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FOSTERING SCIENCE LITERACY AMONG CULTURALLY AND LINGUISTICALLY DIVERSE MIDDLE SCHOOL STUDENTS

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SO LIM KIM

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ABSTRACT

Fostering Science Literacy Among Culturally and Linguistically Diverse Middle School Students

So Lim Kim

Dr. Deoksoon Kim, Chair

Most science education reform efforts are designed to promote science literacy for all students. In order for students to effectively apply abstract science concepts and knowledge to their lives, they must develop strong science literacy skills. Yet culturally and linguistically diverse (CLD) students, whose language and cultural backgrounds are different from mainstream American culture, often lack full access to all the educational avenues that would help them fully develop science literacy. Consequently, this dissertation explored and documented the ways educators have investigated and modified multiple aspects of science-based teaching and learning in order to benefit CLD students.

This three-paper dissertation investigates three pedagogical approaches for supporting CLD students' science literacy: culturally relevant pedagogy, translanguaging, and writing-to-learn. Research on these three pedagogical approaches is crucial for examining factors that affect CLD students in developing science literacy and providing recommendations on how to support them. To investigate CLD students' experiences in-depth, this dissertation used a multiple-case study design to conduct analyses within each case as well as across all cases.

The first paper investigated how middle school CLD students applied their family and cultural knowledge to learning science content in school. This study addressed the development

of students' science literacy by examining CLD students' engagement with "HomeFun," a set of culturally relevant activities. The second paper explored CLD students' science literacy development in a translanguaging science classroom. By inquiring into participant students' experiences with translanguaging and perceptions of its use, this study uncovered tensions between how translanguaging can facilitate students' comprehension of science content while underscoring students' desire to use English to improve their English language skills. The third paper examined how writing-to-learn can shape CLD students' science literacy development. In a case study of six CLD students' experiences with writing and content analysis of their compositions, this study revealed how writing helped students develop their thinking, effectively facilitating knowledge transfer from school-based contexts to real-world ones.

Together, these studies demonstrate the usefulness of culturally relevant pedagogy, translanguaging, and writing-to-learn for fostering CLD students' science literacy. Furthermore, each study offers insight into influences on CLD students' ability to develop science literacy, such as the importance of family engagement or the pervasive nature of school-based monoglossic language ideologies. The three pedagogical approaches effectively support students socially, culturally, and academically, to make meaningful connections between science concepts and the world around them. In exploring the application points of culture, language, and literacy within science-based learning, this research offers science educators new insights and educational practices in support of CLD students.

CITATION TO PREVIOUSLY PUBLISHED WORK

Portions of this dissertation are from the material that has been published or is in the preparation process for publication.

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DEDICATION

To all heartful educators

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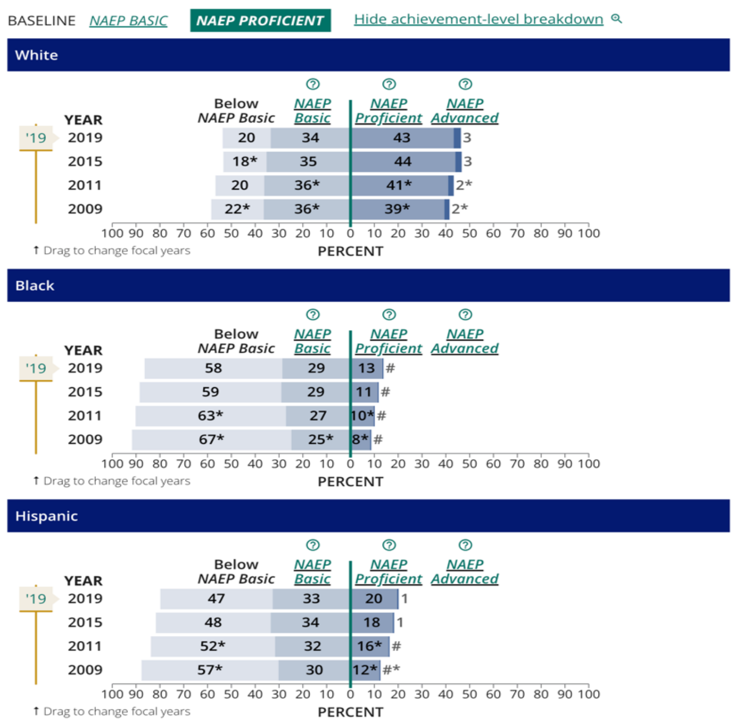
CHAPTER ONE

Introduction

Since 2014, demographic growth for students of color has outnumbered that of white students in U.S. public schools (Paris, 2017). Despite science education reform efforts designed to promote science literacy for all students, the process of developing science literacy is particularly challenging for culturally and linguistically diverse (CLD) students who come from language and cultural backgrounds differing from the white-normed, English-speaking culture (Brown et al., 2005; Lee & Fradd, 1998; NAEP, 2022). For example, a recent National Assessment of Educational Progress (NAEP) (2022) report on the science achievement levels of eighth graders in the United States identified a persistent achievement gap between white and CLD students (See Figure 1).

Figure 1

NAEP Science Achievement-level Results for Eighth-grade Students by Race/Ethnicity



According to the Programme for International Student Assessment (PISA), becoming scientifically literate is far more complex than the memorization and lecture-based practices characteristic of traditional science classrooms (OECD, 2010, 2019). Science literacy requires students to have both scientific knowledge and literacy skills enabling them to effectively connect and interact with the larger world (OECD, 2019):

> [Science literacy is] the ability to use knowledge and information interactively. In other words, scientific literacy includes "an understanding of how [a knowledge of scientific concepts] changes the way one can interact with the world and how it can be used to accomplish broader goals" (ibid.: 10) (p. 98).

Science literacy depends on students' ability to translate scientific understanding to real-world contexts. Strong language and literacy skills are an essential component of this communicative transfer. Yet effective language and literacy instruction for CLD students requires teachers to incorporate multiple aspects of instruction in the science classroom, including the use of language (Halliday, 1993), science-based literacy practices such as writing (Brisk, 2014; Schleppegrell, 2004), and the particular sociocultural differences (Swain et al., 2015; Vygotsky, 1978) of CLD students who are learning science (Lee et al., 2005; Lee & Fradd, 1996; Lee et al., 2004).

Science Literacy for Culturally and Linguistically Diverse Students

Researchers and professional organizations have defined science literacy in various ways (National Research Council, 1996; Garcia, 1985; Liu, 2009; OECD, 2010, 2019; Pelger & Nilsson, 2016). One definition from the National Research Council (1996) suggests,

> A person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusion. (p. 22)

While this definition provides a broad view of science literacy, it does not make clear for whom and under what conditions it can be applied. Teachers seeking to serve CLD students must cultivate awareness of students' cultural, social, and linguistic backgrounds. They must also stay aware of how students' ability to describe and explain can vary depending on which language they use in particular situations. For example, CLD students may not be able to explain a scientific concept as accurately in English as they can in their first language. Also, CLD students' ability to read and engage conversation in science can vary depending on the language skills being required, whether speaking, listening, reading, or writing. CLD students may have high English proficiency in speaking but lack it in reading or writing.

Accordingly, a broad definition of science literacy is insufficient to define the nuanced cultural and linguistic aspects of science literacy for CLD students. This research therefore expands this definition to include the requirements that science literacy oriented to CLD students' needs is multicultural (Padilla, 2004) and multilingual (Banks, 2004; Cenoz, 2009). It should help CLD students 1) incorporate their own cultural knowledge and experiences with scientific knowledge, 2) engage in social conversations or interactions in the context of science using their full linguistic repertoire, and 3) use both written and spoken language as a resource to make meaning, enhance comprehension, and extend their knowledge of scientific concepts.

Theoretical Framework

Cultural Congruence Framework

This dissertation uses the framework of *cultural congruence* to conceptualize CLD students' science literacy development. This perspective focuses on helping teachers understand and deliver instruction enabling students to build congruence between academic disciplines and their linguistic and cultural knowledge (Lee, 2003; Lee & Fradd, 1998). Research on cultural congruence first emerged in the early 1990s, when it focused on building shared knowledge and experiences between teachers and students

(Au & Kawakami, 1994; Gay, 2002; Lee & Fradd, 1998). Such an approach was useful for promoting student participation and engagement in learning (Au & Kawakami, 1994; Gay, 2002; Lee & Fradd, 1998). Cultural congruence is founded on a recognition of students' constructed knowledge and experiences, from family, traditions, culture, home language, and literacy (Lee, 2003; Villegas & Lucas, 2002). When students' knowledge and experiences are aligned with school learning, teachers effectively prioritizing students' existing knowledge and experiences as intellectual resources enabling them to better utilize and connect with new learning in science classrooms (Boutte et al., 2010; Gay, 2002; Lee, 2004).

Past research demonstrates that cultural congruence has a positive relationship with CLD students' academic performance in science (Gay, 2002; Lee, 2005; Lee et al., 2008; Villegas & Lucas, 2002). Students' academic and verbal performances improve when curriculum and instructions are culturally and linguistically congruent with students' knowledge and experience (Deyhle & Swisher, 1997; Lee et al., 2008; Tharp & Gallimore, 1989). On the other hand, when CLD students' prior knowledge and experiences are deemed incongruent with traditionally based science practices, it poses a challenge for these students. Lee (2003) explains,

> Such discontinuities between cultural expectations and scientific practices require students to shift between different types of knowledge, practices, and discourse if they are to have access to school science without abandoning their home culture. Teachers, in turn, must integrate their knowledge of students' language and

> culture with knowledge of science disciplines if they are to make science accessible and meaningful for all students. (p. 466)

Such perspectives demonstrate how important it is for teachers to actively develop congruence between academic disciplines and CLD students' prior cultural and linguistic experiences. For CLD students who are learning English as a second language, linking English language and literacy development with science discourse is even more crucial (Cummins, 1981; Herrera & Murry, 2006; Lee, 2015).

Purpose of Study

Using this cultural congruence viewpoint, this study sought to explore how three pedagogical approaches oriented to these aims supported CLD students' science literacy development. These approaches were culturally relevant pedagogy (CRP), translanguaging, and writing-to-learn. I was interested to see not only how these practices might support students' science learning, but in how it might also encourage them to bring their cultural and linguistic knowledge and experiences to bear in their process of learning science content. The first approach, CRP, is a theoretical model designed to support CLD students' academic achievement through utilizing their cultural assets (Ladson-Billings, 1995, 2014; Morrison et al., 2008). Translanguaging is a linguistic application of CRP which supports CLD students to utilize their full linguistic repertoire by allowing them to use all aspects of their linguistic knowledge in learning (Alvarez, 2014; Celic & Seltzer, 2013; García, 2012; García & Lin, 2017). Writing-to-learn is a pedagogical approach designed to support students' academic achievement by providing opportunities for students to write to reflect, clarify, and reconnect prior knowledge with new knowledge (Baker et al., 2008; Boscolo & Mason, 2001).

The purpose of this three-paper dissertation was to investigate CLD students' experiences of these pedagogical approaches to understand how they develop science literacy. It also sought to understand what students could express about their experiences with such practices. Accordingly, I sought to examine the effectiveness of integrating culture, language, and writing in the science classroom.

In the first paper (Chapter 2), I explored middle-school CLD students' engagement with "HomeFun," a culturally relevant set of activities inviting students to explore science concepts with their families in home-based learning engagements. To date, not many research studies on culturally relevant pedagogy have specifically addressed science education. Additionally, most studies on culturally relevant pedagogy in science have taken place in elementary education, in contrast to this study, which explored these ideas with middle-school students. Using a multiple case study design, this study explored how CLD students applied their familial and cultural knowledge in the culturally relevant science activity. The following questions guided this paper's research design and enactment:

- How do CLD middle school students draw on cultural knowledge in HomeFun activities?
- How do CLD middle school students perceive and experience culturally relevant HomeFun activities as they learn science?

- How do culturally relevant HomeFun activities foster knowledge transfer from home to school?

The second article (Chapter 3) explored CLD students' science literacy development as they participated in translanguaging practices with their multilingual teacher, Mrs. Irene. Although researchers have explored and documented CLD students' linguistic and cultural needs, there is limited research on translanguaging as a pedagogical practice to develop CLD students' science literacy. Through an investigation of these students' experiences with and perceptions of translanguaging, this study explored how CLD students grew in their science learning, as well as enhanced their science literacy. The following questions guided this study:

- How do emergent bilingual students engage in translanguaging practices in a middle-school science classroom?
- What are their experiences and perceptions with the practice?

The third article (Chapter 4) investigated the potential of writing-to-learn for supporting CLD students' science literacy. While writing-to-learn and its positive influence on students' language development has been documented in English as a second language (ESL) classrooms, the implications of writing-to-learn in science are understudied (Barabouti, 2012; Langer & Applebee, 1987; Manchón, 2011; Soucy, 1994). In addressing this significant gap in the research, this study explored six CLD students' experiences with writing-to-learn in a science class with the following research questions:

- How do CLD students perceive and experience writing in science?

- In what observable ways do CLD students' scientific knowledge and application of that knowledge change through writing?

Context

This study was part of a collaborative effort between Boston College, the Lemelson-MIT (the School of Engineering at the Massachusetts Institute of Technology), and Brown Public School District (BPSD) (pseudonym). In collaboration with two middle schools from BPSD, the two university-based institutions developed and implemented a longitudinal STEM program to provide middle school students with opportunities to engage in transformative STEM experiences. The program was particularly oriented to serving students whose population groups are underrepresented in STEM fields.

The collaboration began with Lemelson-MIT's invent program curriculum as the basis for designing students' STEM learning experiences. This program has eight invent education guides, along with "Junior Varsity (JV) InvenTeams activity guides" (https://lemelson.mit.edu/resources/curriculum-invention). The JVInvenTeams curricula are aligned with Next Generation Science Standards and designed to support middle- and high-school educators in facilitating student-led invention groups. From these eight units, the Lemelson-MIT and Boston College team selected the "Chill Out" unit as the one to modify for CLD students. Chill Out is an instructional unit in which students learn about heat transfer concepts such as convection, conduction, and radiation. Students apply their knowledge in an invention-based task, working in groups of three or four to design and build a lunch box. In order to better accommodate the needs of CLD students, the Boston

College team modified the curriculum by adding 1) visualizations (visual aids), 2) the "HomeFun" culturally relevant activities, and 3) writing instructions and activities. All modification and activities were aligned with content and language standards for seventh grade science standards.

The revised Chill Out unit was designed to run from 8–12 weeks. Six seventh-grade science teachers from two public middle schools in BPSD implemented the Chill Out program during their school day. To date, over 300 students have taken part in Chill Out over the past three years.

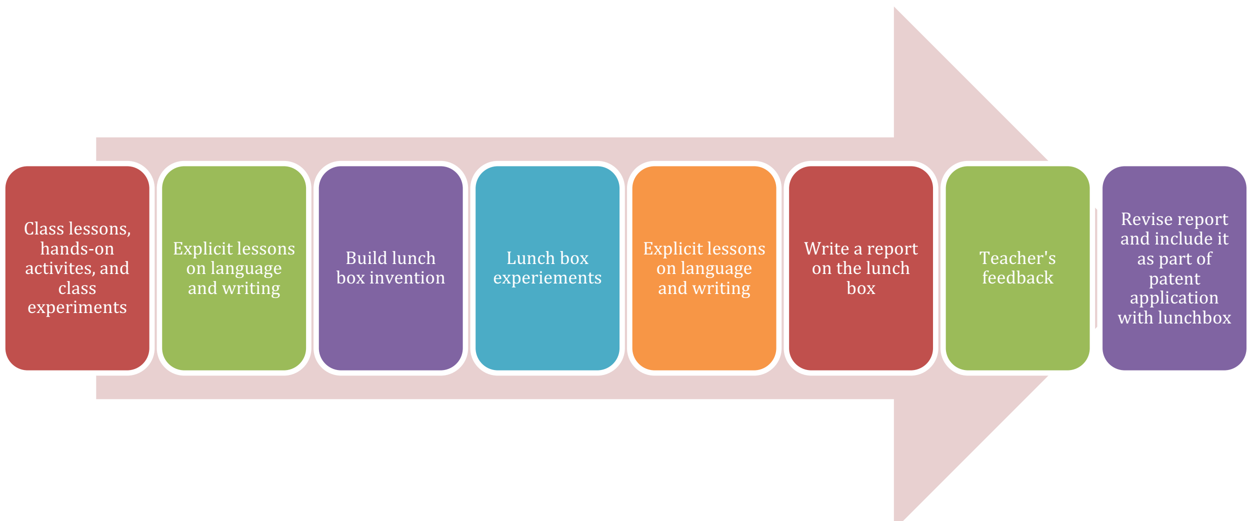
Invention-Based Learning Curriculum, Chill Out

The Chill Out program was based on invention-based learning (IBL) pedagogy, which is an active, student-centered learning approach to teaching science (Kim & Kim, 2021). Within its curricular aims, students must apply science knowledge by inventing an object to solve real-world problems (Kim et al., 2021; Kim & Kim, 2021; Zhang et al., 2019). Unlike a traditional science classroom where students generally receive scientific knowledge through lecture-based classroom activities, IBL promotes interdisciplinary thinking by requiring students to apply scientific knowledge in their projects (Kim et al., 2019; Kim et al., 2021; Zhang et al., 2019).

For the Chill Out unit, students received an empty shoe box, along with access to a variety of materials, and create a lunchbox designed to keep a chilled water bottle cold, even when the lunch box is set under a heat lamp. Students worked in groups, undergoing a cognitively challenging learning process involving problem-solving, learning science content, and applying this content to real-life situations. Students must adopt an inventor's mindset, requiring them to stay open to the many possibilities that exist for solving problems (Zhang et al., 2019) and communicating collaboratively to effectively enact their design.

Figure 2

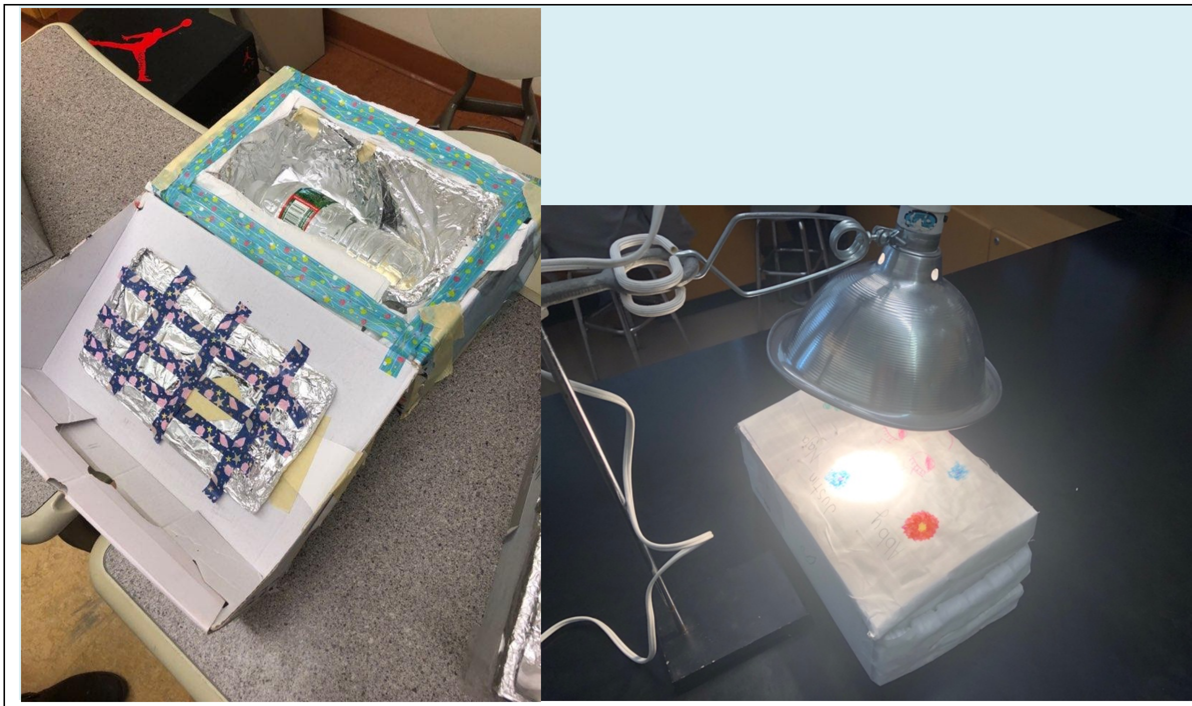
Procedure of Chill Out Program



At the outset of the Chill Out unit, students explored concepts related to heat transfer such as convection, conduction, radiation, insulation, and thermal equilibrium. They did this learning by engaging in whole-class and small group lessons, hands-on activities, and experiments. Teachers explained insulation and the thermoelectric effect and reviewed the usefulness of thermal materials that prevent heat transfer. Two explicit lessons on language and writing were also included to support students in authoring a report on their group's lunch box invention.

Picture 1

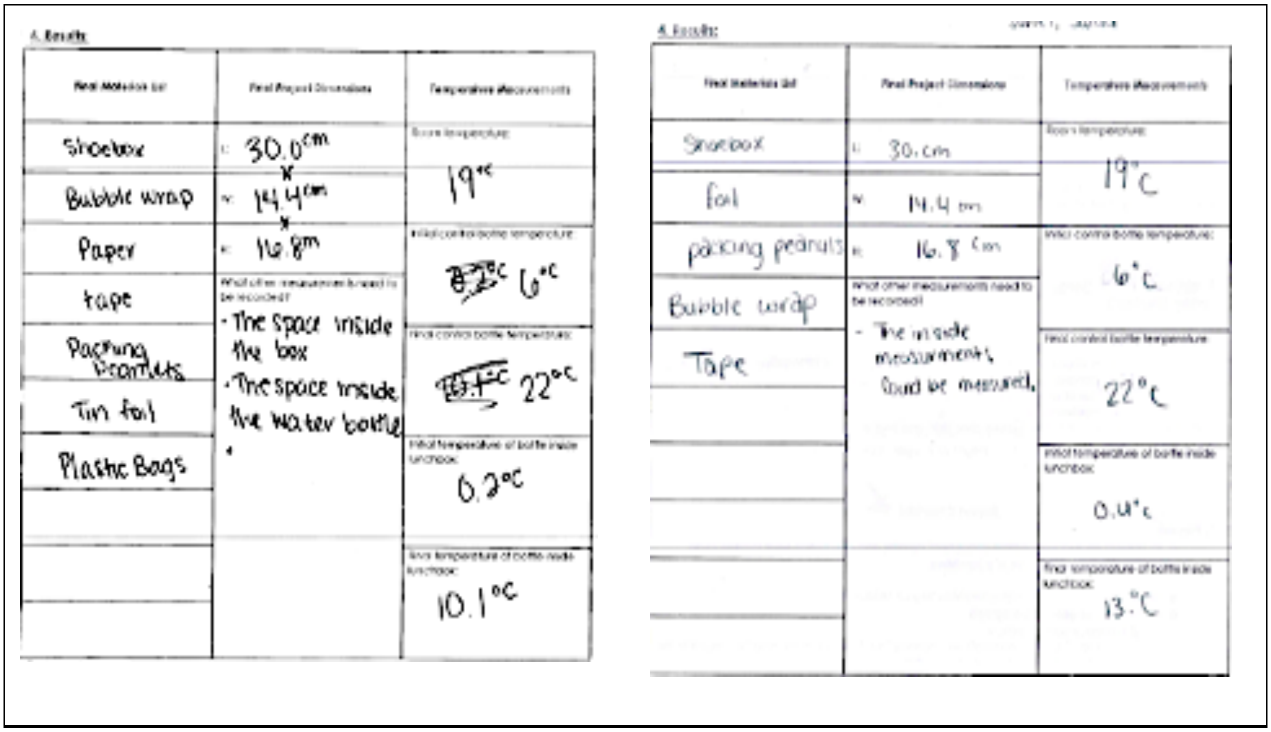
Lunch Box Experiments



For the final project, students worked in groups of three or four to create a lunch box designed to prevent heat transfer. They had access to insulating materials such as aluminum foil, bubble wrap, packing peanuts, old clothes, and construction paper. They used the knowledge and experiences they gained throughout the program to reduce heat transfer through blocking conduction, convection, and radiation with their design and use of materials. Their goal was to create a lunch box that would maintain temperature for a chilled water bottle placed inside, even when the lunch box sat under a heat lamp. Once all groups had created their lunch box, they tested them for effectiveness; each group put their lunchbox under a heat lamp for hours before checking the temperature of the chilled water bottle inside. Their temperature was compared to the control, a chilled water bottle contained in a plain shoebox kept under the same heat lamp.

Figure 3

Examples of Students' Lunch Box Experimental Results



Students used the test results to draft their reports, which were framed as patent applications explaining and promoting their lunchbox invention (Figure 3). Students created both an initial and final draft of their reports and utilized teacher feedback in drafting their final reports. These reports and lunch boxes were subsequently displayed in students' science classrooms for the remainder of the semester.

Research Positionality and Trustworthiness of Study

Since I am a CLD person who learned English as a second language, I have an insider's perspective on what it means to experience cultural diversity and the language learning process. As I observed in these IBL science classrooms from the beginning to the end of the Chill Out curriculum, I gained deep insider knowledge of each classroom's culture, learning science content, and CLD students' experiences.

While this insider perspective gave me deep understandings of participants and their learning experiences, I must also acknowledge the possibility it had the potential to hinder my ability to view the data objectively. To avoid greater bias and become critically conscious towards my process, I cultivated an outsider's perspective as I worked with the data. I actively monitored my positionality and bias throughout the analysis process by writing analytic memos and cultivating a critical stance through conversations with my research team (Merriam & Tisdell, 2016). I regularly dialogued with a member of my dissertation committee and asked an outside researcher to review my analysis and point out any implicit bias. I was careful to discuss any discrepancies in data interpretation until both parties were satisfied.

