“I like sharing ideas because that means people learn”: Cultivating a Kindergarten Science Knowledge Building Community

Michelle Salgado

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Reading Committee:

Mark Windschitl, Chair

Shirley Brice Heath

Phillip Bell

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Abstract

"I like sharing ideas because that means people learn": Cultivating a Kindergarten Science Knowledge Building Community

Michelle Salgado

Chair of the Supervisory Committee:

Dr. Mark Windschitl

Curriculum and Instruction

This dissertation contains qualitative multi-case studies, which are the result of a four-year, teacher-researcher partnership focused on intellectual and social relationality that was co-designed and developed within a kindergarten knowledge building community. This study focuses on elements of a designed learning environment, which were theorized to support a range of participation styles as children leveraged scientific models to learn about complex phenomena, explain their thinking, and engage earnestly as participants in a range of disciplinary practices. Analysis of video data across the three phases of the physics unit and of student-generated models of physics concepts in action, reveals how students collectively *developed* as a knowledge building community and *described* physics concepts. I present a vision of how

student collaboration can support scientific modeling, when the content is grounded in young children's natural capabilities (such as relationships, imagination, play, and movement), in their interests (their playground slide) and through cultural practices (collaborative learning within community and linguistic freedoms). Tracing participation and growth in development with scientific practices, the findings demonstrate how knowledge was co-constructed by students, and unique participation was ultimately leveraged to advance their meaning-making and their models of physics phenomena. The findings suggest that the design framework afforded emergent bilingual children the opportunities to take advantage of a system of supports where they could make intellectual connections between their everyday ideas and experiences to support their development of a relationship with science and scientific practices and with their knowledge building community.

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I will first acknowledge the Coast Salish lands, waters, and people.

I have been fortunate to have been supported by many people throughout this journey and I would like to acknowledge their effort, time, and love. First, I would like to say thank you to my family. To my daughter Marilyn, you have sustained me with your love, your cooking, your stories and laughter. Thank you for bringing so much joy and dancing to our home and for your patience and understanding while I finish this program, you are my heart and soul. To my mother who taught me fierce determination, activism, and instilled a passion to pursue my dreams, thank you for your continued support through meals, conversations, and watching over Marilyn. I am blessed to have you in my life. To my father for teaching me endurance, kindness, and patience and to learn through observation and reflection, you are an inspiration. To my brothers Raymond and Michael and my sister Jennifer, thank you for supporting me in any way that you could from reading stories to Marilyn while I did homework to taking her on adventures that she will never forget.

This dissertation was born from my experiences as an immigrant child coming to the United States at a young age as well as my experiences as an elementary school teacher. My time spent working with and learning from children, families, colleagues, and community based organizations led me to pursue a PhD in education.

I was blessed to meet my research partner, Kaia Tomokiyo during my first year as a doctoral student. She opened up her classroom and made her teaching transparent so that we could better understand how young children in multilingual classrooms engage in science learning. Kaia has been a trusted research partner and I would not be here without her expertise, friendship, and support. Thank you Kaia for all the gifts of time, service, and commitment that you have shared with me.

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This dissertation was community effort and I have been sustained through love, friendship, and family and grounded through my time outdoors as an uninvited guest on Coast Salish lands. Much gratitude to all.

Dedication

Through this research I seek to honor the dreams, challenges, and joys of immigrant and refugee children across the world. May peace, laughter, and hope fill your days.

To the formal and informal educators around the world. May the systems that continue to oppress be disrupted and transformed in order to fully support, appreciate, and fund the work of equitable teaching and learning.

This dissertation is dedicated to my family Marilyn, Nancy, Raymundo, Jennifer, Michael, Raymond, and my research partner Kaia. May good health and happiness always be with you, thank you for your love and support.

