
Undergraduate
Media Integration in Elementary Education I
Media Integration in Elementary Education II
Media Integration in Secondary Settings
Elementary Level II Practicum
Elementary Science Methods
Graduate
Instructional Technology for Pre-Service Teachers
Current Issues, Topics, and Practices in Education

Utah State University
2018 Teaching Science II SCED 4400/TEAL 6900
Teaching Assistant
Department of Teacher Education and Leadership

2017 Technology Integration & Innovation in Education 5500 (online)
Teaching Assistant
Department of Teacher Education and Leadership

2015 Craft Technologies Course 5270/6270
Instructor
Department of Instructional Technology and Learning Sciences

Professional Development Workshops, Utah State University
2017-2018 Year Long Weather Study
Reflective practice
Dolores Dore Eccles Early Childhood Center
NAEYC Accredited Preschool
2015 Sewing Up Science, Paper Circuits and E-Textiles
STEM-U 4-day professional development for teachers

K-12 Teaching
2006-2014 Elementary Science Teacher, Pre-K through second grade
PS 3 The Bedford Village School, Brooklyn, NY

DISTINCTIONS

2019	Research, Scholarship and Professional Growth Committee Travel Award Weber State University
2018	Research and Development Scholarship Department of Instructional Technology and Learning Sciences Utah State University
2016	AERA Sponsored Meeting on Making and Learning Travel Award Children's Museum of Pittsburgh
2015,2016, 2017,2018	Office of Research and Graduate Studies Travel Award Utah State University
2015-2017	Lawson Fellowship Utah State University
2014-2018	Presidential Doctoral Research Fellowship Utah State University
2013-2014	Kerlin Science Fellowship Bank Street College of Education
2006	Herbert Swartzberg Award Queens College, City University of New York

PROFESSIONAL EXPERIENCE

2018	Collaborative research: Using a school-based sensing platform and targeted teacher professional development to support computational thinking integration and student learning PI: Dr. Mimi M. Recker NSF Grant # DRL-1742046 Graduate Research Assistant Utah State University
2016-2017	Tracking youth interest and engagement in makerspace learning activities using wearable technology PI: Dr. Victor R. Lee NSF Grant # CNS-1623401 Graduate Research Assistant Utah State University

2014-2016 Engaging elementary students in data analysis through study of physical activities
PI: Dr. Victor R. Lee
NSF Grant # DRL-1054280
Graduate Research Assistant
Utah State University

COMPLETED GRADUATE STUDENT ADVISEMENT

As Chair of Masters Committee
Fall 2019 Whitney Fowers
As Member of Masters Committee
Fall 2019 Michelle Topham
Stacy Henry

SERVICE

2018, 2019 Invited reviewer of papers for NARST Annual International Conference

2017 Invited reviewer of long papers for FabLearn Conference at Stanford University

2016 Invited reviewer USU Undergraduate Research and Creative Opportunities Grant program

2015, 2016 Invited reviewer of short papers for FabLearn Conference at Stanford University

2015-2016 Ph.D. Student Vice President, USU Department of Instructional Technology Student Association

2014,2015 Invited reviewer for the *European Journal of Engineering Education*

VOLUNTEER WORK

2016 Led six-session afterschool club on force and motion where youth fabricated and experimented with laser-cut cardboard cars.
Cache Makers 4-H, Logan, UT

2016 Co-taught third grade unit on force and motion with laser-cut cardboard cars.
Ellis Elementary School, Logan, UT

1996-2008 Firefighter
Garden City, NY