To ensure I described participants' perspectives, I employed emic voices and thick descriptions in my findings (Merriam & Tisdell, 2016). This work, supported as it was with direct quotes from students, helped me ensure other researchers might find transfer for these results to their educational contexts. To further increase the validity of the study, I triangulated data such as field notes, interviews, and student writing samples (Flick, 2018). Using a variety of data sources enabled me to cross-validate and capture different dimensions of the same phenomenon (Lauri, 2011). I employed at least three different data sources for each study to answer my research questions. This ensured participants had multiple and diverse opportunities to share their experiences with me and enable me to offer a deep and rich understanding of the phenomenon under study.

Definition of Terms

Several technical terms are useful to understanding the constructs of this study.

The term **culturally and linguistically diverse (CLD)** refers to individuals who come from a home environment where cultural values, background, and language differ from the white, middle-class, and English-speaking norms prioritized in traditional U.S. education (Chamberlain, 2005; Herrera & Murry, 2006; Ko et al., 2020; Li, 2013; Murry, 2012). Some studies use the term CLD to refer to English language learners who came from a home environment where English is not the primary language (Herrera & Murry, 2006; Perez, 1996). However, in this dissertation, CLD students encompassed children and grandchildren of immigrants whose home or heritage culture was different from the dominant culture in the United States.

I use the term **English-language-learning CLD students** to refer to students whose primary language or home language was not English and who needed language and literacy support to develop fluency in English. The terms **emergent bilingual** and **English language learning CLD** were used interchangeably to refer to English language beginners who came to the United States less than a year before their participation in the Chill Out program.

Organization of the Dissertation

This dissertation is organized into five chapters:

Chapter 1 – Introduction: This chapter introduces the dissertation, purpose of study, theoretical framework, context, research positionality and trustworthiness of the research, and definition of terms. This was an organizational framework linking the following three chapters.

Chapter 2: This first paper encapsulated the empirical study exploring six CLD students' experiences with the culturally relevant activities called HomeFun, a home-based series of activities designed for students to integrate science-based knowledge with their families' cultural experiences. This study explored how culturally relevant pedagogy found practical application in promoting CLD students' science literacy development and knowledge transfer.

Chapter 3: This empirical study examined the experiences of four emergent bilingual students in relation to translanguaging in their science class. The article discussed translanguaging as an effective pedagogical tool to develop students' science content. It also underscored the complexity of such experiences for students, who feel strongly motivated to learn English. This paper discussed effects of translanguaging in learning science and family engagement as well as the consequences of monoglossic ideology on emergent bilingual students.

Chapter 4: The third paper examined how the writing-to-learn pedagogical approach shaped CLD students' science literacy development. This study was uniquely contextualized in an IBL classroom, exploring the interplay between invention-based instruction and writing-to-learn. Subsequently, this paper discusses how writing-to-learn can be an effective learning tool for CLD students in the context of IBL classroom.

Chapter 5: This final chapter offers brief summaries of each paper and discusses the connections across the three studies. The recommendations for future research are also included.

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CHAPTER TWO[1]

Creating Inclusive & Engaging Science Learning through Culturally Relevant Practice

Immigrants and children of immigrants are an ever-increasing population in the United States (Snyder et al., 2018). As the number of first- and second- generation immigrants rise, numbers of culturally linguistically diverse (CLD) students have also increased (Saad et al., 2013; West & Maffini, 2019). CLD students have been studied by many scholars (Benet-Martínez & Haritatos, 2005; Chamberlain, 2005; Schwartz & Zamboanga, 2008; West & Maffini, 2019) and are typically defined as individuals who navigate between their family culture and the dominant culture. Sometimes CLD students are not fluent in their heritage language but are nevertheless deeply embedded in both their heritage and the dominant culture. For example, a child who was born and raised in the United States but embedded in a Mexican community could identify her/himself as a CLD student and bicultural Mexican American. Despite the increasing number of CLD students, many science teachers still struggle to address cultural diversity in the classroom (West & Maffini, 2019). In this article, I present how culturally relevant pedagogy (CRP) can be intentionally embedded in science curriculum to support CLD

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student engagement and comprehension in science classroom within a CRP framework (Ladson-Billings, 1995).

To better engage and support diverse student populations in science classes, an invention-based learning (IBL) approach was introduced to a middle school science curriculum (Kim et al., 2019; Kim & Kim, 2021). IBL is a type of project-based learning implemented through a collaboration among Boston College, the Lemelson-MIT program, and a local school district. A team from Boston College modified one of eight Lemelson-MIT IBL curricula called "Chill Out" and add a culturally relevant family activity, "HomeFun." This unit focuses on heat transfer concepts and guides students to invent lunch boxes to block heat transfer. The HomeFun activity is aligned with the curriculum unit and designed to facilitate knowledge transfer from students' home knowledge to school knowledge by connecting students' cultural background with school science. Even though knowledge transfer has been investigated by many researchers in the last few decades (Boone et al., 2012; Reade et al., 2008; Roux et al., 2006; Thompson et al., 2006), not many studies have explored knowledge transfer in a cultural context outside of school. This study explores how a culturally relevant school activity can promote knowledge transfer and demonstrates how purposeful engagement between school, family, and culture can foster science learning.

Despite previous studies on culturally relevant pedagogy in science, studies on culturally relevant invention-based learning are scarce. Also, although researchers have explored English language learners' linguistic and cultural needs (Lee et al., 2005; West & Maffini, 2019), little research has specifically examined cultural needs of CLD students. Taking a sociocultural perspective on science learning, this study uses a multiple–case study design to explore six middle school CLD students' experiences with culturally relevant HomeFun activities in the IBL program. This study was guided by the following research questions:

- How do CLD middle school students draw on cultural knowledge in HomeFun activities?
- How do CLD middle school students perceive and experience culturally relevant HomeFun activities as they learn science in the culturally relevant IBL program?
- How do culturally relevant HomeFun activities foster knowledge transfer from home to school?

Literature Review

In order to answer the questions, I build on previous research in culturally relevant pedagogy, funds of knowledge, and knowledge transfer.

Culturally Relevant Pedagogy

The term culturally relevant pedagogy, also referred to as culturally relevant teaching (Ladson-Billings, 1995), was introduced in the 1990s as a responsive approach to more effectively instructing African American students. CRP aims to empower students' cultural competence while improving their academic achievement (Ladson-Billings, 1995). Ladson-Billings (2009) argued that CRP does not teach the dominant culture using minority students' cultural referents. Instead, it teaches that "they are aspects of the curriculum in their own right" (p. 20). The concept of cultural inclusion has been further extended and applied in various research and practice as a culturally embracing approach to teaching marginalized students (Gay, 2002; Ladson-Billings, 2009, 2014; Morrison et al., 2008).

Culturally Relevant Pedagogy in Science

Despite the popularity of CRP, science pedagogy infrequently incorporates diversity, culture, or language as part of science curriculum (Boutte et al., 2010; Johnson, 2011). Teachers in this content area typically believe science is a "fact-driven" subject, leading them to deem culture as an inappropriate subject to incorporate into science curriculum (Boutte et al., 2010; Johnson, 2011; Laughter & Adams, 2012). Research from Boutte et al. (2010) reveals teachers believe CRP could be appropriate for use in social sciences (such as social studies), language arts, and fine arts but not in "hard sciences" like science and mathematics (p. 2). To help teachers recognize and adopt science as a socially and culturally relevant subject, researchers have provided interventions designed to help teachers implement CRP in science classrooms (Barton & Yang, 2000; Laughter & Adams, 2012; Mensah, 2011).

One such research team, Roth and Barton (2004) have argued that cultural experiences should be a foundation of science curriculums if teachers seek to create a culturally inclusive and empowering learning environment. Science is a cultural subject in which students construct knowledge both inside and outside the classroom. Roth and Barton's (2004) work offered teachers a list of culturally relevant science activities that match the Grade 9-12 National Science Education Standards and reduced the gap between CRP in research and practice, such as an inner-school gardening project. Working from a community-based problem related to drug dealing in abandoned areas of the community, students and the program leader brainstormed the gardening project together. Using their knowledge of their own community and gardening, the students transformed a lot into a community garden. The gardening project was relevant not only to their culture and community but also to their grade level science standards. In so doing, they learned about the science concepts behind the gardening process, which included climate, soil, water, and its measurement and scale.

Similarly, many researchers (Au & Kawakami, 1994; Gay, 2002; Lee et al., 2005) have adopted and expanded CRP to connect cultural knowledge to school knowledge. Gay (2002) highlighted the importance of bridging students' cultural knowledge with new learning materials. She argued that culturally relevant learning experiences can make academic learning more meaningful and personal to students. She provided examples of CRP in science that include engaging students in (1) building communities, (2) adopting cross-cultural communications, and (3) providing culturally congruent classroom learning. She also emphasized the importance of knowing the cultures of different ethnic groups in order to appropriately adopt and incorporate them into classroom learning.

Funds of Knowledge

To understand students' diverse cultural knowledge, many studies use funds of knowledge as a framework to investigate the cultural experiences of students and merge them with classroom lessons (Barton & Tan, 2009; McLaughlin & Calabrese Barton, 2013; Razfar & Nasir, 2019; Warren & Rosebery, 2008). Funds of knowledge refers to the historical and practical knowledge that cultural groups accumulate over generations (Moll et al., 1992). Basu and Barton (2007) examined the relationship between funds of knowledge and science learning among students with high needs. Their findings indicated students' interests in science developed when their science learning experiences were related to their future visions for their lives. Also, students' interests increased when the learning environment matched their desired social relationships and the purpose of learning science (Basu & Barton, 2007). This suggests students who develop an interest in science are more likely to explore scientific phenomena outside of school and investigate at a deeper level. Similarly, many researchers have found that students in a funds of knowledge–oriented science project participate more, perform significantly better, and make a positive connection between themselves and science (Barton & Tan, 2009; Rivera Maulucci et al., 2014).

Knowledge Transfer

To successfully integrate students' funds of knowledge into school contents, it is important to know how knowledge transfers from one context to the other. Teachers must help learners master content and recognize the acquired knowledge to successfully expand it to a different setting (Barnett & Ceci, 2002; Engle, 2006). This cognitive process of transferring one's mastered knowledge from one context to the other is called "knowledge transfer" (Barnett & Ceci, 2002; Engle, 2006; Perkins & Salomon, 2012; Scardamalia & Bereiter, 1987). Knowledge transfer is an essential educational skill since it indicates a high level of comprehension for learners (Barnett & Ceci, 2002). The purpose of education diminishes if students cannot apply and expand what they learned in school to the outside world (Perkins & Salomon, 2012). Students should be able to transfer their knowledge to actively engage in the social world. However, many studies indicate the failure of current education systems to promote or foster knowledge transfer (Chi & VanLehn, 2012; Engle, 2006). This is because content areas are commonly taught as isolated knowledge. Perkins and Salomon (2012) states it as that “people commonly fail to marshal what they know effectively in situations outside the classroom or in other classes in different disciplines” (p.248). Without expansive framing of learning contents in different settings, the students’ school-based knowledge can be isolated and irrelevant for students’ daily lives (Engle et al., 2012).

Methods

I adopted a multiple–case study design to intensely investigate the CLD students’ experience in the culturally relevant IBL program (Merriam & Tisdell, 2015). This method allowed me to focus on the specificities of each CLD student’s experience while conducting a small-group comparison using multiple and detailed data sets.

Context

This project was part of a large collaboration between Boston College, the Lemelson-MIT program at the Massachusetts Institute of Technology, and a public school district in the Northeastern part of the United States. The Chill Out curriculum was originally created by Lemelson-MIT as an after-school activity guide. However, the modified version of the Chill Out curriculum was implemented during the school day for the participating public school district. Teachers incorporated the Chill Out curriculum into the seventh-grade science as part of their regular unit of study on heat transfer.

Chill Out Curriculum.

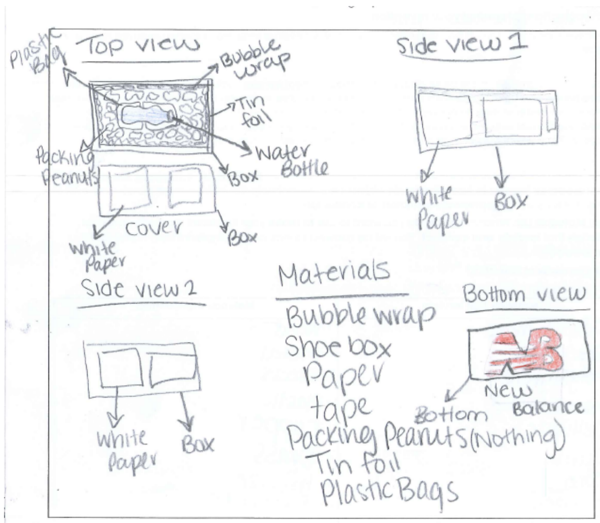
The Chill Out curriculum focused on heat transfer concepts such as thermal equilibrium, conduction, convection, and radiation. One of the main goals of the curriculum was to provide students opportunities to use the heat transfer knowledge to invent objects relevant to their daily lives. Throughout the Chill Out unit, students gained STEM knowledge and skills related to heat transfer concepts through diverse class activities and lab experiments. The major invention for the unit was a lunch box. Students applied heat transfer knowledge to create an effective lunch box out of a shoe box. After completion, students and teachers evaluated their lunch boxes for effectiveness by placing a chilled water bottle inside and setting the lunch box under a heat lamp. They compared experimental results to a control and recorded the results with their lunch box design (Figure 4).

Figure 4

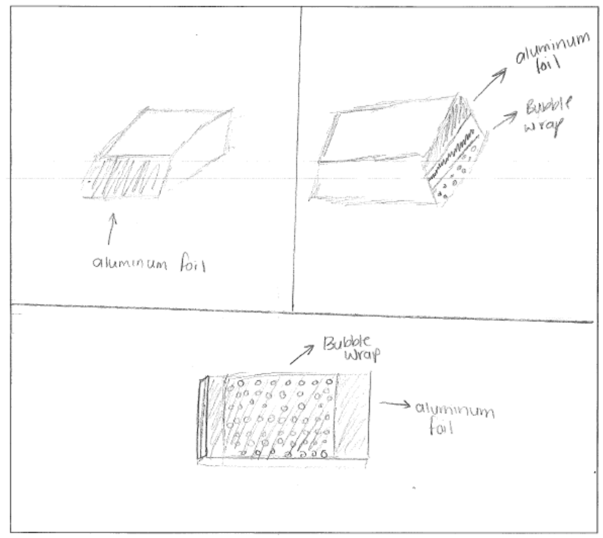
Examples of Students' Lunch Box Invention Design and Record Experimental Results

Naomi	Sam

Naomi



Sam



Naomi

4. Results:

Final Materials List	Final Project Dimensions	Temperature Measurements
Shoebox	L: 30.0cm x	Room temperature: 19°C
Bubble wrap	W: 14.4cm x	
Paper	H: 16.8m	Initial control bottle temperature: ~~0.2°C~~ 6°C
tape	What other measurements need to be recorded?	
Packing Peanuts	· The space inside the box	Final control bottle temperature: ~~10.1°C~~ 22°C
Tin foil	· The space inside the water bottle	
Plastic Bags		Initial temperature of bottle inside lunchbox: 6.2°C
		Final temperature of bottle inside lunchbox: 10.1°C

Sam

4. Results:

Final Materials List	Final Project Dimensions	Temperature Measurements
Shoebox	L: 30. cm	Room temperature: 19°C
foil	W: 14.4 cm	
packing peanuts	H: 16.8 cm	Initial control bottle temperature: 6°C
Bubble wrap	What other measurements need to be recorded?	
Tape	- The inside measurments could be measured.	Final control bottle temperature: 22°C
		Initial temperature of bottle inside lunchbox: 0.4°C
		Final temperature of bottle inside lunchbox: 13°C

To make the Chill Out unit more culturally relevant, the Boston College team incorporated diverse visualizations, science-literacy curriculum (patent writing application), and HomeFun activities. The related teaching materials and curriculum resources were provided and discussed in meetings with participating teachers, and further modifications were made according to the teachers' feedback. I focused on Mr. Kyle's classroom for this study. Mr. Kyle is a skilled science teacher who has been teaching for over five years. He was an active participant and contributor to the Chill Out unit modification. I chose Mr. Kyle's classroom because he taught students from diverse cultural backgrounds and he was interested in my studying about students' perspectives and opinions about the Chill Out lessons in his science classroom.

HomeFun Activity.

Within the Chill Out curriculum, a total of four HomeFun activities were provided for students to complete with their families (Table 1). The HomeFun activities were based on culturally relevant pedagogy and designed to apply family cultures, knowledge, and traditions to the school learning. These activities promoted culturally relevant learning both at home and in the school context (Table 2). Mr. Kyle encouraged students to share their HomeFun activities in class. He shared both students' and his own HomeFun activities to provide various examples of diverse home cultures in his classroom.

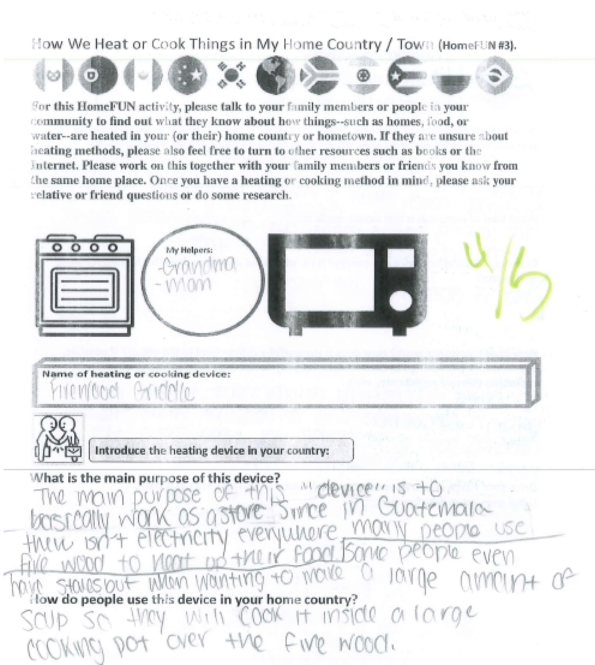
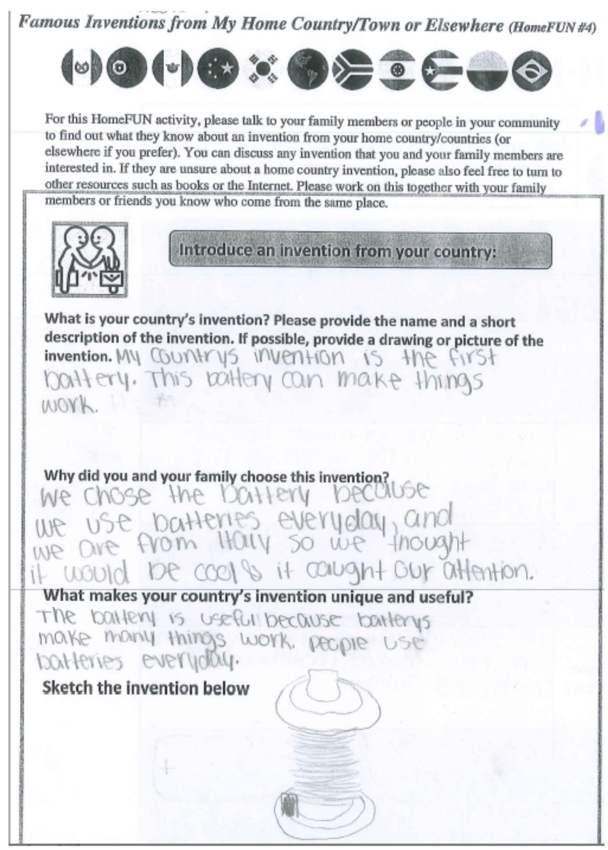
Table 1

HomeFun Activity Topics

1. How we heat or cook things in my home country/town
2. Famous inventions from my home country/town or elsewhere
3. Clothing that keeps us warm or cool
4. How we keep cool in my home country

Table 2

Examples of HomeFun Activities

How we heat or cook things in my home country/town	**Famous inventions from my home country/ town or elsewhere**
	

How We Heat or Cook Things in My Home Country / Town (HomeFUN #3).

For this HomeFUN activity, please talk to your family members or people in your community to find out what they know about how things--such as homes, food, or water--are heated in your (or their) home country or hometown. If they are unsure about heating methods, please also feel free to turn to other resources such as books or the Internet. Please work on this together with your family members or friends you know from the same home place. Once you have a heating or cooking method in mind, please ask your relative or friend questions or do some research.

My Helpers: -Grandma -Mom

4/5

Name of heating or cooking device: Firewood Griddle

Introduce the heating device in your country:

What is the main purpose of this device? The main purpose of this "device" is to basically work as a stove. Since in Guatemala there isn't electricity everywhere, many people use fire wood to heat up their food. Some people even have stoves but when wanting to make a large amount of soup so they will cook it inside a large cooking pot over the fire wood.

How do people use this device in your home country?

Famous Inventions from My Home Country/Town or Elsewhere (HomeFUN #4)

For this HomeFUN activity, please talk to your family members or people in your community to find out what they know about an invention from your home country/countries (or elsewhere if you prefer). You can discuss any invention that you and your family members are interested in. If they are unsure about a home country invention, please also feel free to turn to other resources such as books or the Internet. Please work on this together with your family members or friends you know who come from the same place.

Introduce an invention from your country:

What is your country's invention? Please provide the name and a short description of the invention. If possible, provide a drawing or picture of the invention. My Countrys invention is the first battery. This battery can make things work.

Why did you and your family choose this invention? We chose the battery because we use batteries everyday, and we are from Italy so we thought it would be cool & it caught our attention.

What makes your country's invention unique and useful? The battery is useful because batterys make many things work. People use batteries everyday.

Sketch the invention below

Participants

I selected six CLD students from Mr. Kyle's classroom using a purposive sampling method (Merriam & Tisdell, 2015). I followed three selection criteria for choosing participants: (1) participants self-identified as bicultural, 2) participants were either immigrants or children/grandchildren of immigrants, and 3) participants fully participated and completed the Chill Out unit (Table 3).

Table 3

Student Demographics

	Mandy	**Naomi**	**Cynthia**	**Nidia**	**Mia**	**Sam**
Grade	7th	7th	7th	7th	7th	7th
Gender	Female	Female	Female	Female	Female	Female
Home Country	Italy	Canada	Greece	Italy	Guatemala	Morocco

Data Collection

I collected three types of data for this study: (1) classroom observation notes, (2) interviews, and (3) HomeFun activities.

1. Observation notes: I observed classroom lessons and activities three to four times per week. The observation notes were kept for analysis purposes.
2. Interviews: I conducted two semi-structured interviews with each student. The initial interviews, conducted shortly after the program completion, took

approximately 15 minutes per individual. The follow-up interviews were conducted at the beginning of the following semester and took approximately 30 to 40 minutes per student.

3. HomeFun activities: I collected students' completed HomeFun assignments for analysis. The HomeFun activities included teacher's feedback and comments.

Data Analysis

In order to begin the data analysis process, I reviewed all the interview transcripts, field notes, and student HomeFun activities. By doing so, I was able to build a comprehensive understanding across the data sets. As I read, I wrote down overall impressions in the margins.

My next step was to merge the three data sets into one document per student. These were then uploaded to Atlas.ti, a qualitative data analysis program for a qualitative thematic analysis (Braun & Clarke, 2006). I analyzed these documents inductively to understand both explicit and implicit meanings pertaining to students' experiences (Guest et al., 2012). Before I began coding, I familiarized myself with the data by listening to voice-recorded interviews, reading field notes, and exploring HomeFun activities.

Using my familiarity with the data from phase one work, I created initial codes related to my research questions during the second phase of analysis. I established 133 initial codes across the data sets which included codes such as, "live version of science," "HomeFun family involvement," and "connection between HomeFun activities and school science." Codes were generated and refined in a cyclical process that included adding, combining, and splitting codes that addressed all interviews, observation, and

HomeFun data. For example, “family member’s cultural experience” and “participant’s cultural experience” were merged into “cultural engagement.” The third phase of the analysis involved thematic categorization of codes. The themes were reviewed and compared to the entire dataset in order to ensure they were closely related to the data. The thematic categories included cultural engagement, positive invention experience, relationship between culture and science, family involvement and engagement, attitudes towards HomeFun activities, and helpful support/resources/strategies.

This fourth phase of the analysis involved reading and rereading each transcript, field notes, and HomeFun activity to refine themes, keeping an eye out for other emerging themes and codes. A visual report based on my list of themes was created as the fifth and final phase analysis to discern broader themes within the data. During the conceptualization and finalization of themes, I carefully reread each coded excerpt across the data sets, summarizing each into one- or two-sentence summaries. In addition to writing well-described explanations of the data, I refined my analytical thinking as I shared and discussed the themes with an independent researcher. Through discussion, we resolved disagreements about our interpretations.

Findings

Findings indicate these six CLD students’ engagement, knowledge, perception, and experience during the Chill Out unit. I organized findings into three sections: (1) the CLD students’ cultural engagement with HomeFun activities, (2) the CLD students’ perception and experience with HomeFun activities, and (3) the connection between the HomeFun activities and science learning.