INTRODUCTION

This dissertation is about understanding the cultivation of a knowledge building community and instructional design elements that support a linguistically diverse classroom engaging in scientific practices through diverse participation. Many other studies have focused on grades other than kindergarten and have not explored the relationship between the learning environment, kindergarten learners, and their earnest engagement in scientific practices and resulting conceptual growth. The literature on primary grades with asset-focused perspectives of emergent bilingual children in science education are limited. Many scholars have put forth rich theoretical and conceptual frameworks for use in such studies and I have attempted to resource from multiple theories and perspectives in order to create a set of instructional design elements in support of equitable and robust science teaching and learning at the earliest grades.

Through this dissertation study, I write to honor the sacrifices, trust, and hope of the children and families from immigrant and refugee backgrounds who made up a majority of the student population of this study. I am interested in contributing my knowledge, experiences, and commitment to contribute research towards more equitable science education in order to better understand how we can create learning environments in which our most institutionally underserved children can thrive and in which all learners can benefit. In conducting this research and completing this dissertation my goal is to understand and communicate the perspectives, challenges, and joyful possibilities of kindergarten science. This study is an opening conversation for all (families, educators, researchers, policy makers) to engage in as we work to better understand the scientific capabilities of some of our youngest learners. This dissertation will contribute to the field of science education by studying the following broad questions:

1. Under supportive conditions, how do kindergarten children create, revise, and utilize scientific models to make sense of everyday phenomena?
2. Under supportive learning conditions, how do emergent bilingual children use resources and opportunities to learn in different ways to engage in scientific practices?
3. What roles do particular relational routines, activity structures, and discourse norms play in supporting kindergarteners to develop generative and equitable ways of talking together about science ideas in planned and unplanned ways?

Summary of Study Design

These qualitative multi-case, design-based studies explore one kindergarten classroom of learners engaged in scientific practices in a physics unit of study. The first study explores children's engagement in the scientific practice of modeling and the corresponding conditions of support to do this work. The second study explores the participation of three emergent bilingual kindergarten children and how they took advantage of different modalities, settings, and opportunities to learn across the physics unit. The third paper will focus on how and why educators can create knowledge building communities in science classrooms and features logistics, design elements, and instructional strategies.

This study took place in a kindergarten classroom within a Title 1elementary school with a rich linguistic and culturally diverse student community. Data from this study include video, student artifacts, and teacher and student interviews. All lessons were recorded and field notes from all lessons, interviews and interactions detail the teaching and learning interactions that took place in the classroom. This study provides a foundation for designing with and for kindergarten learning communities in order to better understand the capabilities and possibilities of primary science endeavors.

Synopsis

This dissertation contains three sections written as stand-alone articles. As such, the reader may find similarities across these in conceptual framing, methodology, and some redundancy in describing supportive learning conditions. My goal with this dissertation is to feature deep explorations into specific scientific practices, participation of specific learners, and how kindergartners' diverse ways of knowing and communicating about science travel and get socially and intellectually renegotiated across settings. The dissertation study aims to contribute to the literature the complexities and possibilities for conceptualizing kindergarten classrooms as knowledge building communities of engaged and capable science learners. Findings generate empirical evidence that kindergarteners can productively, cooperatively, and eagerly engage in the modeling process in order to develop conceptual understanding with abstract physics concepts using both everyday and scientific talk during investigations and discussions. In addition, these learners can engage in this work through unique and agentic means and do so via diverse participation. This study holds implications for educational theory by pushing back on perceived developmental progressions (NRC, 2012; Metz, 1995) and assumptions about young children's capacity for extended inquiry. Additionally, this study will offer guidance on design innovations for practitioners wanting to better support young children during scientific modeling investigations. Finally, this study holds implications for future policy work and curriculum design to rethink the possibilities and potential for young learners collectively learning through the reification and untangling of abstract science concepts. I appreciate your flexibility as a committee member and reader of my work. The structure of the dissertation is as follows:

Section 1: Cultivating a Kindergarten Knowledge Building Community: Modeling as a (Re)visionary Scientific Practice