CLD Students' Cultural Engagement with HomeFun Activities

Family inclusion was a prominent theme in this study. Family members contributed cultural examples, experiences, and knowledge to the HomeFun activities for all six CLD students. There were two types of cultural knowledge and engagement presented in the HomeFun activities: direct and indirect cultural knowledge (Table 4). I identified direct cultural knowledge as cultural understanding acquired through a student's own experiences. In contrast, indirect cultural knowledge was the cultural knowledge gained through a family member's experience or passed down in stories from family.

Table 4

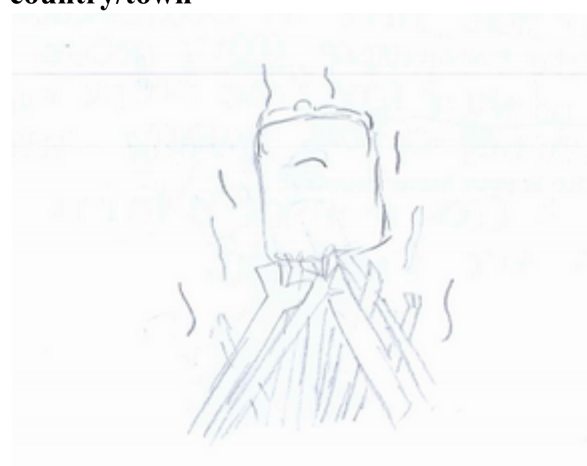
Family Involvement, Topics for HomeFun Activities, and Types of Engagement with Cultural Experiences

Student's Responses	Mandy	Naomi	Cynthia	Nidia	Mia	Sam
Family Involvement	Father and grandmother	Mother	Mother and father	Father	Mother, father, and grandmother	Mother and father
Topics	Brick Oven	Parka	Greek slippers; Wood stove	Italian skirts; Battery	Guatemalan sweatshirt; Firewood griddle	Moroccan clay oven
Types of Engagement	Direct	Indirect	Direct	Direct	Direct	Direct

Mia utilized her direct cultural experiences as the main source of information in the HomeFun activities. For example, Mia explored Guatemalan sweatshirts as an insulating clothing to prevent heat transfer based on her experience of wearing them in Guatemala. She indicated that the Guatemalan sweatshirts have a symbolic and personal meaning to her life because of her experience with her family members in Guatemala: “When I went to Guatemala, I bought one for myself. It was really warm.” She explored the material of the clothing, cotton, and how it absorbs heat and prevents heat transfer.

Picture 2

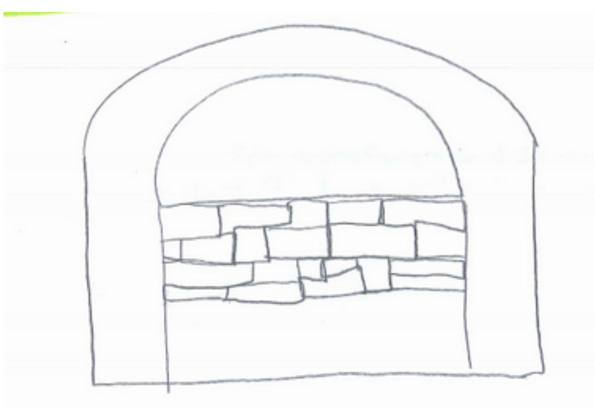
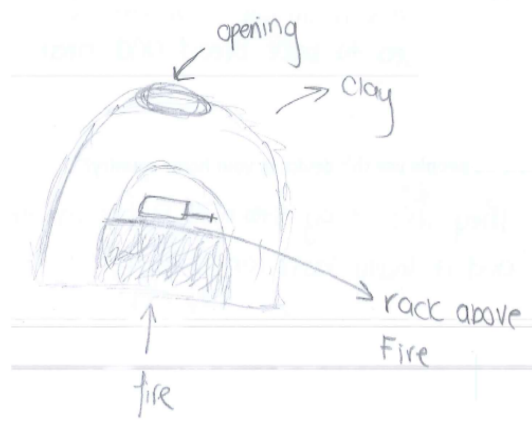
Drawing of Mia’s Guatemalan Sweatshirts and Firewood Griddle

Clothing that keeps us warm or cool	**How we heat or cook things in my home country/town**
	
“When I went to Guatemala, I bought one for myself. It was really warm” *Science concept explained: none*	“I chose this heating device because I think it is cool that we don’t always need a stove to make food” *Science concept explained: conduction*

Mia also illustrated life for ordinary people in Guatemala to explain the rationale for firewood griddles. She explained that electricity is not supplied to every part of the country in Guatemala. Therefore, many people use firewood to heat up food. Mia voiced her opinions about the firewood griddle as a “cool” way to cook because it is different and unique from what people commonly use in the United States, where electricity is supplied almost everywhere. She referred to her experience of using firewood griddles to illustrate how they heat up food effectively using natural resources (Picture 2). She demonstrated how the oven successfully delivers heat through conduction by making firewood directly touch the cooking pot.

Picture 3

Drawings of Mandy's Italian Brick Oven and Sam's Moroccan Oven

How we heat or cook things in my home country/town	**How we heat or cook things in my home country/town**
	
"It gets really hot and the hot air rises to the food. The type of heat transfer...is convection" *Science concept explained: convection*	"This heating device has been used for centuries and no home is a home without these ovens, It's a tradition!" *Science concept explained: convection and conduction*

Mandy and Sam also included their direct experience of using traditional ovens (Picture 3). Mandy chose an Italian brick oven as a heat transfer device reflecting back on her memories of making Italian food with her grandparents: "At my grandmother's house, we have a brick oven out in the backyard." Mandy referenced her experience to demonstrate her knowledge of the oven's energy source and its function: "Traditionally, it's used with coal or wood but now usually natural gas or even electricity... it gets really hot and the hot air rises to the food. The type of heat transfer is convection."

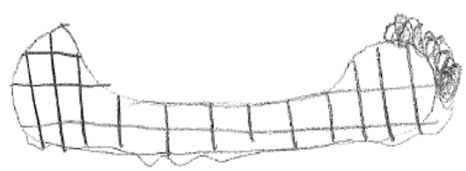
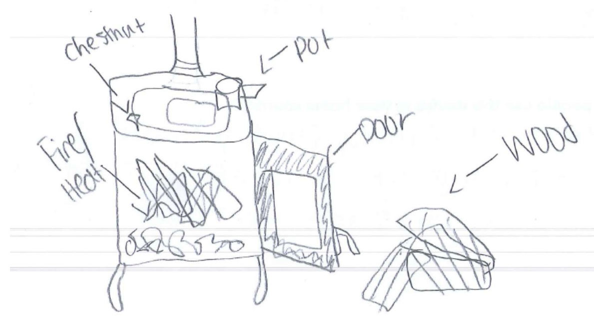
Sam also illustrated her knowledge of traditional ovens. She demonstrated the effectiveness of a traditional Moroccan clay oven: "They use it by starting a fire in the clay oven and it usually lasts for 6 hours…this heating device has been used for centuries and no home is a home without these ovens, It's a tradition!" This statement indicated the cultural importance of the oven to Moroccans and Sam's strong connection to culture and customs in Morocco. Sam also illustrated the functions of the Moroccan clay oven and explained its heat transfer mechanism: "This device uses thermal energy, potential, and radiation…. It delivers heat by using conduction and convection. Conduction because the fire is below the object. Convection because the air circulating is warmer and helps deliver heat to the object."

Like Sam and Mandy, Cynthia's choice was based on her personal experience with Greek slippers. She introduced traditional Greek slippers, hand-knitted by her grandmother, as a piece of insulating clothing to prevent heat transfer (Picture 4). She explained, "[The slippers are] fairly easy to make, warm, comfortable, don't take up a lot of space." As a background information, Cynthia described how Greece has four seasons, and the weather gets relatively cold. Cynthia stated that "this [Greek slippers] connects to my family because all the grandmothers make warm slippers that they knit and felt."

In another example, she referred to her experience using a Greek wooden stove as a heating device in her country. She shared that many people in Greece use wood to keep the house warm and cook food. She indicated her strong cultural and family connection to Greece by writing how meaningful this device is to her family and how it reminded her of life in Greece.

Picture 4

Drawing of Cynthia's Greek slippers and Greek Wood Oven

Clothing that keeps us warm or cool	**How we heat or cook things in my home country/town**
 "The color is light and not heavy. Light colors reflect" *Science concept involved: None*	 "My grandparents have one at their house and it's really useful because it reminds them of the old days, keeps them warm, and still cooks food." *Science concept involved: None*

Nidia also made a reference to her direct cultural experience with Italian skirts and the Italian invention of batteries (Picture 5). Like Cynthia, Nidia shared her knowledge of the weather in Italy to provide background information about the importance of her cultural clothing. Then, she introduced the skirts as clothing that helps and prevents heat transfer. She wrote, "if the skirt is a lighter color, it will not absorb heat, but if the skirt is darker, it will absorb heat." Nidia also explored batteries as an important Italian invention. She mentioned that her daily experience of using batteries and her cultural link to Italy created a connection between her and the invention. She expressed that it is "cool" to realize batteries were invented in her home country because batteries are one of the essential items that people use daily.

Picture 5

Drawings of Nidia's Italian Skirts and Batteries

Clothing that keeps us warm or cool	**Famous inventions from my home country/town or elsewhere**
	
"In Italy, girls wear skirts. I chose a skirt because I am a girl and skirts are popular for girls in Italy…" *Science concept explained: none*	"We chose the battery because we use batteries every day, and we are from Italy. So, we thought it would be cool and it caught our attention." *Science concept explained: none*

On the other hand, Naomi utilized her family members' experiences as resources to connect herself to the cultural object. Naomi introduced parkas as an insulating clothing from Canada and included an indirect cultural experience of observing her grandfather wearing it to prevent heat transfer: "My grandfather goes hunting in the winter and wears his parka and it keeps him very warm" (Picture 6). She explained the wet and cold climate in Canada during winter to explain what kind of materials are used to make parkas and why parkas are used as an insulating clothing for hunting. She explained that this clothing reminded her mother of childhood in Canada: “When we wear parkas in the winter, it reminds my mom of the winters she spent there.” Her description indicated that she was able to connect to her cultural object through her mother’s and grandfather’s experiences and memories.

Picture 6

Drawing of Naomi’s Grandfather’s Parka

Clothing that keeps us warm or cool

“My grandfather goes hunting in the winter and wears his parka and it keeps him very warm”

Science concept explained: none

Every CLD student made a reference to either direct or indirect cultural knowledge and experience within the HomeFun activities. They all demonstrated a variety of pre-existing knowledge and opinions about their topics that were strongly related to culture and family.

CLD Students’ Perceptions and Experience with HomeFun Activities

Every CLD student reported that one or more family members were deeply involved in their HomeFun activities. They all reported a positive, enjoyable experience connecting with their family, country, and home culture. The HomeFun activities brought their families together and made learning more personal and meaningful to the CLD students and their family members. The HomeFun activities provided an opportunity to share cultural knowledge, experiences, and values. For many, the family discussion brought back memories from their countries and pride in their culture.

Mandy: "That Was Cool to Learn [That] It Was a Big Italian Thing".

Mandy mentioned that being able to talk about the Italian brick oven with her grandmother was very useful, fun, and "cool":

> It was pretty cool, being able to talk about the brick oven because I have a little bit of experience. So, I just asked her [grandmother] a lot of questions about it. She talked about how it works and how she makes the pizza or the bread on it, and it was really good.

In addition to learning about fundamentals of the Italian oven, she also learned family history behind it. She learned her grandmother's story about how the brick oven was created by her ancestors. After learning more, she became excited about the culture and tradition of her family oven. She reported that she was proud to know such a great invention was part of "a big Italian thing."

Sam: "It [HomeFun Activity] Actually Connected You [With Family]".

Like Mandy, Sam had fun learning about her country's invention, the Moroccan clay oven, from her family. She enjoyed her mother's amusing story about cooking with the oven back in Morocco. Her mother told her that because the oven is huge, she had to almost walk inside the oven to place the food. She said listening to her mother's experience of using the Moroccan clay oven reminded of her experience of the hot weather in Morocco. Sam added that talking to her mother about the Moroccan clay oven brought back memories of her life back in Morocco and made her feel connected to her country and family again: "I felt it [HomeFun activity] actually connected you [with family] …it was bringing back memories, just thinking, just like pictures."

Sam was also fascinated to learn about the differences between the United States' and Morocco's cooking cultures. She learned that cooking has a different meaning and values in Morocco compared to the United States. She explained that most Moroccan family members participate in cooking, so it is easier, more collaborative, and interactive than it is in the United States:

> I learned a lot of things. It was just that even if it was back then, it [cooking] was easier to do because there were a lot of people working together. So, I feel you can communicate over it. You have a conversation instead of just putting it in the oven and putting a timer on it.

Mia: "It Was Fun Because Usually I Don't Really Talk About This Stuff With My Mom".

Mia also built a strong connection to her family and culture while engaging in the HomeFun activities. She learned about the Guatemalan firewood griddle from her mother and grandmother. She enjoyed this activity not only because she had a meaningful interaction with her family but also because she was able to learn about her mother's childhood experiences. Mia enjoyed hearing her mother's childhood stories and realized how different her childhood experiences were from hers:

> It was fun because usually I don't really talk about this stuff with my mom. So, her and my grandma [were] sitting down with me, they were just talking that wasn't about the product. But my mom mentioned a lot of childhood memories, which I didn't know about.

Mia explained that her mother had to do a lot of house chores and manual work such as making skirts to help her grandmother. Mia mentioned how new and valuable these stories were to her. She said that the HomeFun activities was especially enjoyable because, through learning more about her mother's childhood experiences, she was able to understand, learn, and connect with her mother more.

Naomi: "When We Do It with Our Family, I Think It Made More Sense To Me".

Naomi also reported a similar experience. She had fun discussing her home country with her parents because it brought back memories of her family visits to her grandfather and cousins in Canada. She said her parents were very involved in the HomeFun activities. She enjoyed learning about her grandfather's hunting stories from her mother. Her mother shared her own experience of hunting and the weather in Canada. She mentioned that she had seen her grandfather wearing a parka to go hunting. She found the HomeFun activities enjoyable and helpful because they were connected to her family's experiences and memories. She added, "when we do it with our family, I think it made more sense to me."

Nidia: "It is so cool!".

Nidia also reported how fun it was to connect with her father and learn about Italian inventions together. She said her father was very involved in the HomeFun activity. They searched together to collect information about Italy and its inventions. Nidia mentioned that it took them a long time to decide which invention they wanted to explore in depth, but it was fun to do with her father. Nidia said she was astonished to find out that many great inventions were first invented in Italy. Nidia and her father chose the battery as an Italian invention to explore because it was very closely connected to their daily lives. As they researched more about the history of batteries, they were surprised to find out how batteries evolved throughout history:

> I don't think about a battery every day and it's like not a big thing that I do think about. So, when I was doing research and I saw it at first, I didn't know what it was. It looked weird. So, I looked into it more and I figured out that it was [how] the first battery looked like! I was just confused how that can turn into what it is today.... It is so cool!

She emphasized that it was "so cool" to learn about Italian invention.

Cynthia: "You got to write your own personal life and what it's like at home".

Like Nidia, Cynthia enjoyed learning about cultural objects related to her life: "I liked it because you got to write your own personal life and what it's like at home, what you're like, and where you're from." She reported that talking to her parents about Greece brought back memories of her grandmother's Greek slippers and those memories made her feel connected to her country again. She also mentioned that this was a good opportunity for her to learn about her family tradition like knitting. Cynthia mentioned that the HomeFun activities provided a meaningful opportunity for her and her family to share memories, values, traditions, and experiences that brought them closer than before.

In sum, the HomeFun activities (1) helped the six CLD students to feel closer to their culture and family, (2) helped recognizing science in their culture and daily lives, and (3) encouraged family to be involved in their children's schoolwork. Each student reported having a valuable experience connecting with family and that they appreciated learning about their family's experiences, culture, and knowledge. It was an opportunity for the students to think about and appreciate their culture, traditions, and values, which were often ignored or forgotten during their ordinary lives. In addition, the interviews with the CLD students also revealed how the family and cultural experiences are also connected to science concepts taught in class.

Science Learning Through HomeFun Activities

The HomeFun activities helped the CLD students to develop understanding of the heat transfer concepts learned in school. All students reported positive effects of HomeFun activities on their learning science. They shared that the HomeFun activities helped them comprehend heat transfer concepts, made science learning engaging and personal, and connected home and school learning.

Most CLD students reported increased understanding of science concepts after completing the HomeFun activities. For example, Sam stated that learning about the Moroccan clay oven helped her to understand the concept of thermal energy. Even though she had known about the Moroccan oven all her life, she did not recognize the heat transfer principles embedded in the heating device. Once she learned about the fundamentals of the clay oven, heat transfer concepts “made more sense” to her:

> While looking at the oven, I didn’t really think about science. It’s an oven. And then while doing this, I really thought about it. I’m like, “That makes sense now!” How the potential [and] thermal [energy work] ... It just made more sense!

Similarly, Mandy, Mia, and Naomi reported that the HomeFun activities made science concepts easier to comprehend. The in-depth conversations with family and the cultural examples in the HomeFun activities helped their comprehension. Nidia illustrated how the HomeFun activities increased her understanding of heat transfer concepts by pushing her to think beyond the given information:

> Because when you learn about it in the books, they are not going to have these [cultural objects] as examples. So [when you do the HomeFun activities] you have to use your brain and actually think about it and see how they come together. Not just look at the book and get the answer from it.

In addition to the increased comprehension, all of the CLD students stated that the HomeFun activities made science learning more fun, engaging, and personal to their lives. For example, Naomi explained that the HomeFun activities were enjoyable because investigating a real-world and cultural object made science realistic. Similarly, Mia and Mandy found HomeFun activities enjoyable and “cool” because they were related to their home, culture, and identity. Mia mentioned that learning from home culture made science less “sciency” and more friendly. Similarly, Mandy stated that learning science from her home culture was cool because "it's something special." Sam also stated that learning from cultural experiences and traditional knowledge was an interesting and meaningful way to study science compared to learning science from a textbook because "it had to do with my [her] culture and transition."

Students also explained how the HomeFun activities became a bridge to connect school and home. For example, Naomi explained that the HomeFun activities were helpful because they were closely related to what she was learning at school. She illustrated how her understanding of radiation developed through engaging in the lunchbox invention process and the HomeFun activities:

> I think that the HomeFun activities connect to the project because it is talking about how to keep you warm using conduction, radiation and convection and use all those. So, the HomeFun activities help us [to] know more about what they taught us in the classroom [and] how everything works.

Even though the home-based and school-based activities were different from each other, she was able to make a connection. She reported that her family and herself "had to figure out where the radiation was coming from in the HomeFun activities and how the radiation from the lunchbox." She expressed her excitement when she figured out the connection between the two activities: "it was good... like who came up with it?'"

As she mentioned, Naomi's writing on her lunch box demonstrated her understanding of heat transfer and its connection to the HomeFun activity. For example, after explaining the process of heat transfer in her lunchbox, she made a connection to a real-life example of how humans prevent heat transfer:

> The first type of heat transfer is radiation, which is emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles that cause ionization. The radiation is most seen when occurring with the tin foil in the project because the movement from the heat going into, and the box hitting the tin foil on top and white paper.... Humans try to stop heat transfer from coming to them in the summer, so they would most likely put a white t-shirt on or a lighter color t-shirt.

Understanding how color and heat transfer relate to one another demonstrated the connection between school knowledge and home knowledge.

Cynthia also made a connection between the lunch box invention and the HomeFun activities. She expressed her enjoyment of applying her school knowledge to home: “I couldn’t wait because I like connecting my home culture to school!” She figured out that both activities focused on the fundamentals of heat transfer. She thought about how she prevented her lunch box from heat transfer to apply the same concepts to the HomeFun activity. Her report writing demonstrated her understanding of heat transfer and an attempt to connect to real life:

> In my cooler, I see conduction…. I see conduction because when we close the box, there is more heat and cold trying to come in and out of the cooler. For example, when you’re in your house and the heat is on, when you open a window the cold and heat fight to see where they are going to go.

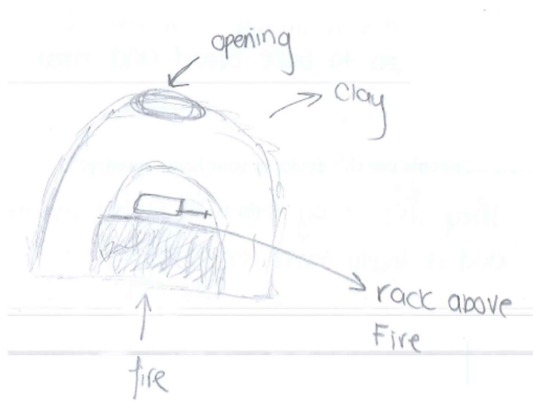
However, despite the positive reports on connecting science with home, not every CLD student successfully applied the scientific concepts to HomeFun activities. While some demonstrated clear understanding of the science fundamentals behind the cultural object, others struggled to make a connection. For instance, Mia, Sam, Cynthia, and Mandy chose similar traditional heating devices from their countries but their ability to apply heat transfer concepts to the heating device varied. In addition, Nidia's and Naomi's HomeFun activities did not include any heat transfer concepts.

Sam and Mia successfully bridged their knowledge of heating devices to understand scientific concepts learned in class. Their explanation and scientific interpretation demonstrated their understanding of the fundamentals of heat transfer. Sam included both convection and conduction as types of heat transfer used in Moroccan clay ovens. She stated that the Moroccan clay ovens involve "conduction because the fire is below the object (food placing rack). Convection because the air circulating is warmer and helps deliver heat to the object." Sam also explained how this process of heating involves both thermal and potential energy.

While Mia chose a similar heating device, the fire griddle, she provided a different explanation. Mia indicated that conduction is the major heat transfer mechanism used in the fire griddle: "It does successfully deliver heat to the object through conduction. This is because when the cooking pot is touching the wood. Then, the heat will transfer directly." The two students' drawings demonstrated why and how the type of heat transfer differs between the Moroccan oven and the Guatemalan firewood griddle (Picture 7).

Picture 7

Drawings of Sam's Moroccan Clay Oven and Mia's Firewood Griddle

How we heat or cook things in my home country/town	**How we heat or cook things in my home country/town**
	
"Conduction because the fire is below the object (food placing rack). Convection because the air circulating is warmer and helps deliver heat to the object" *Science concept explained: conduction and convection*	"It does successfully deliver heat to the object through conduction. This is because when the cooking pot is touching the wood. Then, the heat will transfer directly." *Science concept explained: conduction*

Sam's Moroccan clay oven has a rack above the fire; thus, conduction occurs when the high-temperature rack transfers heat to food. In addition, because the Moroccan oven is shielded with clay, the heat inside the oven continues to warm up the food. Sam's illustration and description showed her understanding of the fundamentals of Moroccan clay ovens. Mia's explanation of the firewood griddle also showed her understanding of heat transfer concepts. She indicated conduction as a type of heat transfer because the firewood griddle heats up the pot with direct contact with fire. She did not include convection as a type of heat transfer because, unlike the Moroccan clay oven, the firewood griddle does not have a shield that keeps heated air around the food. Both Sam's and Mia's explanation accurately demonstrate the type of heat transfer and its fundamental mechanisms used in their devices.

Even though Mandy and Cynthia chose similar heating devices, their connections to science were not as strong as Sam's and Mia's explanations. Mandy wrote that the Italian brick oven involves mounting of hot air inside. However, she was not able to draw a connection to any of the heat transfer concepts that are involved in the process. She wrote that convection may be involved in the process but did not provide an explanation or reason. Similarly, Cynthia's wood stove explanation did not include any scientific explanation. She wrote, "a wood stove works by putting wood into the stove and burns. That's how it creates heat." She understood that heat is generated in the stove by burning woods, however, she failed to explain what type of heat transfer occurs to cook food. Furthermore, Nidia and Naomi's illustrations and explanations only included their experiences and cultural knowledge, not scientific concepts behind the cultural object.

Discussion and Implication

The findings showed how each student used culture as resource, connection, and motivation to learn science. The students' reports on increased comprehension illuminated the positive effects of utilizing culture as a resource to teach science and connect school and home. In addition to their increased understanding of the heat transfer, the CLD students enjoyed being connected to and learning about their culture, tradition, family values, and experiences. The HomeFun activities provided an opportunity to recognize the family values, traditions, and wisdom from their family and heritage. In this section, I discuss the findings regarding culture and knowledge transfer.

Culture as a Medium to Transfer Knowledge from School to Home

Knowledge transfer is a constant and ongoing process that students encounter and actively engage in throughout learning (Engle, 2006; Salomon & Perkins, 1989). Based on analysis for this study, I argue that cultural connections can effectively facilitate the process of knowledge transfer. According to Engle et al. (2012), a sense of connection and authorship helps creating personal connections to learning (Engle et al., 2012). In this case, each CLD student's cultural knowledge provided a sense of ownership because the school-based knowledge was personally connected to their own experiences. The HomeFun activities provided an opportunity to explore their funds of knowledge (Moll et al., 1992) and facilitated family involvement in school science. The students reported that HomeFun activities brought the family together and evoked pleasant memories of their country.

In addition, learning about heat transfer concepts through cultural connection was meaningful and special because it involved family conversation about their own stories. The students reported that these activities made science "cool," "fun," and enjoyable. For example, Sam expressed her excitement that "I did [enjoy it] especially because it had to do with my culture and tradition." Cynthia also commented, "I couldn't wait cause, I like connecting my home culture to school!" The process of linking school with home culture made science more relatable and less "sciency". The HomeFun activities helped the students to be enthusiastic and motivated to explore science beyond their required lessons at school. The HomeFun activities became a bridge to connect school knowledge to home knowledge by creating a culturally relevant and engaging learning environment for students.

Knowledge Transfer: An Individually Diverse and Bidirectional Process

Perkins and Salomon (2012) argued that three bridges, *detect-elect-connect*, are necessary for knowledge transfer. *Detect* is when a learner identifies and "detects" the object, situation, or phenomenon related to the learned knowledge. *Elect* is when a learner explores the link between the knowledge and an object/situation/phenomenon. *Connect* is the process where a learner successfully expands the knowledge and applies it to a new setting. According to Perkins and Salomon (2012), the process of constructing these three bridges is unconscious and natural for students who have mastered the content.

The six CLD students engaged in *detect-elect-connect* doing the HomeFun activities. They *detected* the heat transfer concepts by recognizing their cultural objects as a heating device. Then, they explored the object to *elect* the heat transfer principles. Lastly, they *connected* the heat transfer principles learned in school to the cultural object. Some, like Cynthia, Mandy, and Sam, went one step further to connect their cultural object with the lunch box invention.

Nonetheless, the process of *connect* did not come naturally for everyone. There was significant variation in how each student made connections between the two contexts. The connection came easily and spontaneously for students like Sam and Naomi. As described by Perkins and Salomon (2012), Sam described making these connections as easy and natural. For example, Sam's HomeFun activities also demonstrated her understanding of heat transfer and a successful application of her knowledge to a cultural object, the Moroccan clay oven. Nevertheless, this wasn't the case for everyone. Unlike Sam and Mia, Mandy, Cynthia, and Naomi were able to make some connection and Nidia was unable to make any connects between the HomeFun activities and school science (Table 5).

Table 5

Differences in Student Outcomes

Strong connection	Weak connection	No connection presented
Sam and Mia	Mandy, Cynthia, and Naomi	Nidia

Knowledge transfer varied among the students as a result of the three factors: (1) the degree of content knowledge, (2) individual differences in timing, and (3) the complex process of knowledge transfer. First, acquiring deep knowledge of content is foundational to knowledge transfer (Bransford et al., 2000; Chi & VanLehn, 2012; Engle et al., 2012). As Engle et al. (2012) state, “the most fundamental prerequisite for transfer is that the particular content to be transferred has been learned in a sufficiently deep, strong, and lasting way” (p. 216). The CLD students who had trouble understanding heat transfer concepts in school struggled to transfer knowledge to their cultural experience. Once they built a strong understanding of heat transfer concepts, they were able to connect and apply the heat transfer knowledge to HomeFun activities.

Second, there were individual differences in the amount of input required for knowledge transfer. Sam and Mia, for example, were able to seamlessly transfer their knowledge from school to the cultural context without much effort from the beginning. On the other hand, Mandy, Cynthia, and Naomi needed multiple conversations and reviews to start making connections between the two contexts. This illuminates the individual differences in the amount of input necessary to engage in knowledge transfer. Furthermore, the timing of knowledge transfer varied among students. In some cases, students may still have been developing content knowledge when engaged in HomeFun activities, and were therefore not ready to transfer knowledge. For example, Nidia's the eureka moment likely came later in the unit than it did for Mia. For students like Nidia, HomeFun activities served as an opportunity to strengthen content knowledge, whereas, for others, it provided an opportunity to apply knowledge from one context to the other. Nidia's own assessment of her learning supported this: "I mean, it wasn't easy. I had to actually do work and research for it, but it got easier over time."

Lastly, the findings illustrate that the knowledge transfer process is iterative bi-directional rather than a simple and one-way process. To begin with, heat transfer knowledge gained from school was used to understand the phenomena in the HomeFun activities. HomeFun activities then became a resource to strengthen the knowledge gained from school. The students' knowledge constantly accumulated and developed during the process of knowledge transfer and this process resulted in a positive feedback loop. It confirms the previous study that in the successful cases "the degree of intercontextuality can get so strong that a larger encompassing context is formed that seamlessly incorporates learning and transfer contexts" (Engle et al., 2012, p. 218). It was evident when some CLD students voluntarily transferred knowledge from the HomeFun activity to the lunch box invention. For example, Naomi figured out the connection between the lunch box invention and her HomeFun activities, feeling both surprised and excited, she expressed, “it was good... [I was] like ‘who came up with it?’”

This study provides several implications. First, students need to have various opportunities to engage in learning in diverse contexts. As different individuals require different amounts of input, providing diverse contexts and practices is necessary to facilitate knowledge transfer. Second, culture is a useful resource for students to connect their school- and home-based knowledge. Culture can function not only as a motivational factor to learn science, but as an effective academic resource, making science learning more personal and meaningful to students. As they experience science learning as a friendly and enjoyable process, students are less anxious toward science and more willing to engage with it inside and outside the classroom (Gay, 2002; Roth & Barton, 2004). Through culturally relevant activities like HomeFun, students can develop pride in their home cultures while learning science more effectively.

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CHAPTER THREE

"If It Is Explained to Me in My Language, I Can Understand More": Translanguaging Science Practices to Support Bilingual Learners.

For decades, English-only rules in many schools have had a documented, negative impact on culturally and linguistically diverse (CLD) students who come from backgrounds differing from white, middle-class, and English-speaking norms (Chamberlain, 2005; Gunderson, 2017; Herrera & Murry, 2006; Li, 2013). Many schools are built on monoglossic language ideologies, which consider monolingualism as a societal norm, which lead them to make few provisions for second-language learners (Flores & Rosa, 2015; Gunderson, 2017; Kaveh & Lenz, 2022). Educational research and practice seeking liberatory aims must help diverse learners bring their cultural resources into educational spaces (Larsson, 2016; Lee & Oxelson, 2006). Teachers dedicated to such work effectively counter "the institutionalized ways people…perceive, understand, and make sense of contemporary U.S. immigration that justifies native (white) dominance, and reinforces hegemonic power" (Huber, 2011, p. p.380). Without such efforts, CLD students can suffer from school experiences that make them feel like outsiders or ashamed of using their native languages and dialects (Bonilla-Silva & Embrick, 2006; Kohli et al., 2017; Ryan et al., 2007). Such language policy and practice enacted in educational settings perpetuates inequities for diverse students who do not have access to insider knowledge of mainstream language practices (De Costa, 2020; Flores & Rosa, 2015).

Multicultural education has thus sought to support the cultural and linguistic needs of CLD students by building appreciation for students' cultural backgrounds and knowledge (Boutte et al., 2010; Davis, 1996; Okazaki, 2009; Saad et al., 2013). Such classrooms value and recruit students' languages, cultures, and customs, shifting classroom spaces from hegemonic to multicultural (Hornberger & Link, 2012; Liu & Fang, 2020; Menken & Sánchez, 2019; Wei, 2014). In the past two decades, many pedagogical approaches have been developed to support multicultural educational goals, the most well-known of which is culturally relevant pedagogy (CRP), a practice that aims to improve the academic performance of CLD students by linking school learning with students' home culture (Karlsson et al., 2018; Ladson-Billings, 1995; Wei, 2014). Numerous studies have demonstrated how CRP creates effective learning environments and promotes equality by making learning more comprehensible and meaningful to CLD students' lives (Bassey, 2016; Chamberlain, 2005; Kim et al., 2021).

One of the most valuable linguistic applications of CRP in classrooms is translanguaging, which views and uses students' first language as an asset for learning curricular content, as well as the English language (García, 2012; Hornberger & Link, 2012). Translanguaging can be especially helpful for CLD students who are learning English or emergent bilingual students who have recently immigrated to the country and only beginning to learn English. Translanguaging can help them engage in school work that would otherwise be too challenging if they only had access to content in their second language (García, 2012; García & Wei, 2014; Wei, 2014). By drawing on students' full linguistic repertoire, translanguaging facilitates an in-depth understanding of subject matter content for emergent bilingual students (Celic & Seltzer, 2013; Espinosa et al., 2016; Karlsson et al., 2018). It also promotes effective communication and allows emergent bilingual students to focus on content learning (Canagarajah, 2011; García & Lin, 2017; Rowe, 2018).

Translanguaging practices can especially help students navigate the linguistic challenges of science-based content (Karlsson et al., 2018). Science-based language involves grammatical features, technical terms, and patterns that are difficult for emerging bilingual students to comprehend (Fang et al., 2010; Fang & Schleppegrell, 2010). While the language of science can create a barrier for second-language students, neither does it benefit students for teachers to oversimplify language or dilute content-based learning (Karlsson et al., 2018). Teachers who do so may inadvertently create additional and unnecessary barriers for emergent bilingual students to learn science-based content (Karlsson et al., 2018; Turkan & Liu, 2012).

Although researchers have explored CLD students' linguistic and cultural needs, there is limited research on CLD students' experiences of translanguaging as a pedagogical practice in science classrooms. This study seeks to address that gap by exploring the experiences of four middle school emergent bilingual students. These students' perceptions and experiences with translanguaging in a middle school science classroom offer valuable insights into the ways translanguaging can benefit emergent bilingual students. This study was guided by these core questions:

- How do emergent bilingual students engage in translanguaging practices in a middle-school science classroom?
- What are their experiences and perceptions with the practice?

Literature Review

Monoglassic Language Ideologies in the U.S. Schools

Even though the United States is a multilingual country with no official language, English-only ideology has historically been a norm. Monoglossic ideology refers to the ways people generally consider monlingualism as a societal norm (Flores & Rosa, 2015; Larsson, 2016). From a monoglossic perspective, languages are separate entities from one another; people tend to adopt additive or subtractive views of what it means to learn a new language (García & Lin, 2017; García & Wei, 2014; Kleyn & García, 2019; Larsson, 2016). Subsequently, schools typically view bilingualism as additive or subtractive (de Mejía, 2002; Flores & Rosa, 2015). An additive approach to bilingualism, also called “elite” bilingualism, is often practiced by members of affluent communities whose primary language is English (Flores & Rosa, 2015). They view bilingualism as a sign of giftedness, a useful skill, and an educational practice designed to improve students’ cognitive ability (de Mejía, 2002; Flores & Rosa, 2015). Students from families with this view receive encouragement to enrich themselves and learn a second language for intellectual and pragmatic purposes. In contrast, a subtractive view of bilingualism or “minoritized” bilingualism takes a deficit view of those whose primary language is not English (Flores & Rosa, 2015). Often, these students come from less affluent communities, and they are encouraged to learn English at all costs, even at the expense of their first language. A subtractive approach means these students’ bilingualism is often viewed as a problem because they are not English-proficient (de Mejía, 2002; Flores & Rosa, 2015). English-only policies and monoglossic language ideologies reflect this deficit view and schools are often organized around them (de Mejía, 2002; Flores & Rosa, 2015; Gunderson, 2017).

Since most schools use English as the only language of schooling, monoglossic ideologies have effectively moved throughout educational practice. Indeed, schools are one of the most influential societal contexts to shape learners’ language ideologies and practices (Kaveh & Lenz, 2022). Bilingual and multilingual students in monolingual school settings are the most susceptible to English-only norms of school (Kaveh & Lenz, 2022). Many research studies indicate that bilingual/multilingual students in these environments shift their language preference from their first language to English to assimilate to the English-speaking norms in school settings (Babino & Stewart, 2017; Block & Vidaurre, 2019; Kaveh & Lenz, 2022). This is because bilingual students in monolingual settings often experience the ways their first language is devalued and marginalized; this effectively leads them to move their language ideology and preferences to English-only (Kaveh & Lenz, 2022; Potowski, 2007).

Translanguaging

Given the ways social contexts like school can so strongly influence students' language ideologies and beliefs (Slavkov, 2017), educational practices built on heteroglossic language ideologies designed to promote multilingualism and linguistic diversity strongly encourage bilingual students to utilize their full linguistic repertoire in school (Block & Vidaurre, 2019; Potowski, 2007). In contrast to monoglossic perspectives, heteroglossic ideologies consider languages as only one dimension of a student's linguistic repertoire (García, 2008; García & Wei, 2014; Kleyn & García, 2019). Translanguaging is one of the pedagogical practices that most strongly reflects heteroglossic language ideology (Kleyn & García, 2019).

Translanguaging is a practice first described by Williams (1994) and later extended by (García, 2008). It is a process by which bilingual students use their full language repertoire to learn, communicate, and create (García, 2008; García & Wei, 2014; Kleyn & García, 2019). According to Espinosa et al. (2016), it is natural for bilingual students to engage in translanguaging practices in daily conversations and activities. Many scholars have demonstrated the ways translanguaging is an additive schooling practice by encouraging students to use all their linguistic knowledge and skills to learn in school (Espinosa et al., 2016; García & Kano, 2014; Lopez et al., 2017; Rowe, 2018; Velasco & García, 2014). Since translanguaging focuses on the meaning-making process, it creates opportunities for students to utilize their linguistic knowledge as resources (Byrnes, 2009; Cole, 2019; Conteh, 2018; García & Wei, 2014).

As a result, translanguaging is a powerful pedagogical tool for enhancing CLD students' language and literacy skills (Hornberger & Link, 2012; Velasco & García, 2014). Students who can translanguage communicate effectively, expressing themselves more fully and accurately than if confined to English-only practices (Alvarez, 2014; Hornberger & Link, 2012; Velasco & García, 2014). Since translanguaging allows students to use vocabulary and sentence structures from their first language, it can reduce English language concerns for emergent bilingual students (Alvarez, 2014; Canagarajah, 2011; Hornberger & Link, 2012). By eliminating this mental load, translanguaging allows emergent bilingual students to solely focus on content regardless of their English language proficiency (Canagarajah, 2011; García & Lin, 2017). As a result, many research studies indicate translanguaging enhances students' subject matter comprehension and promotes positive attitudes toward academic learning (Conteh, 2018; Espinosa et al., 2016; García & Wei, 2014).

Translanguaging offers similar advantages in writing as it does to students' oral language development, ensuring emergent bilingual students with limited English proficiency can fully enjoy the benefits of writing (Velasco & García, 2014). Writing is a vehicle to enhance student comprehension and language is integral to writing (Langer & Applebee, 1987; Pelger & Nilsson, 2016; Velasco & García, 2014). In order for students to experience writing as meaningful and supportive, they benefit from using their first language to access their full linguistic repertoire of meaning, ideas, and thinking (D'Warte, 2014; García & Kano, 2014). When emergent bilingual students use all of their languages and linguistic knowledge and resources, they not only learn content, they strengthen their second language acquisition process (Espinosa et al., 2016; García & Kano, 2014; Khote, 2018).

Methodology

This multiple case study sought to investigate four emergent bilingual students' experiences and perceptions related to translanguaging practices in a monolingual school. A multiple-case study design allowed for an in-depth analysis (Merriam & Tisdell, 2015) of translanguaging practices both within and across the four cases, compared with what a single case study might have revealed. The following sections introduce the school where participants learned, along with the context of the translanguaging science classroom where they worked alongside their teacher, Ms. Irene. This section also discusses participant students and their teacher, data sources, and analytic processes for this study.

Context

This study was part of a collaborative effort between Boston College, the Lemelson-MIT (which was the School of Engineering at the Massachusetts Institute of Technology), and the Brown Public School District BPSD (pseudonym). In collaboration with BPSD, the two university institutions developed and implemented a longitudinal STEM program designed to give middle-school students transformative STEM experiences. The program was particularly geared to serve students from populations who are underrepresented in STEM fields. As one of the primary researchers for this study, I collected data and shared it with my Boston College team.

The program used Lemelson-MIT's invention-based curriculum as the foundation for the STEM learning experiences. This program had eight invention education guides, along with "Junior Varsity (JV) InvenTeams activity guides" (https://lemelson.mit.edu/resources/curriculum-invention). The JVInvenTeams curriculum was aligned with Next Generation Science Standards and designed to support educators in grades 6-10 and their students in designing and building inventions. Among the eight units, the Lemelson-MIT and Boston College team modified the unit titled "Chill Out," in which students learn about heat transfer concepts such as convection, conduction, and radiation to build a lunch box invention, for use in a 7th grade science classroom. The Chill Out program was based in the invention-based learning (IBL) pedagogy, which is a student-centered learning approach to teaching science; in this particular class (D. Kim, Kim, & Barnett, 2021; Zhang, Estabrooks, & Perry, 2019), student invented objects to solve real-world problems. Unlike a traditional science classroom where students might sit in lectures or receive direct instruction designed to passively convey scientific knowledge, IBL promoted interdisciplinary thinking by requiring students to apply scientific knowledge with hands-on, project-based learning (D. Kim et al., 2021; S. L. Kim & Kim, 2021; Zhang et al., 2019).

The Boston College team further modified the Chill Out unit for CLD students by adding 1) visualizations (visual aids), 2) the "HomeFun" culturally relevant activities, and 3) writing instructions and activities. The modification and activities were aligned with content and language objectives for the 7th grade science standards. The revised curriculum was designed to be implemented over 10-12 weeks. Six seventh-grade science teachers across two public middle schools from the same school district incorporated the Chill Out program into their school day curriculum. This study focused on one of these six science teachers' classrooms and four of her CLD students during the 2019-2020 academic year.

Content and Procedures

The Chill Out Curriculum.

As an IBL curriculum, Chill Out required students to apply knowledge and experiences to solve real-world problems. Using an empty shoebox as a base, students had to invent a lunchbox by working through a cognitively challenging learning process. They discovered and solved problems as they learned science content and applied it to real-world problems. Through this complex inventing process, the Chill Out curriculum invited students to adopt an inventor's mindset, and cultivate an open mind from which to discern possibilities for solving problems (Zhang et al., 2019).

In the beginning of the Chill Out program, students learned and explored concepts related to heat transfer such as convection, conduction, radiation, insulation, and thermal equilibrium. They engaged with these ideas in whole-class lessons, along with a series of hands-on activities and experiments. Their teacher explained insulation and the thermoelectric effect and allowed them to explore thermal materials that prevent heat transfer. Two explicit lessons on language and writing were included to prepare students to draft a report on their lunch box invention. For the final project, students worked in groups of three or four to create a lunch box that prevented heat transfer using the knowledge and experiences they gained throughout the program. Their main goal was to reduce heat transfer through blocking conduction, convection, and radiation to ensure a water bottle inside the lunch box stayed cool. Insulating materials available to them included aluminum foil, bubble wrap, packing peanuts, old clothes, and construction paper.

After each group completed their invention, their lunch box was tested for effectiveness. Each group received a bottle of water which they placed inside the lunchbox before putting the lunchbox under a heat lamp for approximately one hour. Students used the results of these tests to write their reports, which they framed as patent applications explaining and promoting their lunchbox invention. Prior to asking students to write their reports, their teacher provided supportive language and writing lessons on how to compose a science report to appeal to the public. Students practiced these writing skills through short activities. The lessons and activities focused on language use, academic vocabulary, and structures of report writing.

HomeFun Activities.

HomeFun activities were created to help students connect home knowledge to school content. Every student completed four HomeFun activities with family members (Table 6).

Table 6

List of HomeFun activities

1) How we heat or cook things in my home country/town
2) Famous inventions from my home country/town or elsewhere
3) Clothing that keeps us warm or cool
4) How we keep cool in my home country

These activities were designed to help students to relate what they were learning about heat transfer to their family's cultural and social knowledge, effectively promoting culturally relevant learning connections between school and home. The HomeFun activites were written in students' first language and students had a choice to write their HomeFun responses in either their first or second language.

Ms. Irene's Translanguaging Science Class.

Davis Middle School (pseudonym) was the participating school for this study and was in an economically mixed suburb in the Northeastern part of the United States. Although the school district had a high number of students whose first language was not English (45.2%), English was the medium of instruction for schools in this district. This study focuses on a translanguaging science classroom led by Ms. Irene. Ms. Irene was an English as a Second Language (ESL) and science teacher at Davis Middle School. At the time of this study, she had been teaching ESL classes for three years; this was her first year to teach science. She spoke three languages fluently- Spanish, English, and Portuguese- and used all three languages with her students on a regular basis.

Ms. Irene's science class was not originally created to be a translanguaging class. She had no building-level support, training, or resources to create a translanguaging classroom, but she nevertheless decided to use all three languages to teach science to support the emergent bilingual students in her classroom. Ms. Irene reported that she had not heard of the translanguaging pedagogy before nor had received training or resources to enact it. However, she believed students needed to use their first language to master content learning and subsequently used her language resources to support her students. As a multilingual herself, she deeply empathized with her emergent bilingual students and devoted herself to their growth. She was the only teacher using translanguaging practices at Davis Middle School.

Out of 18 students, she had eight Spanish speakers who were learning English as a second language, 16 Spanish-English speaking bilinguals, two Portuguese speakers, and two English-speaking monolinguals. Absent any English-only language restrictions in her classroom, many students used both their first and second language to communicate with one another. Ms. Irene conversed freely with all of her students using all three languages. She also provided verbal and written directions in all three languages and freely encouraged students to use their home languages to learn in any context. For assignments, students could choose whether to write in their first or second language or both.

Participants

The student participants in this study were four seventh-grade emergent bilingual students who attended Davis Middle School. Students were selected for this study based on three criteria. They were 1) immigrants who had lived in the United States less than a year, 2) English language beginners, with proficiency levels below World-Class Instructional Design and

Assessment (WIDA) Level 2, and 3) full participants in the Chill Out curriculum who completed the inventing project in Ms. Irene's science classroom.

Table 7

Student Demographics

	Carter	Linsey	West	Brian
Grade	7^{th}	7th	7th	7th
Gender	Male	female	male	male
Home Country	Guatemala	Guatemala	Guatemala	Guatemala
First Language	Spanish	Spanish	Spanish	Spanish
English Language Proficiency Level	WIDA Level 1	WIDA Level 1	WIDA Level 1	WIDA Level 1

Based on these criteria, Carter, Linsey, West, and Brian were the four participants at the center of this study. They had all arrived in the United States from Guatemala less than a year ago and spoke Spanish as their first language. Their English proficiency level was 1, the lowest in WIDA's standards (Gottlieb et al., 2007). In the translanguaging classroom, they mainly spoke Spanish to each other and with Ms. Irene. They all fully participated in the Chill Out program and successfully completed the lunchbox inventing project.

Data Collection

Data for this study was comprised of classroom observations, student writing samples, and semi-structured interviews. I visited Ms. Irene's classroom during the Chill Out unit, collecting field notes as I observed. Interviews with the four emergent bilingual participants provided insights into their experiences with translanguaging. Students' written documents offered insight into their learning process, both at home and in the classroom.

Classroom Observations.

I observed in Mr. Irene's science classroom for two or three times each week for three months. I took field notes on lessons, teaching materials, activities, and interactions as detailed as possible to gain insight into students' experiences. My observations focused on students' learning progress and their interactions with Mrs. Irene and peers. I also conducted informal conversations with Mrs. Irene after each lesson, which helped contextualizing my observations.

Semi-structured Student Interviews.

Semi-structured student interviews were conducted with students after they completed the Chill Out program. Although conducting student interviews is challenging, it is an essential way to hear students' voices and gain insight into their experiences (Wagner, 2018). We met in the school library during lunch hour for interviews that lasted 40-50 minutes each. For security reasons, the school did not allow unauthorized adults in the building; as a result, Ms. Irene kindly translated my conversational interviews with each student. Each interview was audio-recorded and transcribed verbatim by a bilingual research assistant. To verify the accuracy of the translations, the Spanish portions of the student interviews were translated again by a private professional translator.

Interview questions were based on the research questions and designed to help student participants share about their experiences and perceptions related to translanguaging in science learning. Questions covered four major topics:

(1) Perceptions toward translanguaging (e.g. "What is your opinion about translanguaging?" and "Which language(s) do you prefer to use in classes?")
(2) Translanguaging experiences in school (e.g. "Do you use Spanish at school?" "If yes, when and how often do you use it?)

(3) Translanguaging experience in the science classroom (e.g. “Could you describe your experience translanguaging in your science class?” and “How was your experience using both Spanish and English in the science classroom?”)

(4) Writing experience in the translanguaging science classroom (e.g. “What language did you choose to write the final report?” and “Why did you choose to write in that language for your report?”)

I did a form of member-checking during interviews by restating questions and students’ responses to be sure I understood their meaning; such procedures can increase validity in research with young research participants (Creswell, 1994).

Student Writing Documentation.

I examined the texts and reports written by the four emergent bilingual participants. This included initial and final drafts of report writing during class and all written HomeFun activities. Students’ compositions were collected and translated into English by a professional translator prior to analysis. The documents were important in offering insight to participants’ content knowledge development and language use during science instruction. Additionally, the design and experimental results and pictures of the lunchbox inventions offered helpful supplementary material corresponding to students’ writing.

Data Analysis

As I began data analysis, I endeavored to develop a comprehensive understanding of students’ experiences by reading interview transcriptions, field notes, and student writing documents in their entirety. As I went, I took notes on my general impressions in the margins.