This paper explores the cultivation of a kindergarten knowledge building community focused on the practice of scientific modeling. Using case study methodology of a diverse classroom of twenty-seven students, I examine how kindergarten children over time use everyday observations, taught ideas, the theories of their peers and the practice of modeling to advance their understanding of playground slide collisions. Analysis of video and artifacts such as student-generated models of physics concepts in action, reveals how they shifted from treating modeling as a traditional school task to engaging with it as a (re)visionary practice. An interdependent instructional design framework supported rich sensemaking opportunities in which students linked observable with unobservable events related to the playground slide collision. I present a vision of equitable kindergarten science, with the content grounded in young children's natural capabilities (such as collaboration, imagination, play, and movement), in their interests (their playground slide) and the explicit valuing of diverse discourse contributions (heterogeneity). This study addresses the following questions:

1. How do kindergarten children create, revise, and utilize scientific models?
2. How do different supportive conditions work together to help kindergarten children shift their engagement within the practice of modeling?

Section 2: "These powers walk...to all the parques": A multi-case study of diverse engagements in physics by emergent bilingual kindergarteners

In this study, I document how instructional design elements create multiple and diverse opportunities to learn and participate both individually and collaboratively in a knowledge building community. Utilizing case study methodology of three emergent bilingual kindergarten students, I examine how these focal students participated in different ways across a science unit. In addition, this study seeks information to better understand how children demonstrate the process of knowledge construction as they participate in a knowledge building community. This study addresses the following questions:

1. Under supportive learning conditions, how do emergent bilingual children use resources and opportunities differently to engage in scientific practices?
2. What disciplinary knowledge do children demonstrate when their classroom and membership is conceptualized as a knowledge building community?
3. What roles do relational routines, activity structures, and discourse norms play in supporting kindergarteners to develop generative and equitable ways of talking together about science ideas in planned and unplanned ways?

Paper 3: Back to School Essentials: A Scientific Knowledge Building Community

I summarize both studies from paper one and two for a practitioner article which focuses on the essential elements of creating and sustaining a knowledge building community with a particular focus on instructional design elements in primary grades. This article will feature essential strategies and real examples from a kindergarten classroom to better understand how to support the design of a learning environment where students work collaboratively to build knowledge. The article will explore discursive practices, instructional strategies specific to science, and equitable approaches to teaching science. The following questions will be addressed in this article:

1. How can practitioners design instruction that supports knowledge building by a community of young learners?
2. What kinds of instructional strategies, routines, norms, and perspectives can educators adopt in order to teach science in an inclusive and equitable manner?

SECTION 1

Cultivating a Kindergarten Knowledge Building Community: Modeling as a (Re)visionary Scientific Practice

Designing meaningful opportunities for student engagement in dynamic and complex phenomena through scientific practices is at the center of current science education reform (NRC, 2007; NRC, 2012). However, in the United States, research on early elementary students' science learning, particularly with and through disciplinary specific practices, has generally been understudied (see Hapgood et al., 2004; Metz, 2011for exceptions). In elementary school, learners rarely experience the scientific practice of modeling during their early foundational years (Schwartz et al., 2009) and we have a limited understanding of the dynamics of primary student interactions with models (Danish & Phelps, 2011), with few asset-focused reports on children from institutionally marginalized communities.

Educational interactions, particularly involving discourse, are necessary for equitable learning. Such communications are influenced by the social and historical power dynamics within the classroom privileging and deprivileging particular discourses (Heath, 1983; Rogers, 2011). The cultural richness of discourse and participation diversity brought to the classroom sometimes stands in contrast against particular talk norms found within traditional classroom settings (Heath, 1983). Young children of color and their ways of knowing and doing science are often viewed from deficit perspectives, as they can appear to be distinct from institutionally normed ways of learning science (Bang et al., 2012). Motivated by gaps in the literature, this study aims to contribute to the field of early elementary science education in support of kindergartener's ingenuity and earnestness in their engagement with scientific modeling. This study explores kindergarten children engaged in understanding the physics of playground slide collisions. Through a series of discussion-rich learning experiences centered around the revision of scientific models, the intellectual work and collaboration of five and six-year old children is featured. I explore how young learners from diverse cultural backgrounds shift their engagement from a tasked assignment to modeling as a revisionary practice. This study addresses the following questions:

1. How do kindergarten children create, revise, and utilize scientific models?
2. Under supportive conditions, how do kindergarten children shift their engagement within the practice of modeling?