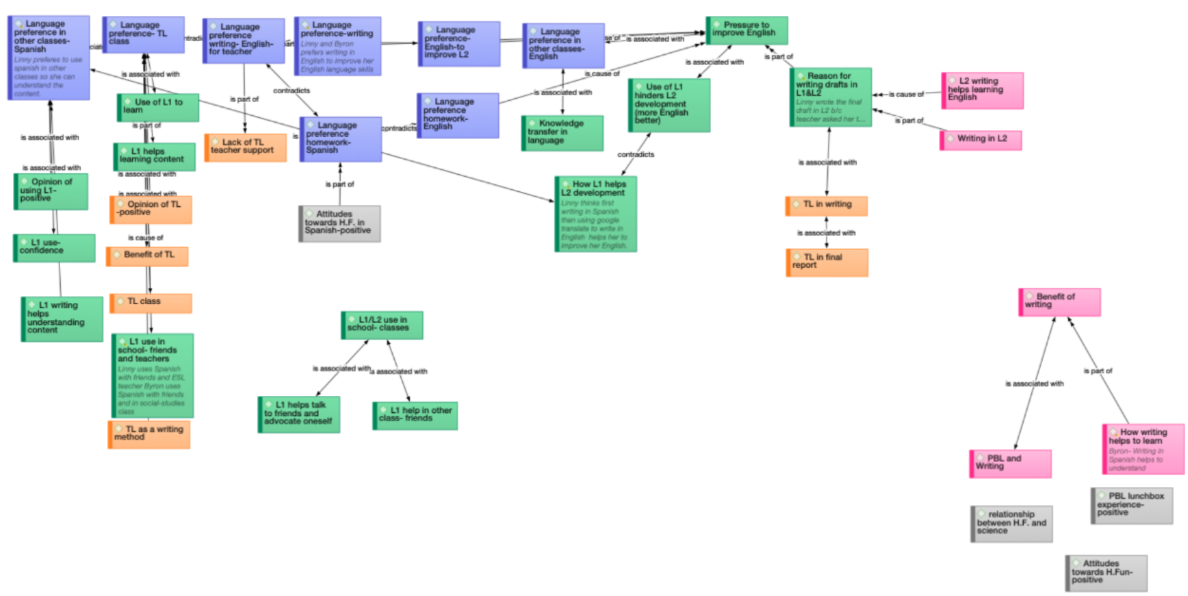
Analysis of Interview and Observation Data.

Another early analysis step was to upload interview transcripts and field notes into Atlas.ti, a qualitative data analysis software. This created a text for qualitative thematic analysis (Braun & Clarke, 2006), which can be used to discover explicit and implicit meanings through inductive analysis (Guest et al., 2012). Following procedures outlined by Braun and Clarke (2006), I conducted six phases of thematic analysis. The first phase began prior to coding, where I familiarized myself with the data by listening to all voice-recorded interviews while reading the professionally translated transcripts. Although students spoke in Spanish and my Spanish language proficiency is not high enough to fully understand without translation, this listening phrase helped me hear participants' tones, reactions, expressions, and other nuances of their voices. I also reviewed field notes from classroom observations and became familiar with all collected data.

In phase two, I generated initial codes related to my research questions as I read the data. As I generated codes, I engaged in a cyclical process of refining codes by adding, combining, and splitting codes to speak across interview and observation data. Phase three of analysis was a reorganization of codes into thematic categories. I reviewed and compared these themes to the entire data corpus to ensure themes were closely connected to the data. I revisited each transcript and field notes entry to add, remove, and/or combine codes as needed. In this fourth phase of analytic work, I read and re-read each transcript and field note entry to refine themes, staying open to other emerging codes/themes as I worked. Within phase five, I used Atlas.ti to create a visual representation from my list of themes (Figure 5), to find broader patterns in the data. As I worked to conceptualize and finalize themes, I carefully re-read the coded excerpts across the data sets to compare them with themes and wrote one-or-two sentence summaries of each theme to encapsulate their meaning. The final stage of analytic thinking was in composing well-described explanations of the data to present findings.

Figure 5

Examples of Visual Representations of Codes



Analysis of Student's Writing Documents.

I uploaded students' writing into Atlas.ti to support a qualitative deductive content analysis (Bingham & Witkowsky, 2021). Deductive content analysis is a top-down approach to data analysis that can be used to apply an existing theory or conceptual framework to data to see how it aligns. I created codes based on a science literary framework developed by Garcia (1985) and expanded by Chiappetta and Fillman (2007). I used the following predetermined science literacy categories as an analytic lens on students' compositions: 1) science as a body of knowledge, 2) science as a way of investigating, 3) science as a way of extending knowledge, and 4) science as a way of interacting with society. I also remained open to adding other ideas as they emerged from this analysis process. I created definitions for each category to take a systematic approach to analyzing the writing documents. As I read students' compositions, I marked excerpts where students' work presented evidence related to each category. I created a word document for each category where I pasted excerpts from student writing that fit the category. Once I conducted this analysis, I also referred to Ms. Irene's rubric scores for students' writing to discern how closely she agreed with what I observed in students' compositions. I held two virtual meetings with Ms. Irene to discuss my findings and gather her thoughts to strengthen the validity of my conclusions.

Following analytic processes outlined by Hatch (2002), I wrote a descriptive sentence for each category and asked an independent researcher to compare these findings statements with the word documents I created with descriptions and writing excerpts. As I wrote up findings, I selected representative excerpts from students' writing to support an explanation of findings.

Findings

Findings are organized into four main ideas: 1) translanguaging in HomeFun activities: engaging family to school science, 2) supporting emergent bilinguals to learn science through translanguaging, 3) report writing: demonstration of scientific knowledge, and 4) emergent bilingual students' preferences of using translanguaging contradict their experiences.

Translanguaging in HomeFun Activities: Engaging Family to School Science

Throughout their interviews, Carter, Linsey, West, and Brian indicated specific ways their family members contributed cultural knowledge and experiences to the HomeFun activities as they worked in their first language. Students reported their families engaged with them in their schoolwork. All four students said they completed HomeFun activities in Spanish with their family members (see Appendix A). They appreciated how their family members actively engaged with HomeFun activities, suggesting translanguaging had a positive influence on these students' family engagement with science content.

Carter talked about how his dad shared about family traditions and a heating/cooling device he used in Guatemala. He said he enjoyed the HomeFun activities because he had an opportunity to "saber más sobre las tradiciones de [su] familia *(learn more about [his] family traditions)*" from his parents. Similarly, West explained how his parents were able to contribute their experiences and knowledge in the HomeFun activities because they could speak in Spanish. As he responded to my question about what it was like to use Spanish for his homework, he said,

> Bien, porque pregunté a mis papás si ellos sabían sobre esto. Entonces, ellos me explicaron un poco de qué es lo que se usaba en, de verdad, de lo que se usaba un poco en Guatemala.
>
> *(Good, because I asked my parents if they knew about this. So, they explained to me a little about how it was used in Guatemala, like for real, of what/how it was used in Guatemala sometimes.)*

With these words, West indicated that speaking in Spanish allowed his parents to be involved in his schoolwork and share their knowledge and experiences related to the topic.

Linsey expressed that she enjoyed completing HomeFun activities in Spanish with her family, helping her to "saber más de nuestros países *(know more about [their] countries)*." Brian also elaborated how translanguaging experience made him feel "bien [good]" because he had no language restrictions in completing the assignments. When asked about his experiences doing the HomeFun activities with his family, Brian said,

> Lo siento muy bien, porque yo ya sé español, y puedo agregar palabras como que ya se en inglés.

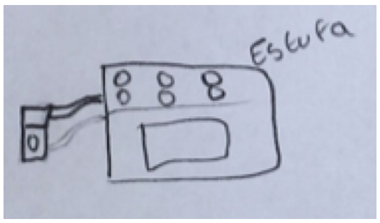
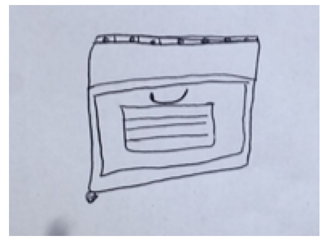
(I feel good because I already knows Spanish, and I can just add the English words I knows).

Brian's explanation suggests translanguaging eliminated language restrictions, effectively enabling families to contribute their family and cultural knowledge to school science-based work. Students learned more about their culture and home traditions from their family members than they might have had been required to complete the assignments in English, which would have constituted a barrier for families.

In addition to learning about their culture and traditions, these emergent bilingual students benefitted from working with the science subject matter together. They benefited from their family members' help in exploring how their home-based heating or insulating devices worked (e.g., "*the stove absorbs gas and that allows the stove to have fire*"). They also learned more about which energy sources those devices utilize (e.g., "*needs gas*," "*uses kinetic energy*," and "*aluminum*") to cook food or prevent heat transfer. For example, Carter and Linsey wrote about a stove that their families used at home to cook food. Carter explained the stove utilized gas as the main energy source to create and transfer heat to warm up food: "La estufa absorve el gas y eso hace que aya fuego en la estufa *(the stove absorbs gas and that allows the stove to have fire)*." Likewise, Linsey explained how her stove "usa energia kinetica [energia cinetica] *(uses kinetic energy)*" to transfer heat to the object. Both Carter and Linsey's examples indicate they made strong, science-based connections between home and school-based content.

Table 8

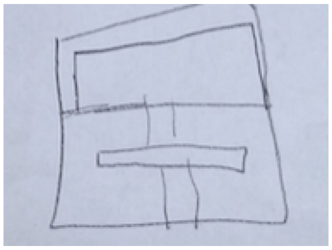
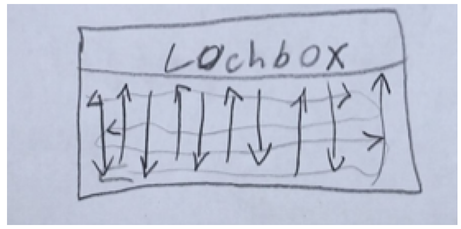
Carter and Linsey's drawing of a heating device: stove

Carter	Linsey
	
"La estufa absorve el gas y eso hace que aya fuego en la estufa *(The stove absorbs gas and that allows the stove to have fire)*"	"Usa energia kinetica *(Uses kinetic energy)*"

West and Brian also wrote about insulating objects, such as lunch boxes, that their families use to keep food warm throughout the day. West explained that the lunch box is used to "mantener to la calecfacion pocible [toda la calefacción posible] *(maintain as much heating as possible)*" and it is the solution to maintain the lunch hot "para la [su] cultura *(in his culture)*." West's description showed how well he understood insulation, along with his family's cultural connections to the lunch box. Likewise, Brian named the materials used in the lunch box to explain how it prevented heat from escaping to keep the food warm throughout the day: "de cajas, aluminio, papel de burbujas, y nailo *(of boxes, aluminum, paper of bubbles and nylon)*." Both West and Brian were able to explain heat transfer concepts related to items like an insulated lunch box that they and their family members used daily.

Table 9

West and Brian's insulating device: lunch box

West	Brian
	
"Seria el primero esnaser un solucion para cultura *(It will be the first solution for culture)*."	"De eajas, aluminio, papel de burbujas, y nailo *(Of boxes, aluminum, paper of bubbles and nylon)*."

These examples indicate students benefited from using their first language to interact with family members about science content and made strong cultural connections between these devices' usefulness in their families and cultures. Working on the HomeFun activities in their native language also enabled students to engage in the science subject matter together with their families.

Supporting Emergent Bilinguals to Learn Science through Translanguaging

While the HomeFun activities demonstrated the role of translanguaging for supporting family engagement, the use of translanguaging in the classroom was also supportive for these students. Since translanguaging removes the undue burden of language restriction, students were freer to understand the science content and fully participate in written and oral classroom activities. All four participants explained that translanguaging enabled them to learn science like all the other students in the classroom.

Speaking and Listening

In response to my question about how translanguaging helps him understand science, Carter indicated he understands science better when he can access it in Spanish, compared to English.

> "Aprendo mejor cuando me explican en español, así sé más los verbos, cómo los utilizan que en inglés".
>
> *(I learn better when they explain it to me in Spanish, that way I know the verbs more, how to use them, than in English).*

He went on to say,

> Porque si, bueno, no puedo utilizar mucho en inglés. Entonces, si lo puedo entender un poco, pero no puedo explicarlo. Entonces, si me lo explica en mi idioma yo puedo entender más y mejorar más en estos aspectos".
>
> *(Because, if well, I can't use a lot of English. Then, I can understand it a bit but I can't explain it. So, if it is explained to me in my language, I can understand more and get better in these areas)*.

With these words, Carter indicated the role of translanguaging in helping him more fully understand science content. He had no barriers to understanding science based on his beginner level of English language proficiency.

In the same vein, West remarked that he was able to learn more in Spanish than he would be able to learn if content were solely in English; he viewed translanguaging as essential for him to understand science topics in class. He was able to learn more and gained more content knowledge in the translanguaging class compared to other non-translanguaging classes because he was able to understand the learning materials. When asked how the translanguaging supported his learning, West answered,

> Porque voy a entender más lo que se está aprendiendo en ciencias [en español]
>
> *(Because I am going to better understand what is being learned in science in Spanish).*

Similarly, Lindsay and Brian both believed that translanguaging facilitated their science learning because they comprehend it better in Spanish than in English:

> **Linsey:** Cuando el maestro se explica en inglés, no entiendo. Si lo explica en español ya entiendo.
>
> *(When the teacher explains in English, I don't understand. If they explain it in Spanish, then I understand).*
>
> **Brian:** Cuando está hablando español, me ayuda a comprender por las explicaciones que me da y entiendo español
>
> *(When you [Ms. Irene] are speaking Spanish, it helps me to understand the explanations that you [Ms. Irene] give me and I understand Spanish).*

In addition, Brian mentioned that translanguaging helped him to learn and understand science-based content area vocabulary he did not know in English. Taken together, students' statements suggest translanguaging enabled them to participate and learn content like any other student without a language barrier in the classroom. With no language restrictions, they were able to fully participate, engage in class lessons, and understand the science content. Such benefits seemed useful not only for oral communication, but for writing, as well.

Translanguaging in Writing

Carter, Brian, and West believed translanguaging was helpful for them as writers learning science. Ms. Irene and Carter had the following exchange about this in response to my question about whether he understands better when writing in Spanish or English:

Ms. Irene

¿Cómo entiendes mejor las cosas, cuando escribes en español o cuando escribes en inglés? *(How did you learn things better, when you write in Spanish or when you write in English?)*

Carter

Español, entiendo mejor, bueno, because it is my language. Y se me facilitan las cosa. *(Spanish, I understand better, well,* because it is my language. *And it makes things easier for me.)*

Writing in Spanish supported Carter's understanding of the science content and increased his access to full participation in class activities. In addition, Carter added that removing linguistic concerns in writing helped him to think about science contents as he writes which helped his comprehension:

> Porque, cuando voy escribiendo [en español], estoy pensando en cómo [sobre] son las ciencias.
>
> *(Because, as I am writing, I am thinking about how sciences are).*

Without linguistic concerns and distractions, Carter was able to solely focus on science content matter and develop his thinking as he wrote. This allowed Carter to enjoy the benefits of reflective and constructive writing processes. Brian experienced a similar thing, and appreciated being able to use either language if he did not know a word in either English or Spanish

Que las palabras que no sabía [escribir] como en ingles, las decía en espaniol.

(The words that I didn't know how to [write] in English, I would use Spanish).

Being able to write without language restriction enabled Brian to fully participate in the writing process and focus on the writing content rather than the language. Likewise, West, who translanguaged throughout his report writing, explained it as a "method" to engage in writing:

Lo escribí un poco español y un poco inglés, porque yo intenté como mi method

(I wrote a little Spanish and a little English because I tried like my method).

Altogether, each participant reported positive experiences of translanguaging as they learned science, suggesting that removing language restrictions yields significant benefits for emergent language learners understanding science content.

Report Writing: Demonstration of Scientific Knowledge

Although students had not yet developed proficiency in English, translanguaging enabled them to fully participate in writing process and successfully complete their inventions and final reports. The degree of scientific knowledge about heat transfer varied between participant students, yet every participant's final draft displayed some scientific knowledge of heat transfer. Carter, Linsey, and Brian wrote their initial draft in Spanish, then translated entire draft into English using Google Translate. For his report, West translanguaged between English and Spanish.

Scientific Knowledge and Application of Knowledge.

Carter and Linsey's reports were the strongest in terms of indicating scientific knowledge; their papers included the three main heat transfer concepts (conduction, convection, and radiation), as well as explanations of how they applied these concepts to the lunch box project:

> **Carter**: Conduction is contact transfer. During the experiment, conduction occurs between the table and the bottle
>
> **Linsey**: Conduction is the transfer of thermal energy from one substance to another through direct contact. During the experiment, conduction occurs when we place the bottle on the table. To prevent being affected by heat transfer through conduction, humans have invented the gloves because when they are put on we don't burn.

Both Carter and Linsey's reports showed their understanding of conduction as a direct transmission of heat through a substance of different temperature. Also, their explanations that conduction occurred between the table and the bottle showed their understanding of heat transmission through contact during the lunch box experiment. Linsey's report extended scientific knowledge to real-life examples, suggesting she was not only able to apply the concept of conduction in the experimental setting but also able to extend the scientific knowledge further to connect with real-life examples.

Carter and Linsey also included the scientific concepts of convection and radiation, indicating they knew these concepts from their lunch box invention. Linsey's report demonstrated she understood all three concepts: "convection is the transfer of thermal energy by the circulation or movement of a fluid (liquid or gas)." She went on to add that convection occurred as gas moved through the air. Her explanation demonstrated she understood convection as the transmission of heat, because she described the way it took place in the lunch box experiment.

Regarding the concept of radiation, Carter explained "radiation is the transfer that produces deep electromagnetic covers," then elaborated where the radiation occurred and how it was prevented in the lunch box experiment:

> "Radiation occurs when the lamp throws a lot of radiation, but the box materials such as aluminum reflect radiation…. since [aluminum] is the one reflects the radiation."

Both Carter and Linsey's reports demonstrated that they acquired knowledge about the three types of heat transfer concepts and their roles in the experiments. They understood the scientific concepts and were able to both apply them in the experiment and write about them later. Such activity represents their understanding went much deeper than simple memorization of scientific facts.

Although Brian's report demonstrated only partial understanding of the heat transfer concepts, he still demonstrated learning. His report included two out of the three heat transfer concepts, conduction, and radiation. Of these two, he was able to write about how radiation was evident in the lunch box experiments: "During the experiment, radiation occurs when the lamp throws a lot of radiation, but the box materials such as aluminum reflect the radiation."
With these words, Brian demonstrated he had at least a partial understanding of the three heat transfer concepts and he understood radiation the best.

An analysis of West's report suggested he gained limited knowledge of the heat transfer concepts:

> Heat transfer is hot to cold. Heat transfer in three ways, through conduccion radiaccion and comvection (*conduction, radiation, and convection*). Thermal equilibrium is when things have the one of the gools *(goals)* of this project is to provent *(prevent)* heat transfer by frio para que no sea caliente *(cold so it's not hot).*

Although his explanation included the three concepts of heat transfer, his scientific knowledge was less developed than those of Linsey, Carter, and Brian. Nevertheless, each of these students possessed only an emergent level of English language ability; translanguaging enabled them to participate more fully than they would have been able to do if their teacher had only worked with them in English. They were able to invent, learn about scientific concepts through experimentation, and write about their scientific knowledge.

Emergent Bilingual Students' Preferences of Using Translanguaging Contradict Their Experiences

Despite these seeming positive experiences around translanguaging for giving students access to content learning and supporting strong home/school connections, participants had mixed opinions about whether they thought translanguaging was best for them. It appeared that although Ms. Irene provided them access with her linguistic skills, they still felt pressure to speak and write well in English.

Speaking.

Although Brian's responses demonstrated how much he benefited from translanguaging for understanding science content, he offered an opinion about translanguaging indicating he felt conflicted about needing that support. When asked about his opinions of using both Spanish and English in the science classroom, Brian shared his opinion saying that, "que debería solo usar un idioma *(I should only use one language)*." He explained this is because he wants "aprender… más del inglés *(to learn more English)*." In contrast, when asked what language he preferred to use in learning science subject matter, rather than seeking to improve his English, Brian chose Spanish.

Ms. Irene: Si pudieras elegir una clase en donde se habla solamente en inglés, o una clase en donde se habla inglés y español. ¿Cuál preferirías?

(If you could choose between a class where you only spoke English and one where you spoke both English and Spanish, which one would you prefer?)

Brian: Hablar? *(To talk?)*

Ms. Irene: No, para aprender ciencias. *(No, to learn science).*

Brian: Español *(Spanish)*

Brian's responses illustrate how his preferred language changes depending on what he is being asked to do. If he was trying to learn science, he preferred Spanish. If he was trying to improve his English language, he preferred English. This implies that he knows Spanish benefits his content learning but also believes using English will improve his English language proficiency. He seemed to feel an obligation to use English.

Like Brian, West also felt translanguaging positively supported his comprehension of science content, but he wanted to get better at English; this led him to indicate a preference for English-only instruction over translanguaging. He explained this was because he needed to practice more English in class:

> Porque si yo hablo mucho en español, entonces, no estoy practicando más inglés. Entonces, tengo que intentarlo… porque cuando voy a estudiar algo de ingles, y estoy hablando en español, hablo mucho español. Entonces no voy a aprender nada, porque entonces solo voy a recordar el español y no el inglés.
>
> *(Because if I talk a lot in Spanish, then I'm not practicing more English, so, I have to try it… because when I am about to study something in English, and I'm speaking in*

> *Spanish, then I speak a lot of Spanish. So then, I am not going to learn anything, because I am only going to remember the Spanish and not the English).*

His statement showed that he is not content with speaking Spanish in the translanguaging class because he "*only remembers in Spanish*." He believed using more English would improve his English language skills; he also believed that what he learned in Spanish could not be transferred to his English-only classes because he did not know the English words. West's negative perception towards the translanguaging classroom was also related to how different it was from the rest of the school. West wanted to learn science in an English-only classroom so he could utilize learned English words and phrases in classes outside of Ms. Irene's class. When he was asked which language he would prefer to use for science, this is how he elaborated on:

> Inglés. Oh si, para aprender, digamos, porque en otras clases me puede servir. En las clases que no hablan español, entonces puedo usar eso, que ya sé [reconozco], que ya entiendo que están diciendo eso [entiendo el concepto]. Como que si me están explicando algo de la radiación, o como en algo de matemáticas ocupamos las ciencias.
> *English. Oh yes, to learn, like, because it could be helpful for me in other classes. In classes where we don't speak Spanish, so then, I could use this, that I know [recognize], and that I know what they are talking about [understand meaning]. Like if they explain something about radiation, or in math we use science.*

West believed English-only in science class would help him learn English vocabulary that he could utilize in his other monolingual classes. His response indicated how much pressure he felt to learn English, since he did not have translanguaging support outside of Ms. Irene's science classroom. This seemed to negatively affect West's opinion about translanguaging practices in the science classroom. Linsey also reported she thought it might be best to use only English because other teachers do not understand Spanish nor practice translanguaging outside of Ms. Irene's classroom:

Ms. Irene

Cuando tu tomas notas, anotaciones en la clase, tu escribes en español?

(When you take notes, annotations in class, do you write in Spanish?)

Linsey

No. *(No.)*

So Lim

Why do you write in English?

Ms. Irene

¿Por qué escribes en inglés? *(Why do you write in English?)*

Linsey

Para que entiende la maestra. *(So that the teacher understands.)*

Students' responses demonstrated how translanguaging could benefit them but still feel like a conflicted space; their opinions about it were shaped by the fact that they only had access to this support in a single classroom. The school environment and institutional attitudes about translanguaging, reflected as they were in the fact that no other teachers could offer it, made them feel uncomfortable about having translanguaging support with Ms. Irene. Their desire to improve their English language skills and the lack of translanguaging support outside of Ms. Irene's classroom significantly shaped their language preferences and choices.

Writing.

Similar patterns were evident in students' language preferences for writing. Even though Ms. Irene could have read and graded their final reports in both English and Spanish, three out of the four participants opted to translate their entire report from Spanish to English. Only one student, West, used both English and Spanish in his final draft. Their language choice for these final reports was the opposite of their choice for HomeFun activities, which they wrote in Spanish.

In interviews, all four students stated their strong preference for writing in English. Some even expressed strong feelings of dissatisfaction when they wrote their initial report draft in Spanish. For instance, despite his positive experience of translanguaging in learning science content, Carter recalled and expressed feelings of discomfort about writing his initial draft in Spanish.

SoLim

How was it to write this initial report in Spanish?

Carter

Un poco costoso porque quería escribir en inglés. *(A little bit hard because I wanted to write in English.)*

SoLim

Why did you want to write in English?

Carter

Para mejorar mi escritura y aprender cómo escribir las palabras. *(To improve my writing and to learn how to write the words).*

When asked about his experience of writing his final draft in English, Carter's voice brightened; he spoke satisfactorily that doing so had helped him learn some English verbs through writing in English:

SoLim

Then, when you wrote your final draft in English. How was this experience?

Carter

Cool. Cool, because así aprendí a usar un poco más los verbos y escribir más palabras. *(Cool. Cool, because in this way, I learned to use the verbs a little more and to write more words.*

SoLim

How did you write? Can you explain the process of writing it in English?

Carter

Usando Google Translate. *(Using Google Translate)*

Carter's feelings about writing in Spanish were positive when he talked about writing to learn science content. However, when he thought about writing as a means to improve his English language skills, he felt more negatively about using Spanish to communicate his thoughts in writing. Such a response suggests Carter believed using English more often would help him improve his English language skills. It also showed his heightened sense of urgency and pressure to improve his English.

Likewise, even though Linsey demonstrated a positive attitude towards using Spanish to learn science, she expressed her preference to write in English to improve her English language skills:

SoLim

If there is a choice to write in Spanish or English, which language would you choose?

Linsey

Ingles. *(English.)* Porque si estoy escribiendo [en inglés] me quedan las palabras y yo puedo aprender más [inglés].

(English. Because if I am writing [in English], the words stick with me and I can learn more [English]).

Linsey's answer also showed her desire and pressure to improve English affected her language preference in writing. Brian offered similar sentiments, putting great emphasis on learning English in the translanguaging class.

West expressed a different language preference compared to Linsey, Carter, and Brian. Although he also emphasized that learning English in the science classroom was important to him, he also viewed translanguaging as an effective means to learn English. While other students believed writing in English was the best way to improve their English language skills, he believed using both languages helped him learn English. He explained that it was helpful to use Spanish to complete the sentences he could not complete in English:

West: Quiero aprender inglés, y entonces lo intento a escribirlo. Para ver si lo puedo escribir bien. Los escribí un poco español y un poco inglés, porque yo intenté como... como mi method.

(I want to learn English, and so I try to write it. To see if I can write it well. I wrote a little Spanish and a little English because I tried like… like my method.)

West's writing reflected his feelings; he was the only student among the four emergent bilinguals to write his final draft using both languages. He also did not believe he needed to translate the entire draft from Spanish to English like Carter, Linsey, and Brian did. Although West also expressed a powerful desire to practice and improve his English like other students, his positive view of translanguaging in improving writing in English gave him peace in using it to support every aspect of his learning.

Discussion and Implications

Effects of Translanguaging in Learning Science and Family Engagement

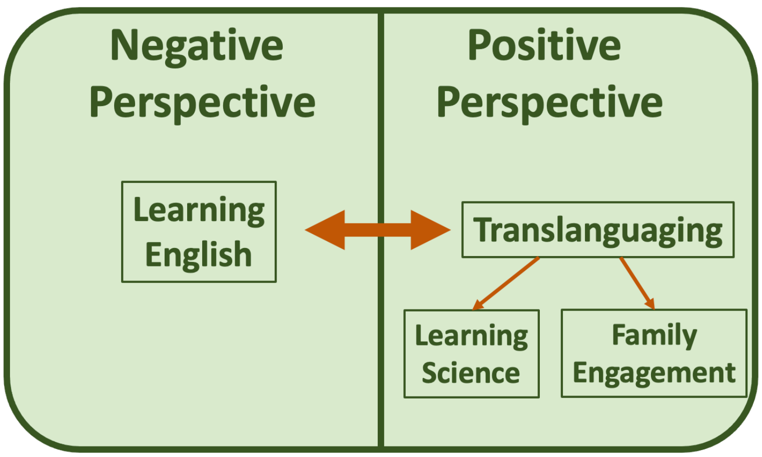
Findings in this study indicate translanguaging did support these four emergent bilingual students to successfully meet science standards. This is aligned with previous research demonstrating the positive effects of translanguaging for student comprehension and engagement (Dougherty, 2021; Gren, 2022; Poza, 2017; Prilutskaya, 2021); this study suggests translanguaging increased students' science content comprehension and strengthened their families' ability to participate in their children's school-based work.

According to Washington and Seidenberg (2021), the challenges of learning academic content multiply for students who must learn in a different language than the one in which they are proficient. Since translanguaging enables students to understand content to the same degree as English-proficient students (Gren, 2022; Prilutskaya, 2021), it effectively levels the playing field for low English proficient students who do not have enough English language skills to learn core content without support.

Not only did all four emergent bilingual students fully participate and successfully complete their reports, Linsey and Carter's papers even indicated higher-order thinking skills suggesting they transferred knowledge from a known context to a previously unfamiliar one (Perkins & Salomon, 2012; Thompson et al., 2006). They were both able to apply the concepts of conduction, convection, and radiation to their lunch box experiments. Linsey even connected this knowledge to the concept of gloves, which she indicated people use to prevent conduction. In Linsey's words, translanguaging enabled these students to "*understand better*" and focus on "*how sciences are*". Using translanguaging as a "*method*" gave these students equal access to science content and enabled them to fully engage in the learning process (Celic & Seltzer, 2013; Cenoz & Gorter, 2020; Fu et al., 2019).

Figure 6

Effects of Translanguaging in Learning Science and Family Engagement



Another distinctive benefit of translanguaging emerging from this study was the family engagement. I argue that translanguaging had a significant role in advancing family involvement for these students and could become a crucial tool to support school/family partnerships among language minority families. There have been countless studies claiming the importance of family engagement on students' academic achievement, motivation, and behavior in school (Bouffard & Stephen, 2007; Morningstar et al., 1995; Schnell et al., 2015). This kind of engagement goes far beyond schools inviting parents to participate in school-led programming such as parent meeting, orientations, and volunteering opportunities (Grant & Ray, 2018). True family engagement must aim for a culturally responsive and mutual partnership between school and family to support student success (Baker et al., 2016; Garbacz et al., 2017; Grant & Ray, 2018). Family engagement, therefore, encourages families "to take their place alongside educators in the schooling of their children, fitting together their knowledge of children, teaching, and learning with teachers' knowledge" (Pushor & Ruitenberg, 2005, p. 13).

Even if parents desire this kind of engagement, language and cultural barriers can make it extremely challenging for language minority parents to contribute their knowledge and experience to their children's schoolwork (Daniel-White, 2002; Kerbaiv & Bernhardt, 2018; Violand-Sanchez et al., 1991). Translanguaging can support this by removing these unnecessary language restrictions, enabling students and parents to work together. When students can help their parents take an active part in what they are learning at school and learn more about their countries, family traditions, and science, all of this makes science activity "cool" and "bien (*good*)." In Brian's words, he "*feels very good*" to use Spanish in his homework, because everyone could utilize their full linguistic repertoire building literacy exchanges together.

Consequences of Monoglossic Ideology on Emergent Bilingual Students

This study confirms previous research that despite translanguaging support, students can still internalize and adopt monoglossic ideologies in monolingual school settings (Babino & Stewart, 2017; Flores & Rosa, 2015; Kaveh & Lenz, 2022). Such ideas trigger negative attitudes towards translanguaging practices and can cause students to favor English-only learning setting over translanguaging-based ones (Aoyama, 2020; Gren, 2022). The emergent bilingual students in this study showed awareness of the linguistic power imbalance; despite positive experiences learning science content through translanguaging, all of them indicated a preference for learning in English to "*improve*" their English. West went so far as to say that whatever knowledge he gained in the translanguaging class is not valuable if it cannot be explained in English: "*I am not going to learn anything, because I am only going to remember the Spanish and not the English.*"

Such words indicate the power of linguistic policies to shape students' language ideologies, leading them to favor English over their first language and further perpetuate monoglossic ideologies (Kaveh & Lenz, 2022).

This study also shows how students' attitudes towards translanguaging practices differed by learning tasks and contexts. It was significant that all four participants enjoyed translanguaging with their families for HomeFun activities, suggesting the social context of home and family made them feel positively about it. It makes sense that students would prefer to speak Spanish in their homes, where Spanish is spoken every day. However, at school, they felt differently about translanguaging. In social contexts where English was the dominant language and social norm, they preferred English-only practices over translanguaging. They felt less positively about the translanguaging practice that helped them learn science. When they focused on learning in the broader school setting, they focused heavily on learning English which caused their attitudes towards translanguaging shifts from positive to negative. These findings confirm previous studies indicating students' beliefs and attitudes towards language ideology are shaped by their surroundings, such as school (Block & Vidaurre, 2019; Schwartz, 2018). In short, these students had a strong desire to be part of the English norms at their school, which colored their perceptions of the translanguaging practices they found to be so helpful for learning science. With statements such as, "*I should only use one language*" and "*a little bit hard because I wanted to write in English*" regarding translanguaging practices, they illustrate how much pressure they feel to learn English.

A lack of institutional support for translanguaging was prominent in this study; indeed, it is challenging to create multilingual learning environments for emergent bilingual students in such environment. But such lack of institutional support and monoglossic school systems negatively shape students' beliefs about translanguaging and first language use in the classroom (Aoyama, 2020; Daniel & Pacheco, 2016; Gren, 2022).

This study offers several implications. First, it is important to listen to what students have to say about the educational and pedagogical practices that are useful for them. Students' voices are often left out of these kinds of conversations because their opinions differ from those of the more powerful adults (LeCompte, 1993). Yet, as primary stakeholders in their own educational outcomes, they have every right to contribute their insights and opinions to advance their learning (Lincoln, 1995). Creating increased space for student voices can empower students as well as lead educators to "the new way of knowing" about what it means to teach and learn from students (Lincoln, 1995, p. 92). Second, professional and structured institutional support for multilingual school environments is essential if emergent bilinguals are to fully benefit from translanguaging practices and avoid absorbing monoglossic ideologies (Aoyama, 2020; García, 2011; Grant & Ray, 2018; Gren, 2022). The collaborative process of building multilingual schools will promote an engaging and welcoming learning environment for emergent bilingual students.

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CHAPTER FOUR

Writing-to-Learn for Science Literacy Development: Exploring the Benefits for Culturally and Linguistically Diverse Students

As technology advances, science education has evolved from an emphasis on memorizing facts to helping students develop science literacy. This involves the ability to solve problems and make connections between scientific understandings and real-life situations in order to meet the demands of today's society (Krajcik et al., 2001). New curriculum standards and frameworks have been established to help teachers encourage every student to engage in higher-order thinking and critical reasoning skills (Hoeg & Bencze, 2017; Lederman, 2014; Lederman & Lederman, 2007; Lee, 2005). One of the most valuable strategies to support these outcomes for students is writing, which is a thinking modality that strongly supports a meaning-making process for learners. Writing-to-learn can be especially beneficial in helping students learn science when teachers intentionally integrate it into instruction (Baker et al., 2008; de Oliveira & Lan, 2014; Graham et al., 2020). Many studies have indicated that writing engages students in higher-order thinking and helps them develop both critical reasoning skills and subject matter understanding (Baker et al., 2008; Chen et al., 2013; de Oliveira & Lan, 2014; Pelger & Nilsson, 2016; Sampson et al., 2013). Through writing, students clarify their understanding of content, develop new ideas, and apply what they learn to real-life situations (de Oliveira & Lan, 2014; Rivard, 1994; Sampson et al., 2013).

However, many students find writing challenging; this can be particularly true for culturally and linguistically diverse (CLD) students, whose language and cultural backgrounds are different from many of their peers and teachers (Lee & Fradd, 1996; Manchón, 2011). CLD students who use more than one language at home or in the community may find it challenging to complete school-based writing tasks, which are often in English. Unlike oral language proficiency, proficiency with written language does not develop naturally through social interactions (Boughey, 1997; Brisk, 2020). Furthermore, writing in science-based genres can be even more challenging due to content-specific vocabulary and distinctive grammatical patterns (Fang et al., 2010). To make full use of writing in support of science learning, it is imperative that educators appropriately and intentionally incorporate thoughtful writing instruction into science curriculum and instruction (Fang et al., 2010; Fang & Schleppegrell, 2010). Such intentional instructional work is challenging but worth careful study as the field seeks increasingly effective ways to support CLD students (Fang et al., 2010).

This study explored CLD students' writing experiences in an invention-based learning (IBL) science classroom to understand how they perceived writing as supportive of their science learning. It also sought to identify the ways writing promoted students' knowledge development. The IBL classroom was a unique place to explore writing-to-learn for CLD students. IBL is a type of project-based learning pedagogy emphasizing collaboration and the invention process as a means of building understanding. IBL is inherently hands-on and oriented to problem solving, while also maintaining student interests as central to learning (Kim et al., 2021; Kim & Kim, 2021; Zhang et al., 2019). Teachers who use IBL facilitate learning engagements where students use scientific knowledge, practice thinking processes, design, invent, and come to understand for themselves how to apply science in the wider world (Kim et al., 2021; Kim & Kim, 2021; Zhang et al., 2019). As both IBL and writing are distinctive but effective pedagogical methods to engage students in learning and developing science literacy, teachers can use them together to meet the needs of diverse students by providing creative and supportive opportunities for them to apply knowledge in practice (Boscolo & Mason, 2001; Kim et al., 2021; Kim & Kim, 2021; Zhang et al., 2019).

While there is extensive research indicating the usefulness of writing to support English as a second language (ESL) students (Manchón & de Larios, 2011; Mastan et al., 2017; Soucy, 1994), its use in science-based content areas is understudied. There is even less research on this pedagogical process for CLD students working in IBL-based science educational settings (Kim et al., 2021; Kim & Kim, 2021). This study addresses this gap in the research by exploring what six CLD students in an IBL classroom wrote about their science-based learning, and what they said about their writing process. This study also explored the ways writing supported students' knowledge development and transfer. In an effort to understand how writing impacted students' science literacy development, this study posed the following questions:

- How do CLD students perceive and experience writing in an IBL program?
- In what observable ways does CLD students' scientific knowledge and application of that knowledge change through writing?

Literature Review

This paper builds on previous research (Baker et al., 2008; Boscolo & Mason, 2001; Chen et al., 2013) related to how writing serves learning by addressing 1) the particular language challenges of science, 2) writing-to-learn in science, and 3) the concept of forward search in writing, and 4) knowledge transfer in writing.

Language of Science

According to Tan (2011), many science teachers believe they have no responsibility for teaching language and literacy and are only responsible for helping students acquire science-based content knowledge. This troubling fact means many science teachers effectively misunderstand the ways their subject area heavily relies on language and literacy to communicate and exchange science-based knowledge (Fang et al., 2010).

Moreover, the language of science uses distinct discourse patterns, which make science language and literacy development even more challenging and important for teachers to help students access (Brisk & Zhang-Wu, 2016). Sometimes, to fulfill its purposes, science-based language can be impersonal and even authoritative in nature (Fang et al., 2010; Fang & Schleppegrell, 2010). It relies on patterns of logical reasoning that differ significantly from students' daily dialogues. For example, instead of using conjunctions such as "because" and "but" to directly connect ideas, science textbooks often use words such as "cause," "result," and "occur" to imply relationships and connections (Fang et al., 2010). Additionally, science texts often use dense noun groups, making them even more challenging for students to comprehend (Brisk, 2014; Brisk, 2020; Brisk & Zhang-Wu, 2016).

Accordingly, many scholars emphasize the importance of language instruction and writing practices in science to support student comprehension and access to science content (Brisk & Zhang-Wu, 2016; Fang et al., 2010; Kim & Kim, 2021; Sampson et al., 2013). Brisk and Zhang-Wu (2016) argue students must be taught to use subject-specific academic language; students also need to see others use and rehearse using such language in their own literacy tasks. Such practices enhance students' ability to develop their comprehension alongside their science-based academic language (Baker et al., 2008; Brisk & Zhang-Wu, 2016; Fang et al., 2010; Fang & Schleppegrell, 2010).

Writing-to-Learn in Science

Writing-to-learn is a pedagogical practice designed to support students in developing subject-specific academic language (Baker et al., 2008; Boscolo & Mason, 2001). Yet the process of writing-to-learn is also composed of challenging sub-skills that are important for students to experience. Engaging in the writing process means writers must reflect and elaborate on learned content, formulating ideas, analyzing, identifying contradictions, and revising (Klein, 1999). Such practices demand much of writers, and can significantly strengthen students' knowledge and understanding of academic subjects as they productively struggle with such tasks (Fang et al., 2010; Klein, 2000; Klein & Kirkpatrick, 2010; Knipper & Duggan, 2006). As students participate in such processes, they not only develop their language, but gain a deeper understanding of scientific concepts and strengthen their higher-order thinking skills (Rivard, 1994).

Many studies have shown that learners can use writing as a means of accessing science-based learning in a variety of contexts. According to Fang et al. (2010) students who write in their science classrooms develop deep understanding of science, clarify and consolidate their knowledge, and connect science to their daily lives. As they write, students learn how to clarify their ideas, stay open to new learning, and develop critical thinking as they solve problems (p. 104).

Several key studies demonstrate how useful writing can be to helping students develop critical thinking skills (Chen et al., 2013), deepen their metacognitive awareness (Balgopal & Wallace, 2009), and make connections between science and their daily lives (Baker et al., 2008). Research such Hand et al. (2007)'s study of high school student writing suggests the writing process helped students improve their metacognition and knowledge related to chemistry concepts. Students who engaged in a writing activity spent more time thinking about what they had learned, and their writing enabled them to explain concepts that a control group could not explain. The revision process also enhances students' understanding of content (Hand et al., 2007; Klein, 1999). For students who revised, "the second draft [of their writing] was crucial in allowing [students] to better engage with the science concepts and the language requirements of the task" (Hand et al., 2007, p. 140). The act of revising in writi'g attuned students to monitor their text for contradictions, which led them to reconcile their (sometimes inaccurate) prior knowledge with new learning (Hand et al., 2007).

Forward Search in Writing

Several other studies indicate the apparent usefulness of the revision process for supporting students' science-based learning. This work began most prominently in 1999, when Klein (1999) presented four hypotheses about writing-to-learn. He argued that students develop new knowledge when they are supported in revisiting and reorganizing their initial writing. Students who do so engage in a "forward search," or a process of reconstructing their knowledge as they rewrite compositions they developed in initial stages of their learning.

Within a forward search process, students repeatedly visit their initial drafts to identify and resolve contradictions or expand ideas in their writing. Such thinking requires them to reevaluate their thinking and expand their capacity to infer more accurately about the world (Klein, 1999, 2000). According to Hand et al. (2007),

> [Writers] transform their ideas by ongoing analyses of their texts in terms of expanding inferences, reviewing idea development, noting contradictions, and making appropriate revisions. In this view the writer learns from writing by attending to, and clarifying, the emerging meanings of the text. (p. 740)

Forward search is not limited to writing; it is a notion applicable to any kind of learning experience where students make inferences as part of a problem-solving process (Klein, 2000). For instance, Klein's (2000) research described how elementary students engaged in forward searching by reviewing experimental results to generate ideas and expand their inferences to solve problems. When students write to generate ideas, they effectively broaden and deepen their knowledge and relate their learning to their everyday experiences (Langer & Applebee, 1987).

Knowledge Transfer in Writing

The reflective process of writing also supports learners in transferring knowledge from one context to another (Galbraith, 1999). Since writing is inherently a process of discovery (Boone et al., 2012; Galbraith, 1999), it enables students to restructure their existing knowledge to generate new ideas. According to Flower and Hayes (1980), such a process enables writers to "consciously…probe for analogues and contradictions, to form new concepts, and perhaps even to restructure their knowledge of the subject" (p. 28). This process of reconstruction is closely related to the process of knowledge transfer, or a means by which learners apply knowledge from a known context to an unfamiliar one.

Although knowledge transfer mechanisms are not universally defined, many studies have found crucial factors that facilitate knowledge transfer (Boone et al., 2012; Perkins & Salomon, 2012; Roux et al., 2006; Thompson et al., 2006). Students must be active participants in learning and have access to multiple examples of content linkages from one context to others and they must also have some proficiency in content to do this work effectively (Engle, 2006; Kim et al., 2021; Thompson et al., 2006). Teachers effectively facilitate this for students by helping them be actively engaged in the learning process, through interest-driven or highly motivating activities. Learners must also be able to explore multiple examples of the same content in contexts that are linked to each other (Engle, 2006). According to Engle (2006) intercontexuality, or awareness of the links between two contexts, is important in helping students transfer knowledge. Without sufficient context to help them understand how the knowledge fits in various contexts, it is difficult for them to apply knowledge from one context to another. Lastly, learners must be able to cultivate a deep understanding of content (Bransford et al., 2000; Chi & VanLehn, 2012) to facilitate knowledge transfer. Learners who benefit from these conditions have increased opportunities and capability to extend their knowledge not only to different school-based contexts, but also to their lives outside of school (Kim et al., 2021).

Even though developing knowledge and effectively applying it to wider contexts is often considered the ultimate goal of education, many studies demonstrate that schools do not often reach this goal of helping students transfer their learning from school to the wider world (Engle et al., 2012; Perkins & Salomon, 2012). Writing can help support this process because it not only engages students in a reflective process but enables them to flexibly reconstruct knowledge and apply it in multiple contexts (Flower & Hayes, 1980; Langer & Applebee, 1987).

Methodology

The multiple case study at the center of this article explored this writing-to-learn experience for six CLD students participating in an IBL-based science curriculum. Each student constituted a case, offering an in-depth analysis (Merriam & Tisdell, 2015) of students' writing experiences both within and across the six cases. The following sections introduce the study's context, participant students and teacher, along with data sources and analytic processes for this study.

Context

The study was conducted jointly between Boston College, Lemelson-MIT (which was the School of Engineering at the Massachusetts Institute of Technology), and Brown Public School District BPSD (pseudonym). A longitudinal STEM program was developed and implemented by the two university institutions in collaboration with BPSD. A special focus of the program was to serve student groups who are underrepresented in STEM-related fields.

As the basis for STEM learning, the program used Lemelson-MIT's invention-based curriculum. Eight invention-based education guides were included in this program, as well as Junior Varsity (JV) InvenTeam activity guides (https://lemelson.mit.edu/resources/curriculum-invention). Curriculum for JVInvenTeams was aligned with Next Generation Science Standards and designed for educators and students in grades 6-10. To serve a seventh-grade science classroom with culturally and linguistically diverse students, the Lemelson-MIT-Boston College team adapted the unit entitled "Chill Out," with writing-to-learn tasks. In this unit, students build lunch box inventions while learning about heat transfer concepts such as convection, conduction, and radiation. This unit is aligned with invention-based learning (IBL) pedagogy designed to help students solve science-based problems (Kim et al., 2021; Kim & Kim, 2021; Zhang et al., 2019). In this specific class, students invented objects to solve real-world problems. IBL promoted interdisciplinary thinking by requiring students to collaboratively work together to use their knowledge in problem-solving, project-based tasks (Kim et al., 2021; Kim & Kim, 2021; Zhang et al., 2019). This sort of pedagogy is quite different from traditional schooling contexts where students receive direct instruction and passively listen or take notes.

As noted above, Boston College modified the Chill Out unit for CLD students by adding writing-to-learn activities. They also added visual representations of science concepts and cultural relevant home-based activities called "HomeFun." These modifications aligned with seventh-grade content and language standards. The revised curriculum was implemented for 10-12 weeks. Teachers at two public middle schools in BPSD implemented the Chill Out program as part of their science classroom instruction. This study examined the classroom of one of the six science teachers, Mr. Lee, and six of his CLD students during the 2019-2020 school year.

Procedures and Content

The Chill Out Curriculum.

The Chill Out program began with students learning and exploring concepts related to heat transfer, such as convection, conduction, radiation, insulation, and thermal equilibrium. Mr. Lee helped students explore these ideas through whole-class lessons and a variety of hands-on activities enabling them to explore insulation, the thermoelectric effect, and materials that prevent heat transfer. Students then got an opportunity to apply this science-based knowledge to solve a real-world problem, such as keeping hot food hot, or cold food cold. Students were given an empty shoebox and asked to work in groups of three or four to devise a lunchbox that would prevent heat transfer for items inside by preventing conduction, convection, and radiation. Students had access to aluminum foil, bubble wrap, packing peanuts, old clothes, and construction paper to create their invention.

To ensure the lunch box's effectiveness in preventing heat transfer, each group tested their invention. Each group received a refrigerated water bottle to put in their lunchbox; temperatures were compared to a control test of a chilled water bottle stored in a regular shoe box. Based on the results of this experiment, students wrote reports framed as patent applications to describe and promote their inventions. Mr. Lee provided students with language and writing lessons on how to compose scientific reports that might appeal to the public. Lessons helped students address science-based language use, academic vocabulary, and genre structure. Students practiced these skills in a variety of short, science-based writing activities throughout the unit. Overall, as students worked through this cognitively challenging learning process, they practiced an inventor's mindset, which asked them to cultivate an open mind from which to discern possibilities for solving problems (Zhang et al., 2019); they were also invited and supported to communicate this complex process in their writing.

Writing a Report.

Students submitted both an initial and final draft of their report. They received written and oral feedback from Mr. Lee regarding the scientific concepts in their first draft and had an opportunity to revise them with support during school hours. As they wrote, students had opportunity to collaborate with one another and ask their teacher questions about the science-based ideas in their writing.

Participants

The student participants in this study were six seventh grade CLD students who attended a middle school in BPSD. Using a purposing sampling method (Merriam & Tisdell, 2015), students were selected based on the three criteria: 1) they self-identified as CLD students, 2) they fully participated in the Chill Out curriculum, and 3) they were willing to participate in initial and follow-up interviews (Table 10). Each of the participants were CLD students who were deeply embedded in both their heritage cultures and the dominant culture of the United States. They all self-identified as CLD students and were either the children or grandchildren of immigrants.

Table 10

Student Demographics

	Maggie	Nikki	Caroline	Noa	Maria	Sarah
Grade	7^{th}	7^{th}	7^{th}	7^{th}	7^{th}	7^{th}
Gender	Female	Female	Female	Female	Female	Female
Heritage Country	Italy	Canada	Greece	Italy	Guatemala	Morocco

Data Collection

Data for this study was comprised of classroom observations throughout the Chill Out unit, student writing samples, and semi-structured interviews with students and teacher. Their teacher, Mr. Lee was welcoming to my presence in the classroom; I collected field notes as I observed two or three times a week for the twelve weeks of the Chill Out unit. I conducted interviews with the six CLD student participants, which provided insights into their experiences with writing in the IBL curriculum. I also had informal conversations with Mr. Lee about what I was observing as the unit progressed. Students' reports offered additional insight into their science learning in the classroom.

Classroom Observations.

I observed in Mr. Lee's science classroom for twelve weeks, taking field notes two or three times each week for one hour per visit to gain insight into student participants' experiences. I recorded as much detail as possible regarding lessons, materials, class activities, small-group interactions, and class interactions. My observations centered on students' progress in learning and their interactions with peers and teacher. During this fieldwork, I also conducted informal conversations with Mr. Lee, which helped me expand and contextualize my field notes.

Semi-structured Student Interviews.

Two semi-structured interviews were conducted with students, one right after they completed the Chill Out unit and again at the beginning of the following semester. Both interviews were conducted during lunch hour in a science classroom. Interview questions were based on the key research aim, which was to understand how these CLD students perceived writing in the IBL program, and to see how their scientific knowledge and application of that knowledge changed through their writing process.

The first interviews were conducted individually and took between ten and fifteen minutes per student. This interview included ten questions covering four different topics:

1. Student's demographic information (e.g., "Could you introduce yourself?")
2. Inventing experiences (e.g., "Could you describe your lunch box inventing experience?")
3. Writing experiences (e.g., "What was your experience with writing in the science class?")
4. Perceptions towards writing in science (e.g., "What do you think of writing in science?")