Literature Review

Modeling: A Necessary Kindergarten Practice

The framework for K-12 Science Education (NRC, 2012) stresses the need for students to be more inclusively involved in the sense making aspects of learning science. This includes the conceptual, material, and epistemic work of developing and revising models and generating evidenced-based explanations for complex phenomena (Manz, 2012; NRC, 2012; Achieve, 2013). Engagement with scientific practices and equitably-designed dialogic activities can allow historically underserved students from a variety of backgrounds opportunities to participate in disciplinary discourse at higher rigor than previously afforded (NRC 2012).

Models are representations of events or processes, constructed through joint communal activity towards a disciplinary-specific purpose (Latour, 1988). Modeling and other science practices provide learners with expansive and generative opportunities for diverse engagements with content because models are testable, revisable, and explanatory in nature (Lehrer & Schauble, 2006a; Manz, 2012; Passmore & Stewart, 2002, Schwartz et al., 2009; Windschitl et al., 2008). Serving as an organizing tool and intellectual resource, models support the development of epistemic competence (Gouvea & Passmore, 2017). Modeling is an authentic scientific practice (Latour, 1988) and requires the use of individual and collective disciplinary reasoning.

Models can incorporate young children's natural capabilities such as drawing and lived experiences (both in the classroom and community) which allows researchers and science educators to build instruction and engaging opportunities to learn and participate in investigations (Lehrer & Schauble, 2000, 2006a; Manz, 2012; Schwartz et al., 2009). Specifically, using a variety of models, representations, and multimodal experiences "has been shown to promote improved conceptual understanding" with kindergarteners (Wright & Gotwals, 2017, p. 517).

Modeling can be integral to the learning process in the kindergarten science classroom as it can be developed as a social practice. Researchers have documented the importance of models and modeling as a means for individual and collective knowledge construction (Salgado & Phelps, 2021; Salgado & Tomokiyo, 2018; Salgado & Windschitl, 2017). Models can, under certain conditions, support diverse forms of participation as children collaborate to represent abstract concepts, through inscription and gesture, respond to the ideas of peers, and engage in spontaneous model revisions. A central feature of the learning conditions in these studies was the use of individual and whole class consensus models as well as using a diversity of representations found in read aloud texts and everyday objects such as wheelchair ramps. There is substantial evidence that creating scientific models and representations enables children to learn science in school (diSessa, Hammer, Sherin, & Kolpakowski, 1991; Lehrer & Schauble, 2006) while facilitating the communication of complex ideas to audiences (Brooks, 2009; Roth & McGinn, 1998).

Primary Science Education. Young children first enter school with rich knowledge foundations and a broad capacity for learning science (NRC, 2007). We know that children think in complex and sophisticated ways about natural phenomena (Lee, 2017; Metz, 1995) and have the skills necessary to engage in complex reasoning within the enterprise of science (NRC, 2007). Making predictions and observations, asking questions, and recording evidence for communicating ideas are all documented learning activities in which kindergarteners can participate (Samarapungavan, Patrick &Mantzicopoulos, &, 2011). An emergent body of research demonstrates how young children are capable of engaging in and designing sophisticated scientific investigations (Mantzicopoulos, Samarapungavan, & Patrick, 2009) when their learning environments are designed to leverage their natural modes of inquiry such as play, movement, storytelling, and time for observational practices (Heath & Gilbert, 2015).

Research has been conducted in multilingual primary science classrooms across Europe. In Luxembourg, Christina Siry has conducted studies within multilingual classrooms to explore the intersections of early learners' engagement with "doing science" through discourse-in-interaction as children construct generative science ideas through talk (Siry et al., 2010, 2011, 2012). In Spain, Monteira & Jiménez-Aleixandre's (2016) case study examines how kindergarteners engage in the practice of scientific observation and use those observations as evidence to support emergent claims. These studies all research different aspects of science within primary science teaching and learning but with related themes of participation, discourse, reasoning, and coherent curriculum.