As a form of member-checking (Creswell, 1994), I conducted follow-up interviews later, which took approximately 50 minutes. I talked with students in pairs this time, to accommodate student availability during their lunch hour. This second interview asked more specific questions such as, "before the Chill Out program, did you have any writing experience in science?" and "what changes did you make between the initial and the final draft?" and "what changed about your perception of writing in science?" Students shared readily and clarified my interpretations on a few occasions.

Report Writing Drafts.

Along with the student interview data, students' initial and final report drafts were a key source of data for this study. They provided me with insight into how effectively students developed their content knowledge during the Chill Out unit. Students composed both drafts on a computer; students' initial drafts included their teacher's feedback and students' own notes about what they wanted to revise for their final draft. I compared students' initial drafts with their final drafts to understand how their science knowledge changed; I was able to do this for four of the six participants, since two students lost their initial drafts.

Data Analysis

I began data analysis by reading the entirety of interview transcripts, field notes, and student writing documents. This allowed me to gain a thorough understanding of students' experiences. I took general notes in the margins about my overall impressions as I went.

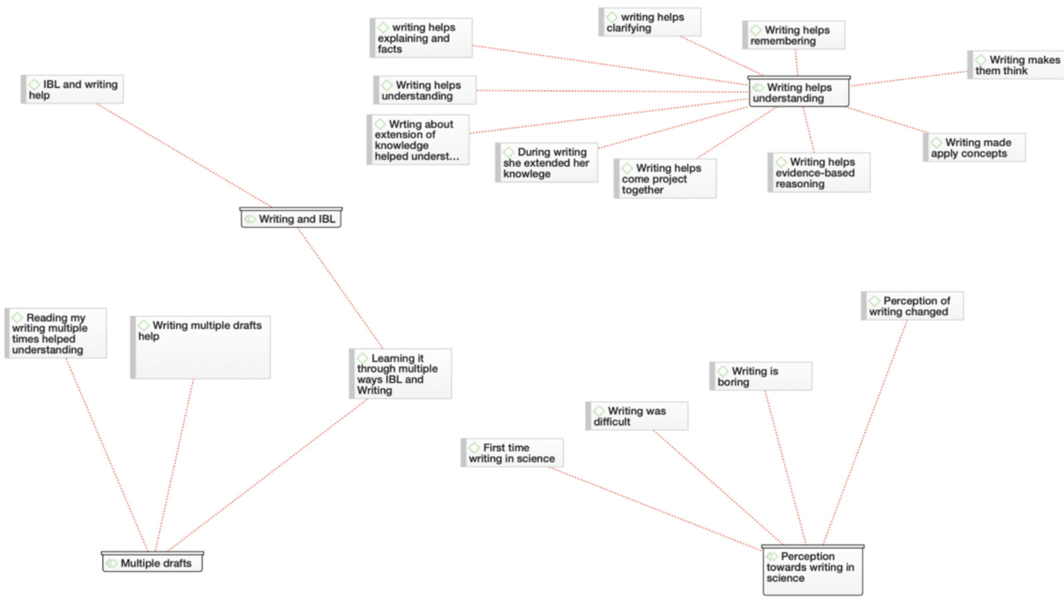
Analysis of Interview and Observation Data.

Adding interview transcripts and field notes to Atlas.ti, a qualitative data analysis program, was another early step of analysis. This process created a document for each student that combined all data sources for each case, enabling me to begin a qualitative thematic analysis (Braun & Clarke, 2006). I inductively analyzed these documents to discover explicit and implicit meanings of students' experiences (Guest et al., 2012). My first step in thematic analysis was to familiarize myself with the data by listening to all voice-recorded interviews and reading the transcripts of interviews before starting to code. The listening phase helped me to understand each student's experience better by discerning their tone, reactions, expressions, and other subtle nuances in what students shared with me. I also carefully reviewed field notes from classroom observations to become familiar with all the data.

During the second analysis phase, I created initial codes related to my research questions based on my familiarity with the data from phase one work. I generated and refined codes in cyclical process, adding, combining, and splitting codes to speak to both interview and observation data. During phase three of analysis, I reorganized codes into thematic categories. To ensure that the themes were closely connected to the data, I reviewed and compared themes to the entire dataset. As part of this fourth stage of analytic work, I read and reread each transcript and field note entry to refine themes, keeping my eyes open to other emerging codes and themes. The fifth and final phase analysis involved creating a visual report from my list of themes (Figure 6), to discern broader patterns within the data. As I conceptualized and finalized themes, I carefully reread each coded excerpt across the data sets and summarized each theme into one- or two-sentence summaries. This work to write well-described explanations of the data helped me refine my analytic thinking, particularly as I shared and discussed these themes with an independent researcher where we resolved disagreements about our interpretations through discussion.

Figure 7

The Initial Visualization of Codes and Categories on Atlas.ti



Analysis of Student Writing Documents.

I conducted a deductive content analysis (Bingham & Witkowsky, 2021) of students' writing, which is a method of evaluating data according to existing theories or frameworks (Bingham & Witkowsky, 2021). I began by uploading students' papers to Atlas.ti and coding with codes I derived from the science literary framework developed by Garcia (1985) and expanded by Chiappetta and Fillman (2007). Using their four predetermined science literacy categories as an analytic lens, I evaluated students' compositions for evidence they were demonstrating 1) science as knowledge, 2) science as investigation, 3) science as extension, and 4) science as meaningful interaction with society. During this analysis, I remained open to other ideas that emerged. To analyze writing documents in a systematic manner, I created definitions for each category and highlighted sentences in students' compositions where each category seemed evident. To check that each category was appropriately represented in my analysis, I pasted selected excerpts from student writing into a word document. This helped me see which categories were more thinly represented or places where students' science literacy did not appear to be fully developed across all four categories.

I also verified Mr. Lee's rubric scores against what I observed in students' compositions, and met with Mr. Lee to share my findings and ascertain his opinions about them. These conversations strengthened the validity of my conclusions. As I sought to conduct careful analytic processes (Hatch, 2002), I wrote a descriptive sentence for each category and asked an independent researcher to compare my findings statements to the word documents I created with descriptions and excerpts. As I further analyzed and described my findings, I used quotes from students' writing to substantiate the points and use students' voices to show the depth and complexity of learning.

Findings

Three major themes were evident as findings in this study. I first discuss students' experiences of writing, which centered on the way writing helped them better understand scientific concepts and clarify their thinking about how to build the lunchbox. The second theme related to how students' writing development between the first and final draft indicated they significantly deepened their scientific knowledge of the heat transfer concepts in the Chill Out unit. In the third and final theme, I discuss the four science-based literacy skills evident in students' reports, to show how writing facilitated their science content knowledge and ability to transfer learning from one context to another.

Students' Experiences of Writing

All six students shared that they believed writing helped them learn science by helping them understand scientific concepts and helping them articulate why they did what they did in the lunch box invention process.

Writing Facilitates Comprehension of Scientific Concepts.

Most students reported having a greater understanding of science concepts after working through the process of authoring their reports. Noa commented that writing helped her understand science better because writing is a personal form of expression and knowledge development that stays with the writer more than reading alone:

> I feel like when you write something, it's easier to understand rather than, reading it from a book. Because it's coming from you. So, you can understand what you write. [When you read,] you don't know what you're reading until after you read it. But when you're writing it by yourself, you think about it more. So, it sticks with you more.

Maggie, Nikki, and Sarah also explained that writing is "an actual thing to help [students] understand [scientific concepts]" because using writing to offer a detailed explanation means they must understand the scientific concepts they were explaining. Caroline added that she believes writing helped her to understand the three main vocabulary words for the unit (e.g., convection, conduction, and radiation), which made her feel confident. She exclaimed, "it's like, I know the main concepts!"

Five out of six students specifically acknowledged that engaging in the forward search process of revisiting and revising own writing during the writing process helped them better clarify their understanding of science concepts. Caroline, Maria, Nikki, Sarah, and Noa all indicated the process of revisiting their writing after completing the first draft and correcting their mistakes increased their scientific understanding. Caroline described the forward searching process as,

> I think [my understanding of the science concepts] developed because we started with one [draft] and we just wrote about our ideas. Then we went back and see what we needed to edit and add more to it and keep developing and more edits.

Sarah added that doing multiple drafts helped because it required her to "look [her draft] over, see mistakes, and rewrite." She mentioned that writing helps her "get everything to the way it's supposed to be [by] trying to make sense [of scientific concepts]." Noa also said that the heat transfer concepts "made more sense" after she wrote about them the first time and then reread her draft to revise. She also said that the writing "came along better" after several rereads. She described the process as "the first few times I read it, I had to think about it, but after that, then I got it more."

Maria's example of how forward searching supported her learning was evident in how she was able to clarify her knowledge of heat transfer concepts. She explained that even though she understood what convection was, she was unable to explain how it differed from conduction in her first draft. In her second draft, she was able to distinguish between them:

> I knew what convection meant but it was just confusing because these two [convection and conduction] are very similar. But the next time I put it [in writing], even Mr. Lee told me [that] it makes a lot more sense.

Taken together, students' statements indicate how writing supported them to develop deeper content knowledge about science concepts.

Writing Helped Students Understand the Lunch Box Invention Project.

In addition to increased comprehension of science content, five out of six students reported that the writing enabled them to better understand the lunchbox inventing project. Caroline described the process this way:

> The writing helps you understand more of what the project's about and uses a lot of details [in comparison to] if you just did the lunchbox project…. I think the writing helped me connect [science concepts to the lunch box project] because I didn't really [understand] conduction, radiation before. But then when I write it and then have a good understanding of it. It helped make the project easier.

Sarah and Maggie also reported that they understood the project because of the writing tasks associated with the invention process. Maggie said that for her project group, "mak[ing] sense" of the lunch box project was difficult, but writing helped to make "a lot more sense." Sarah explained that writing helped her to "not just looking at [the project] but really think about it" which enhanced her understanding of heat transfer.

Furthermore, Maria, Nikki, and Caroline explained that they understood the fundamentals of their lunch box inventions better as they wrote and revised their writing. For example, Maria, explained that writing became the "backstory" of the project, which made "the whole project come together." For Nikki, writing helped her "make more sense of the materials [she] used" in the project. She explained that writing was much more effective than "just getting materials and building something" because writing forced her to show her understanding of what she put into the lunchbox and why. Caroline also explained the writing process "helped make the project easier." Caroline identified the interconnectivity between the lunch box invention and writing experiences, saying she often referred to the inventing experience as a resource for knowing what to write:

> I felt like writing it and doing it…[are] two different ways to see it. Like, actually seeing [the] live version we've been making it…. Sometimes I would go back to the writing, add a little more thing, [then] go back to the lunch box and see both. We can add [something to the lunch box] and go back to the writing, and then edit more.

Her comment illustrated how the lunch box invention and writing experiences complemented each other to facilitate active knowledge construction. Students were noticeably clear about how supportive they found writing-to-learn was to their invention process.

Development of Writing: Comparison Between Initial Draft and Final Draft.

Analysis of students' writing drafts indicated they grew not only in their understanding of science concepts, but in their writing development. Quotations from student writing in these sections have been reproduced exactly with all spelling and grammar errors preserved, to maintain an accurate representation of what students knew and enacted as writers. As indicated earlier, Maggie and Caroline's first drafts were missing, so this analysis was based on comparisons between initial and final drafts for Maria, Nikki, Sarah, and Noa. To varying degrees, all four students' initial and final writings demonstrated they developed and deepened their knowledge of the scientific concepts in the Chill Out unit. As Maria put it, students' initial drafts offered an incomplete articulation of science knowledge compared to their final drafts.

Maria's explanation of radiation deepened significantly between her initial and final drafts. In her first draft, she was only able to explain the heat lamp as a source of radiation; in her final draft, she was able to explain how and where radiation took place within her group's lunch box invention (Table 11).

Table 11

Maria's Initial and Final Draft: Explanation of Radiation

Initial Draft	Final Draft
As of radiation the only thing that happened was the heat **shinning [sic] from the heat lamp** onto to our cooler.	**Radiation is when heat is transferred through electromagnetic waves** and in this project radiation was shown when ***<u>the heat waves from the heat lamp are shining onto the cooler.</u>*** In order to prevent radiation the top of the box is covered with white paper so the heat rays would reflect/bounce off. This step is helpful because ***<u>the heat isn't going transfer into the top and the walls of the shoes box as easily as it would without the paper</u>*.**

Sarah did a similar thing in her writing; in her first draft, she was only able to describe how the tinfoil in the lunchbox reflected radiation. In her final draft, she elaborated that the lamp emitted electromagnetic radiation, like the sun rays; the aluminum foil she used in the lunchbox was one way to limit heat transfer since it caused the electromagnetic waves to bounce (Table 12).

Table 12

Sarah's Initial and Final Draft: Explanation of Radiation

Initial Draft	Final Draft
One good feature of the cooler is the **tinfoil** wrapped around the box which did a great job of **reflecting the radiation** light of the cooler	The radiation that is directed to the cooler is ***<u>electromagnetic radiation which is basically sun rays.</u>*** ***<u>Radiation is present in the lab when the cooler is being tested by using sunlamp and putting</u>*** it directly above the cooler and letting it sit there for over more than 4 hours.... **Aluminum foil** bounces the electromagnetic waves off the cooler.... These steps were effective and limit heat transfer.

Compared to Maria and Sarah's science-based explanations, Nikki and Noa wrote papers with less detail in their explanations. They had more difficulty explaining heat transfer and missed details such as how adding tinfoil and white colored felt prevented heat from passing through their lunch box. Nikki wrote that these two materials repel heat and keep water bottles cold, without explaining how this happened. Noa was able to specify in his final draft that tinfoil and light-colored materials prevent radiation, since they reflect light and do not absorb heat (Table 13).

Table 13

Noa's Initial and Final Draft: Explanation of Radiation

Initial Draft	Final Draft
Heat will bounce of the **tin foil** there for it helps keep our water cold. We also put white colored felt on the outsides of a box. Because felt is an insulator it will keep the water bottle cold but ***light colors (mainly white) reject the heat*** which is also a way to keep the water bottle cold.	The radiation in the cooler is what allows heat to get in or out of the cooler.... ***Light colors and reflectors do not absorb radiation.*** The light and heat will not stay for long once it gets to the alumium [aluminum] foil. ***Heat will bounce of the alumium [aluminum]*** foil there for it helps keep out water cold.

These shifts between first and final drafts reveal how extensively students developed and articulated their scientific knowledge. All four students indicated increased ability to demonstrate their learning; they moved from vague and incomplete explanations of heat transfer concepts to detailed and more complete explanations. Such change indicates how unfamiliar students were with these ideas at the beginning of the Chill Out unit, and how challenging they found it to try and explain these ideas in writing. This analysis of students' writing is aligned with what students self-reported in interviews about the writing-to-learn process.

Science Literacy Skills Evident in Students' Final Drafts

Using the four elements of science literacy as an analytic lens on students' final drafts revealed the presence of all four elements in their writing. In brief, these four elements are scientific knowledge, application of knowledge, extension of knowledge, and investigating methods.

Scientific Knowledge and Application of Knowledge.

While most students' final drafts demonstrated the scientific knowledge of heat transfer (see Appendix B), the degree of applying the knowledge into the lunchbox project varied by students. In addition, all six students' final draft demonstrated their engagement in applying the three types of heat transfer to the lunch box invention experiment (See Table 14).

Conduction. All six students attempted to apply the concept of conduction to their lunch box invention; five of them successfully applied resourceful solutions to address conduction in their lunch box inventions. Caroline, Maria, Nikki, Sarah, and Noa's application of knowledge demonstrated they understood conduction, which is an unseeable and abstract concept, and were able to use that knowledge to effectively combat it in their lunch box. In each of their final drafts, students showed they were able to 1) provide a solution to prevent conduction, 2) use physical evidence from their invention to support their explanations, and 3) use logical assumptions and inferences in their writing. Table 14 indicates this for each student.

Table 14

Application of Knowledge based on Lunch Box Invention – Conduction

Name/Type	Application of knowledge	How they made connection	Examples of student writing
Maggie	Developing	Provide solution to prevent conduction	"Those materials used helped out the cooler because when you have something with light color it reflects"
Caroline	Applied	Providing a solution to prevent conduction	"To prevent conduction we could have put more insulators on the outside and a little bit near the water bottle."
Maria	Applied	Use physical evidence: Temperature of the lunch box	"Conduction is shown when the outside of the box is getting warm so then the layers got warmer."
Nikki	Applied	Use logical assumption of occurrence of conduction in the experiment	"Mostly see conduction when the water bottle and the heat connect"
Sarah	Applied	Use logical assumption of occurrence of conduction in the experiment	"When the cooler makes contact with the lab table and either the cooler emits heat transfer….based on the temperature of the heat transfer"
Noa	Applied	Use logical assumption of occurrence of conduction in the experiment	"The conduction came into our cooler and heated the water bottle resulting the water bottle be a warmer temperature than it was to begin with."

Providing a solution to prevent conduction.

Caroline and Maggie applied knowledge by discussing how they prevented (or could have done a better job of preventing) conduction in their lunch box. Caroline wrote, "to prevent conduction we could have put more insulators on the outside and a little bit near the water bottle." This reflected her knowledge of conduction and how heat transfers. Maggie's explanation of using materials with a "light color" to reflect heat applies to radiation, rather than conduction. This misunderstanding nevertheless reflects that Maggie made a connection between her scientific knowledge in writing and in what she did in her invention; her understanding of conduction was still developing.

Using physical evidence.

Maria's report showed that she used physical evidence such as the increased temperature of a lunch box's surface to determine that conduction was happening. She wrote, "in this cooler project conduction is shown when the outside of the box is getting warm," which suggested she was able to transfer knowledge from the invention process to her explanation of these ideas in her report.

Using logical assumption.

Nikki, Sarah, and Noa, highlighted their knowledge of conduction by making logical assumptions conduction taking place during the experiment. Nikki explained that she "mostly see[s] conduction when the water bottle and the heat connect." Since conduction is invisible to human eyes, her use of "sees" seemed to suggest she was referring to her ability to observe the effects of conduction, when heat from the lamp transferred to the water bottle. Sarah and Noa's writing excerpts demonstrate a similar inference about how conduction worked in the experiment.

Convention. Participant students also attempted to apply their knowledge of convection to the lunch box experiment and explain it in their writing, with varying degrees of success. Of the six students, three applied convection in their lunch box invention directly and write about it effectively.

Table 15

Application of Knowledge into Lunch Box Invention – Convection

Name/Type	Application of knowledge	Examples of student writing
Maggie	Developing	In the project the convection is ***all the heat lamps beating down on the water bottle inside the box***. The cooler has bubble wrap on the side of the cooler and *plastic bags on the water bottle to keep cool air on the inside and warm air on the outside*.
Caroline	-	Student did not discuss convection
Maria	Applied	A way convection is shown in this invention is when…. **[I] try to keep the warm air out and the cool air in.**... **by sealing the lid so the air wouldn't move in or out.** These steps are really effective because now *the warm air wouldn't be going into the water bottle as easily.*
Nikki	Applied	**The convection [is] occurring mostly when the heat comes through the box and mixes with the cold air and make a gas from the warmer spot to the cooler spot**. Some steps that we took to prevent heat from reaching the water bottle was *covering the water bottle itself with bubble wrap and other materials such as plastic bags and packing peanuts*.
Sarah	Developing	Convection is shown when the heat from the lamp begins to heat up the cooler and ***slowly the warm heat from all around the cooler starts to rise and the colder current sinks to the bottom and keeps the beverages cool***.
Noa	Applied	During the project convection would occur **when cold air in the cooler would escape or warm air would sneak in**.

Maria, Nikki and Noa's descriptions showed that they understood how convection occurred and were able to design their lunch box to combat it. Maria wrote, "a way convection is shown in this invention is when…[I] try to keep the warm air out and the cool air in.... by sealing the lid so the air wouldn't move in or out." This except indicates she understood convection takes place through movement of fluid such as liquid or gas; she sealed the lid to prevent this. Nikki's explanation indicated she knew convection could change the water temperature: "covering the water bottle itself with bubble wrap and other materials such as plastic bags and packing peanuts," was an explanation of the materials her group used to prevent convection. It demonstrates she had in-depth knowledge of the scientific concepts.

In comparison, Maggie's explanation was vague, reflecting that she was still developing her understanding of convection: "convection is all the heat lamps beating down" evidenced an incomplete understanding of convection since it did not indicate in which state of matter (air, solid, or liquid) the heat was being transferred. Her prevention plan of "bubble wrap on the side of the cooler" also did not indicate which materials prevented heat transfer or how they did so. Sarah was also in a developing stage of knowledge, writing "slowly the warm heat from [the heat lamp] all around the cooler starts to rise and the colder current sinks to the bottom and keeps the beverages cool." Although her excerpt reflected her understanding of convection as a movement of fluid, including the way warm air rises and cold air sinks, she was not able to apply it correctly to an explanation of what her group did with their lunch box. She was technically accurate to say convection happened in the lunch box, but the water bottle did not stay cool because of convection; the circulation of air eventually raised the temperature inside the lunch box. Sarah's difficulty is an effective example of how challenging it is for learners to apply scientific concepts in real life, particularly when those processes are indirectly observable.

Radiation. Regarding the concept of radiation, five of the six student participants were able to apply and articulate accurate understandings of the scientific concept. Table 16 contains students' explanations of how they accommodated for radiation in their lunch box projects.

Table 16

Application of Knowledge into Lunch box Invention – Radiation

Name/Type	Application of knowledge	Examples of student writing
Maggie	Applied	To prevent the radiation from getting to the water bottle. The bottle was covered with **white packing peanuts** and that was added because when the heat lamps beat through the box, we needed their to be protection on the bottle. **If it isn't covered with packing peanuts the radiation would go right through the box and straight to the bottle and that is defeating the puspose [purpose] of trying to 147elsius147 heat transfer.**
Caroline	Applied	During the experiment radiation occurs when the **heat from the lamp discharges some of the heat to the cooler**. To prevent radiation the cooler was a **light colored lunchbox**
Maria	Applied	In this project radiation was shown when the heat waves from the heat lamp are shining onto the cooler. In order **to prevent radiation the top of the box is covered with white paper so the heat rays would reflect/bounce off**. This step is helpful because the heat isn't going transfer into the top and the walls of the shoes box as easily as it would without the paper.
Nikki	Developing	The radiation is most seen when occurring with the ***tin foil*** in the project because the movement from the heat going into[, and] the box hitting the tin foil on top and the white paper.
Sarah	Applied	Radiation is present in the lab when the cooler is being tested by using sunlamp and putting it directly above the cooler…. **Aluminum foil bounces the electromagnetic waves off the cooler**... These steps were effective and limit heat transfer.
Noa	Applied	The radiation in the cooler is what allows heat to get in or out of the cooler.... Light colors and reflectors do not absorb radiation. The light and heat will not stay for long once it gets to the **alumium foil**. Heat will **bounce of the alumium foil there for it helps keep ou[r] water cold[.]**

Maggie, Caroline, Maria, Sarah, Noa all used the same logic to explain the concept of radiation, showing they understood the heat lamps as the source of radiation in the experiment. They also referenced appropriate materials for ameliorating radiation, such as "white packing peanuts," "light-colored paper," and reflective "aluminum foil," as materials that "bounce the electromagnetic waves off the lunch box to prevent radiation heat transfer." All five students' explanations demonstrate they had a strong understanding of radiation and how their group addressed it in the lunch box experiment.

Nikki's writing indicated she had a more limited understanding of radiation: "the radiation is most seen when occurring with the tin foil in the project because the movement from the heat going into[, and] the box hitting the tin foil on top and the white paper." Although she was able to identify that tinfoil can prevent radiation, her associated explanation indicates she did not understand the source of the radiation because her sentence indicated radiation was only evident when it hit the tin foil and bounced off the white paper. However, radiation came from the lamp regardless of the materials it encountered.

Overall, these CLD students' writing demonstrates they were able to make direct application of scientific knowledge in the experiment and articulate their scientific understandings in written form.

Extension of Knowledge.

Every student included one or more real-life examples beyond the lunch box experiment to support their explanation of heat transfer (Table 17). Five of the six students gave an example of convection, three students gave examples of conduction, and all six students gave examples of radiation. Sarah wrote about the real-life example of a radiation shield:

> In relation to limiting heat transfer, people [have] also created inventions to help prevent heat transfer such as a radiation shield…. [S]sources of radiation can be shielded with solid or liquid material, which absorbs the energy of radiation….to reduce the radiation to a level safe for humans.

Sarah also included an example from daily life: "Oven mitts are used so you don't make direct contact with the metal and burn yourself [which] by the way is conduction, so oven mitts are used to prevent conduction." Maria was also able to provide a real-life example of radiation:

"Many people try to prevent radiation when being out in the beach. They do this by putting on sunscreen so the sun rays don't burn their skin."

Table 17

Students' Real-Life Examples of Conduction, Convection, and Radiation

Name/Types of heat transfer	Conduction	Convection	Radiation
Maggie	Boiling water	-	Light clothes, microwave, light bulb, and fire
Caroline	Opening door	-	Stove (fire)
Maria	Wearing jackets	Keeping window closed (Heat transfer through the air)	Sunscreen, sunglasses
Nikki	-	Opening door (Heat transfer through the air)	Wearing white clothes
Sarah	Oven mitts	Thermos	Biological shield
Noa	Aluminum foil	-	Sunscreen

Even though students could have offered more real-life examples, every participant was able to make one or more connection between their science knowledge and real-world examples. Students offered a diverse set of examples and explanations, indicating they all deepened their learning beyond simple memorization of the examples they saw in the classroom.

Evidence-Based Reasoning.

In their final reports, five out of six student referenced experimental data to support the effectiveness of their lunch box design. Such support indicates another aspect of science-based writing, using data to support conclusions. Students' examples are contained in Table 18.

Table 18

Evidence-Based Reasoning

Name/Type	Examples from student writing
Maggie	The cooler was successful because the water bottle started at 0.2 degrees °C and it ended with 10.1 degrees °C which made it have a 9**.9 temp increase when the control had a 16 degrees °C temp. Increase.**
Caroline	The bottle of the temperature was **6°C and the final bottle temperature was 22°C**
Maria	This invention is a success because the control group[']s…. initial temperature of the water bottle was 6 degrees Celsius and when putting it inside the shoebox under the heating lamp **the temperature of the water was 22 degree Celsius which meant it went up 16 degrees Celsius.** The invention made by 7th graders on the other hand started off at 0.8 degrees Celsius and ended at 8 degrees Celsius meaning it went up 7.2 degree Celsius.
Nikki	In conclusion, the initial control bottle temperature is 6°C and the final control bottle temperature was 22°C. **The initial temperature of the bottle inside the lunchbox was 0.2°C and the final temperature of bottle inside lunchbox was 10.1°C we reduced radiation, convection, and conduction.**
Sarah	Student did not include experimental data.
Noa	The cooler was **successful at keeping the water bottle started at 0.6 degrees 150elsius and it ended at 15.5 degrees 150elsius.**

Students recognized the importance of indicating how they investigated a certain concept (in this case, temperature of the water), and used the data as evidence to support their design. Maggie wrote her lunch box design was successful because "the water bottle started at 0.2 degrees and it ended with 10.1 degrees °C which made it have a 9.9 temp increase when the control had 16 degrees °C temp. Increase." Her comparison between their lunch box and the control's water bottle was an effective way to show how her group's design was successful in preventing heat transfer. Maria also provided a detailed description of the control lunch box to validate her argument:

> This invention is a success because the control group[']s…. initial temperature of the water bottle was 6 degrees Celsius and when putting it inside the shoebox under the

heating lamp the temperature of the water was 22 degree Celsius which meant it went up 16 degrees Celsius. The invention made by 7th graders on the other hand started off at 0.8 degrees Celsius and ended at 8 degrees Celsius meaning it went up 7.2 degree[s] Celsius. Caroline, whose lunch box water bottle temperature was the same as the control lunch box, acknowledged that her lunch box was not successful in preventing heat transfer. Each of these examples indicate students were successful at investigating and logically reasoning out their conclusions based on scientific evidence.

Summary of Findings

While students developed varying degrees of science literacy skills, their writing indicates all of them developed all four elements of science literacy– scientific knowledge, application of knowledge, extension of knowledge, and investigating methods (Table 19).

Table 19

Application of Knowledge in the Lunch Box Invention and Real-Life

Name/ Types of heat transfer	Conduction		Convection		Radiation	
	In lunch box	Real life	In lunch box	Real life	In lunch box	Real life
Maggie	Developing	Boiling water	Developing	-	Applied	Light clothes, microwave, light bulb, and fire
Caroline	Applied	Opening door	-	-	Applied	Stove (fire)
Maria	Applied	Wearing Jacket	Applied	Keeping window closed	Applied	Sunscreen, sunglasses
Nikki	Applied	-	Applied	Opening door	Developing	Wearing white clothes
Sarah	Applied	Oven mitts	Developing	Thermos	Applied	Biological shield
Noa	Applied	Aluminum foil	Applied	-	Applied	Sunscreen

An analysis of student writing in this study shows that the process of acquiring knowledge and accurately applying it, whether in an experimental process or to real-life experiences, is challenging. It requires deep thinking and imagination, active, student-led processes that are far removed from traditional-based instruction techniques of lecture or worksheet-based activities. Maggie, Caroline, Maria, Nikki, and Sarah all demonstrated they gained and applied all three heat transfer concepts, yet each of them had difficulty in applying at least one of these concepts to either a real-world example or to their lunch box experiment. However, they also had many varied opportunities to learn and refine their thinking as they wrote-to-learn and enacted hands-on application of science knowledge in invention-based projects. Accordingly, majority of students developed evidence-based reasoning skills, suggesting they were deeply engaged in developing their own science literacy and successful at doing so.

Discussion

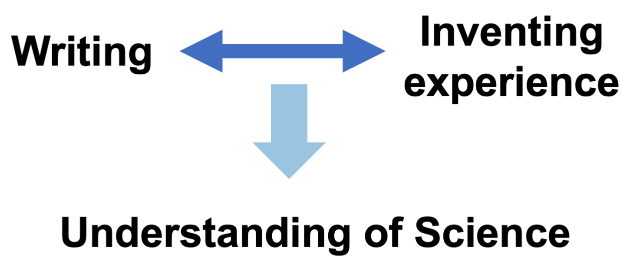
Prior research studies have shown that there are several factors facilitating knowledge transfer among learners (Kim et al., 2021; Perkins & Salomon, 2012; Reade et al., 2008; Thompson et al., 2006). I argue that the combination of inventing and writing experiences effectively helped these students transfer knowledge based on the three factors: 1) their active participation and deep involvement in learning, 2) their use of rich content examples with links, and 3) in-depth understanding of content.

Prior research shows that students' ownership of learning fosters knowledge transfer (Engle, 2006; Kim et al., 2021; Perkins & Salomon, 2012; Thompson et al., 2006). In addition, according to Engle (2006), when students have a sense of authority based on the process of authoring their own writing, they are empowered to engage in intellectual conversations and more effective knowledge transfer. In this study, all six student participants gained ownership and authorship of science concepts as they applied knowledge in their lunch box inventions and composed reports explaining their thinking. The nature of the invention process required students to experiment, make, and refine decisions to solve a problem. As they sought to create an effective lunch box, they experienced firsthand the trial and error involved in making decisions and solving problems. They also developed their ability to explain and demonstrate their knowledge through composition. As authors, they actively participated in the learning process and practiced knowledge transfer.

Furthermore, since the content knowledge required for the invention project and the writing project were closely linked, they were able to write more effectively about heat transfer because they had rich examples from the invention process. Their work to invent became the “live version” of heat transfer in action, enabling them to understand intangible and abstract phenomenon. The same way a forward search process is not limited to writing (Klein, 2000), students did a forward search in their lunch box inventions. As they invented and reflected upon their inventions through writing, they not only transferred but crystalized intangible ideas into the more tangible form of written, documented knowledge (Langer & Applebee, 1987). Caroline explained inventing and writing as the “two different ways to see it.” Indeed, inventing gave students concrete experiences they could use in their writing; in turn, writing gave students ways to clarify the knowledge they gained from their hands-on work. This ongoing process of knowledge transfer between inventing and writing strengthened their understanding of heat transfer, resulting in deep content knowledge (Figure 8).

Figure 8

Knowledge Transfer Between Writing and Inventing



The findings also demonstrate how the writing process further extends student knowledge and ability to apply it in real-world settings. This is congruent with findings from Langer and Applebee (1987), who wrote that the reflective process of writing transforms conceptual knowledge into more concrete forms of knowledge. In this study, Maria, Nikki, Sarah, and Noa's thinking developed significantly between their initial and final drafts. The process of writing and receiving thoughtful feedback from their teacher enabled them to see where their explanations of heat transfer were incomplete or inaccurate. They were able to "make more sense" as they wrote. And as they deepened their content knowledge related to the inventions, they were better able to transfer and extend these applications beyond school settings (Galbraith, 1999; Hand et al., 2007; Kim et al., 2021). They were able to do this as they moved intangible ideas to solid understandings, making connections between science concepts and real-world phenomenon such as boiling water, wearing sunscreens, and the importance of using oven mitts. In short, writing helped them think more deeply. Such findings support previous research on how the writing process can help students grasp abstract concepts and appropriately apply and utilize that knowledge in the larger world (Hand et al., 2007; Kim et al., 2021).

This study has several implications for practice. First, it demonstrates how much students can benefit from diverse and authentic learning experiences to develop, transfer, and extend their thinking. Instead of learning science in a lecture-setting, students benefit deeply from more authentic experiences and knowledge for their lives. Second, students need time and repeated interactions with material to comprehend abstract concepts and apply them to new contexts. As the iterative knowledge transfer loop shows, students need to be engaged in back-and-forth reflective process to develop complex ideas and deep understanding. Therefore, providing sufficient time along with resources is essential for students to develop and extend their thinking. Lastly, writing-to-learn is immensely useful for helping students conceptualize, deepen, and apply their knowledge. Through writing, students develop and strengthen connections between their prior knowledge and new knowledge. Incorporating writing-to-learn in science-based content instruction enables students to not only comprehend difficult concepts but make such learning relevant to their lives.

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CHAPTER FIVE

In this concluding chapter, I discuss thematic connections across all three papers. The chapter begins with a brief review of the study's goals and research questions before offering summaries of each study's results. I conclude by synthesizing themes across these three articles and discuss the recommendations for future research.

Goals and Questions

Using a cultural congruence framework, this dissertation examined the effectiveness of integrating culture, language, and writing into science-based teaching and learning designed to support CLD students. Specifically, each paper explored one of three pedagogical approaches to support science learning: culturally relevant pedagogy, translanguaging, and writing-to-learn. The following research questions guided each paper:

Paper I: Research Questions

> How do CLD middle school students draw on cultural knowledge in HomeFun activities? How do CLD middle school students perceive and experience culturally relevant HomeFun activities as they learn science in the culturally relevant IBL program? How do culturally relevant HomeFun activities foster knowledge transfer from home to school?

Paper II: Research Questions

> How do emergent bilingual students engage in translanguaging practices in a middle-school science classroom? What are their experiences and perceptions with the practice?

Paper III: Research Questions

How do CLD students perceive and experience writing in IBL program? In what observable ways do CLD students' scientific knowledge and application of that knowledge change through writing?

Findings From the Three Studies

Paper I

This study explored six CLD students' engagement with HomeFun, a set of activities designed to foster culturally relevant pedagogical connections between home and school. Findings indicated each student utilized their family's cultural knowledge in HomeFun activities, fostering their familial resources. Students also demonstrated knowledge transfer, which meant they effectively used what they learned from their home-based family experiences to enrich their school-based learning. Further, their knowledge transfer was not one-way from home to school. It was a bi-directional loop: students used knowledge gained from HomeFun activities to inform their science learning in school; they also used their science knowledge to participate in HomeFun activities more fully. Results suggested teachers who incorporate culturally relevant activities like HomeFun can help CLD students deepen their appreciation of their own cultural heritage as a resource for academic success.

Paper II

In this paper, I explored emergent bilingual students' experiences of translanguaging practices in a science classroom to understand what translanguaging meant for them and how it shaped their science learning. Findings revealed translanguaging helped students comprehend science content more fully and encouraged family engagement. Yet students also felt conflicted about learning science in a language other than English, given that they were not afforded opportunities to learn in their first language in other classes. Their assumption that English is best learned through frequent exposure caused student participants to self-report they would prefer an English-only science classroom to a translanguaging science classroom. Participants had such an ardent desire to be a part of their school's English norm, it negatively shaped their perceptions about translanguaging. Accordingly, this study confirmed previous research (Blackledge & Pavlenko, 2002; de Jong et al., 2020; Kaveh & Lenz, 2022) indicating school is a strong influence on students' beliefs and language ideologies.

Paper III

This study explored six CLD students' experiences with writing-to-learn in an IBL science classroom to investigate how writing-to-learn impacted students' science literacy development. Results suggested that writing enabled students to extend their knowledge and make stronger connections between science content and the real world through the process of knowledge transfer. Writing also supported students in making two-way knowledge transfer connections between writing and invention experiences. As students revised their writing through forward searching, they were able to better access their inventing knowledge to describe science content. Writing, therefore, helped CLD students to develop science literacy. In short, writing-to-learn in an IBL classroom helped students develop skills in forward searching and facilitate knowledge transfer, which also supported their science literacy.

Synthesis

An investigation of these three pedagogical approaches—culturally relevant pedagogy enacted through HomeFun, translanguaging, and writing-to-learn—contributes to the conversation of how educators can support CLD students to develop science literacy. Strong science literacy skills are essential for students to develop if they are to appropriately relate abstract ideas and knowledge to themselves and their lives. Each study offers insight into factors that affect CLD students in developing science literacy, such as the importance of family engagement or the pervasive nature of school-based monoglossic language ideologies.

Meanwhile, knowledge transfer was a theme that crossed all three studies. The major goal of learning for students is to be able to make connections (Cross, 1999); students benefit from understanding how abstract concepts can be related, similar, or applicable to their life experiences. This is especially important in science content areas, which can feel distant from students' everyday lives. Despite this, students in these studies developed many links across diverse contexts, including connections to their culture, connections to language, connections to their family, connections to scientific concepts, connections to the inventing experience, and connections to real life.

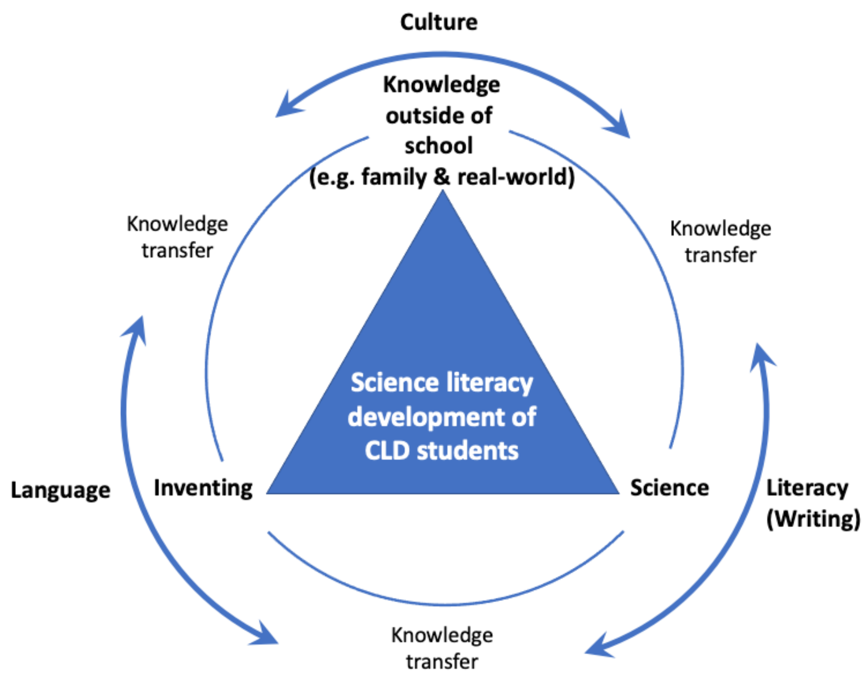
Papers I, II, and III showed how much students benefited in their science learning from the intentional connections between science content and students' cultural and linguistic assets. Through such connections, students were able to create new relationship with science. In paper I, as culture was incorporated in science, students started to view science as "fun" and comprehensible. Such positive feelings facilitated knowledge transfer and helped them better understand heat transfer ideas. In Paper II, when the CLD students used their first language as an asset, students were able to make effective connections between their lives and new learning in science. Students who wrote-to-learn, in Paper III, were able to extend their knowledge to make connections from science learning, experiments, and daily life. Even though heat transfer ideas were abstract and not directly observable, students made application to the ways wearing jackets and using oven mitts were more than just common-sense activities.

Significance of Study

This dissertation contributes to the field of education by exploring and extending the paradigm of knowledge transfer. Historically, knowledge transfer has been studied as a way of connecting prior knowledge to new learning (Perkins & Salomon, 2012; Reade et al., 2008; Thompson et al., 2006). However, no previous studies have explored how culture, language, and writing might facilitate CLD students' knowledge transfer in science. Each study in this dissertation demonstrated several types and degrees of knowledge transfer for students who participated in such intentionally designed learning activities. Using students' language, culture, and writing to expand their science literacy, this dissertation viewed knowledge transfer as an ongoing, simultaneous, and interactive process which helps students access and utilize their knowledge from in and outside of school contexts as a means of strengthening their science literacy.

Figure 9

Science Literacy Developing of CLD Students Through Knowledge Transfer



The three studies demonstrated the ongoing process of knowledge transfer by showing how CLD students could transfer knowledge when they participated in meaningful learning experiences involving their culture, language, writing, and hands-on learning (Figure 9). At the same time, students deepened their understanding of how science has application to inventing and contexts outside of school. Consequently, students found learning more relevant to themselves and their everyday lives.

As a result, this dissertation suggests new ways forward for science education by demonstrating culture, language, and literacy as a useful means for supporting science education and knowledge transfer. Educators who consider the affordances of this study can gain new perspectives in how to develop students' science literacy for CLD students.

For instance, educators can find new applications for culturally relevant pedagogy, translanguaging, and writing-to-learn in science education. Culturally relevant pedagogy and Translanguaging are useful for ensuring students receive science knowledge and can appropriately produce writing reflecting their knowledge transfer capabilities. Writing-to-learn is useful in any subject area, and proved to be a powerful tool enabling CLD students to deepen their science literacy. In sum, the three studies have potentials to engage educators with the three pedagogical approaches—culturally relevant pedagogy, translanguaging, and writing-to-learn— in teaching science and support CLD students' science literacy development through the process of knowledge transfer.

Recommendation for Future Research

This dissertation provided comprehensive view of how culturally relevant pedagogy, translanguaging, and writing-to-learn in supporting science literacy development among CLD students in science. Findings across the three papers demonstrated the effectiveness of these approaches for supporting CLD students' science literacy. It is also important to note such pedagogical approaches require extensive support and expertise from school administrators, teachers, and researchers. Teachers must be adequately trained in these pedagogical techniques, and be supported in their personal commitment to making positive and progressive changes on behalf of their students. Similarly, educational researchers must prioritize studies exploring these diverse spaces, to support and enhance understanding around how best to serve CLD students. Further research into teachers' experiences and perspectives regarding these pedagogical approaches would also be important. As the ones primarily providing education to students, it is critical to study and support teachers' perceptions and experiences, if such pedagogical practices are to become more mainstream, both in the science classroom, and beyond.

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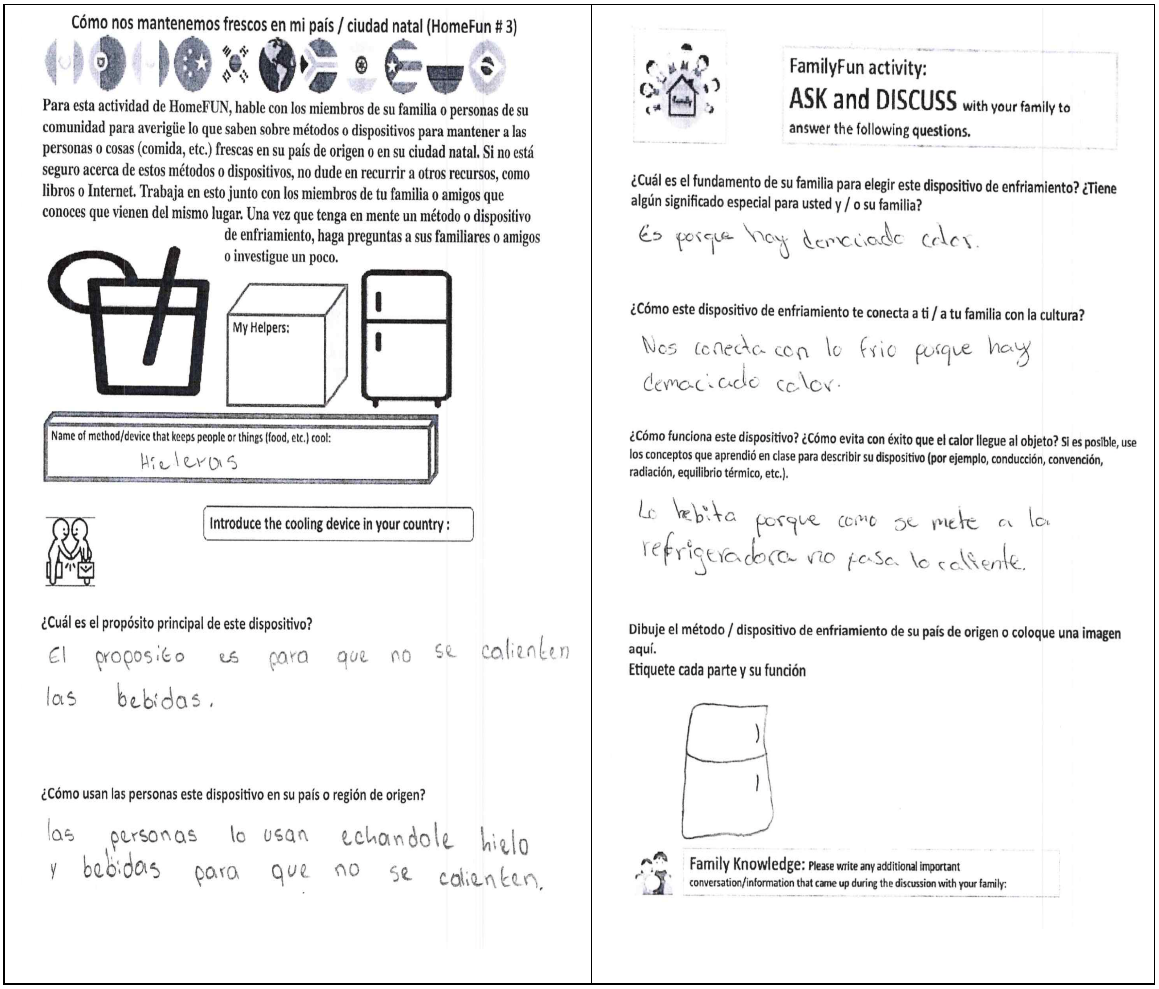
APPENDIX

Appendix A

Examples of HomeFun Activities in Spanish



Cómo nos mantenemos frescos en mi país / ciudad natal (HomeFun # 3)

Para esta actividad de HomeFUN, hable con los miembros de su familia o personas de su comunidad para averigüe lo que saben sobre métodos o dispositivos para mantener a las personas o cosas (comida, etc.) frescas en su país de origen o en su ciudad natal. Si no está seguro acerca de estos métodos o dispositivos, no dude en recurrir a otros recursos, como libros o Internet. Trabaja en esto junto con los miembros de tu familia o amigos que conoces que vienen del mismo lugar. Una vez que tenga en mente un método o dispositivo de enfriamiento, haga preguntas a sus familiares o amigos o investigue un poco.

My Helpers:

Name of method/device that keeps people or things (food, etc.) cool:
Hieleras

Introduce the cooling device in your country:

¿Cuál es el propósito principal de este dispositivo?
El proposito es para que no se calienten las bebidas.

¿Cómo usan las personas este dispositivo en su país o región de origen?
las personas lo usan echandole hielo y bebidas para que no se calienten.

FamilyFun activity:
ASK and DISCUSS with your family to answer the following questions.

¿Cuál es el fundamento de su familia para elegir este dispositivo de enfriamiento? ¿Tiene algún significado especial para usted y / o su familia?
Es porque hay demaciado calor.

¿Cómo este dispositivo de enfriamiento te conecta a ti / a tu familia con la cultura?
Nos conecta con lo frio porque hay demaciado calor.

¿Cómo funciona este dispositivo? ¿Cómo evita con éxito que el calor llegue al objeto? Si es posible, use los conceptos que aprendió en clase para describir su dispositivo (por ejemplo, conducción, convención, radiación, equilibrio térmico, etc.).
La bebita porque como se mete a la refrigeradora no pasa lo caliente.

Dibuje el método / dispositivo de enfriamiento de su país de origen o coloque una imagen aquí.
Etiquete cada parte y su función

Family Knowledge: Please write any additional important conversation/information that came up during the discussion with your family:

Appendix B

Scientific Knowledge of Heat Transfer

Name/Types	Conduction	Convection	Radiation
Maggie	Conduction is the *transfer of thermal energy* from one substance to another through direct contact	convection is the *transfer of thermal energy* by the circulation or movement of a fluid (liquid or gas)	radiation is the electromagnetic waves that *give off heat*
Caroline	Conduction is *the transfer of heat* between objects in contact with each other	convection is the *transfer of heat* by the movement of the heated parts of a liquid or gas.	radiation is the *emission of energy* as electromagnetic waves
Maria	conduction which is *a type of heat transfer* that happens through direct contact	convection is *heat transferred* through the movement of fluid	radiation is when *heat is transferred* through electromagnetic waves
Nikki	The third *type of heat transfer* is conduction, which is the *transfer of energy in the form of heat or electricity* from one atom to another within an object by direct contact. Conduction occurs in solids, liquids, and gases	convection, which is the *transfer of heat* through fluids (gases or liquids) from a warmer spot to cooler spot	the first type of *heat transfer is radiation, which is emission of energy* as electromagnetic waves or as moving subatomic particles, especially high-energy particles that cause ionization
Sarah	Conduction is *the heat that transfers* when object makes direct contact with other objects and emit heat	convection is *a type of heat transfer* which is the movement caused within a fluid by the tendency of hotter and therefore less dense material to rise, and cooler, denser, materials to sink under the influence of gravity	radiation is *the energy that moves from one place to another*, light, sound, heat, and X-rays are examples of radiation. The different kinds of radiation fall into a few general categories: electromagnetic radiation, mechanical radiation, nuclear radiation, and cosmic rays
Noa	Omitted	convection is *heat transfer* that travels through a fluid like air or water.	Omitted

Note. Italics and underlining have been added to the direct quotations below to illustrate the students' understanding of the key concepts.