The literature is also clear about the benefits of literacy activities for supporting young students' scientific understanding and development (Hapgood et al., 2004; Goldman & Bisanz, 2002; Manz, 2012; Palincsar & Magnusson, 2001; Wright & Gotwals, 2017; Varelas & Pappas, 2006). Studies have found that early learners benefit from writing and drawing about science with appropriate scaffolding (Patrick, Mantzicopoulos, & Samarapungavan, 2008; Wright & Gotwals, 2017). The work by Maria Varelas with researchers from the Cheche Konnen Center has explored science through the interdisciplinary integration of science, literacy, and drama (Varelas et al., 2010, 2013). The findings of the Varelas et al. (2010) study illuminates children's negotiating practices to make meaning of science ideas and communicating those meanings to others through interdisciplinary means. Research on early elementary students' ability to do science work in supportive environments has identified that when young children are engaged in writing, drawing, and explanatory discussions about their work with adults, then both science learning and writing skills are reinforced (Wright & Gotwals, 2017). Incorporating interactive read aloud books, both narrative and non-fiction, can support children as they unpack representations and concepts illustrated in accessible text formats. The interactive form of read aloud books supports young learners as they have opportunities to pose and answer questions about the book, critique representations and models found in the illustrations, and use the text as evidence in their models (Salgado & Tomokiyo, 2017, 2018; Salgado & Windschitl, 2017).

We see from these studies the importance of representing ideas and engaging iteratively with model revision, children's capacity to listen, respond, and evaluate a multiplicity of conceptual ideas from shared learning experiences and the potential to inform their models (Wright & Gotwals, 2017; Danish & Phelps, 2011). These aforementioned studies indicate that young children are capable of authentically taking part in a wide range of scientific practices (Metz, 2011; Monteira & Jiménez-Aleixandre, 2016; Patrick, et al., 2008). One conclusion that the literature indicates, is the difficulty in teasing apart the influences of modeling from other practices because the range of different scientific practices are so interconnected. Ideally, within these interdependent practices, modeling no longer remains a "school task," a kind of worksheet to be completed and turned in to the teacher for evaluation. Instead, modeling becomes a unique knowledge building practice in which young children can return to their representations as their ideas shift over time and revisions become necessary to reflect changes in thinking (Jiménez-Aleixandre, Bugallo Rodríguez, & Duschl, 2000). These kinds of shifts appear to occur in highly dialogic learning environments where a shared sense of intersubjectivity allows children to develop their conceptual understandings within a knowledge building community (Hall & Greeno, 2008; Manz, 2012). Models serve as a key mediator and facilitator for sensemaking talk and become a visionary tool for future collaborative work. Thus, modeling for young children is a (re)visionary practice and rightfully belongs in the primary science learning environment.

Research on young children's learning in science has helped us understand some of the capabilities, motivation, and skills of young learners (Hokayem & Gotwal, 2016; Manz, 2012; Monteira & Jiménez-Aleixandre, 2016; Mantzicopoulos, et al., 2013; Manz, 2012; Patrick, et al., 2009; Varelas & Pappas, 2006). The field has limited knowledge however of how emergent bilingual kindergarten learners engage with physics concepts like force and motion (Suárez & Otero, 2013). We know little about the capacities of kindergarten children from immigrant and refugee communities engaged in the collective work of scientific modeling and explanation. Specifically, our understanding is limited for how emergent bilingual kindergarteners create and revise their models and explanations based on both instructed concepts as well as peer-generated ideas. While researchers have studied pedagogical approaches, improved access, and outcomes in science for English language learners (Cervetti et al., 2008; Janzen, 2008; Lee, 2005), the conditions of support that allow kindergarten classrooms to function as learning communities (Brown & Campione, 2002; Scardamalia & Bereiter, 2006) engaged with disciplinary specific practices is understudied. In response to these literature gaps, this study offers an asset-based framework featuring pedagogical supports and equitable learning opportunities that may allow bilingual learners to equitably engage in the creation and revision of models and engage with the ideas of peers in their knowledge building community.

Theoretical Framework

In this study I draw upon a situative perspective (Engström, 1999; Greeno & Gresalfi, 2008) where learning occurs within socially-constituted activity systems and provides opportunities for students to participate in practices meaningful to the community (Lave & Wenger, 1991). Learning being construed as the increasing capacity to play increasingly central roles in authentic work that is valued by a community. This increasing capacity is referred to by Lave and Wenger (1991) as Legitimate Peripheral Participation as a way to describe the relationships and processes that “newcomers” engage in to develop their capacity to become authors and producers of knowledge. Tools such as models and discourse strategies afford children the opportunity to test out and build conceptual connections about natural phenomena. In addition, centering authentic science activity and dialogue as valued practices positions the learner with the authority to make choices and generate new ideas as their representations of phenomena and explanations become more sophisticated over time. In this view, the socially-situated activity system with its tools, artifacts, and relations support the building of knowledge within a community (Lave & Wenger, 1991).

Teachers within such communities engage with student's ideas during the learning process, serving as mediators and facilitators who place student talk and reasoning at the center of effective instruction and in doing so recognize both the individual and collective nature of learning (Vygotsky, 1978; Wenger, 1998). If classroom talk is inclusive in nature and produces equitable sense-making interactions, it can then support learning and participation (Cazden, 2001; Heath, 1983; Tolmie et al., 2010; Scardamalia & Bereiter, 2006; Resnick & Schantz, 2015). This allows students to be positioned as "authors and producers of knowledge… with ownership" of their learning (Engle and Conant, 2002, p. 404) and signals to students that their knowledge is valued to the learning community (Alexander, 2006; Lehesvuori et al., 2013). This positioning of young learners is integral for creating a knowledge-building community where linguistically diverse learners can feel that their everyday stories, experiences, and ideas will be valued and used as resources to understand scientific phenomena (Bricker & Bell, 2014).

Classroom teachers can problematize the assumption that participation and understanding are solely attributes of the student (Gresalfi et al., 2008) and instead, view students as epistemic agents capable of co-creating a collaborative classroom culture (Brown & Campione, 1994; Stroupe, 2014). Expansive forms of learning include one or more of the following: increased capacity to focus on or participate in "finding out" activities either in a group or as an individual, increased conceptual understanding, progression of a skilled performance, meta-cognitive reflection on what one knows or does not know, and ability to engage in discourse related to inquiry.

Conceptual Framing

In this study, the teacher and I observed learning but also the design elements of the learning environment that were present when students engaged in modeling talk and activity. The five design elements of the conceptual framework are meant to support students as they experience modeling as a process involving *collective and sustained* intellectual engagement. To guide the design of the supportive and equitable learning environment, I started by adapting a framework of principles informed by a literature review and summarized in Windschitl and Calabrese Barton (2016). These were drawn from research studies that focused on science learning in classrooms, and drew upon a subset of investigations that employed well-articulated theoretical frameworks to guide the instructional design, documented learning and the conditions that supported learning over an extended period of time, took learning to be both conceptual and participatory in nature, and attempted to develop student understandings that went beyond the reproduction of textbook ideas (Brown & Campione, 1994; Engle & Conant, 2002; Lehrer & Schauble, 2004; Magnusson & Palincsar, 2005; Metz, 2004; Rosebery et al., 2010; Smith, Maclin, Houghton, & Hennessy, 2000). In these studies, students' ideas became the central focus of discussions and they served as explicit objects of inquiry which could be collectively revised by the learning community (Scardamalia & Bereiter, 2006). This outcome is particularly salient to a vision of teaching for centering cultural and linguistic heterogeneity (Rosebery et al., 2010) within a science classroom as children learn to resource shared ideas for reasoning and sensemaking purposes.

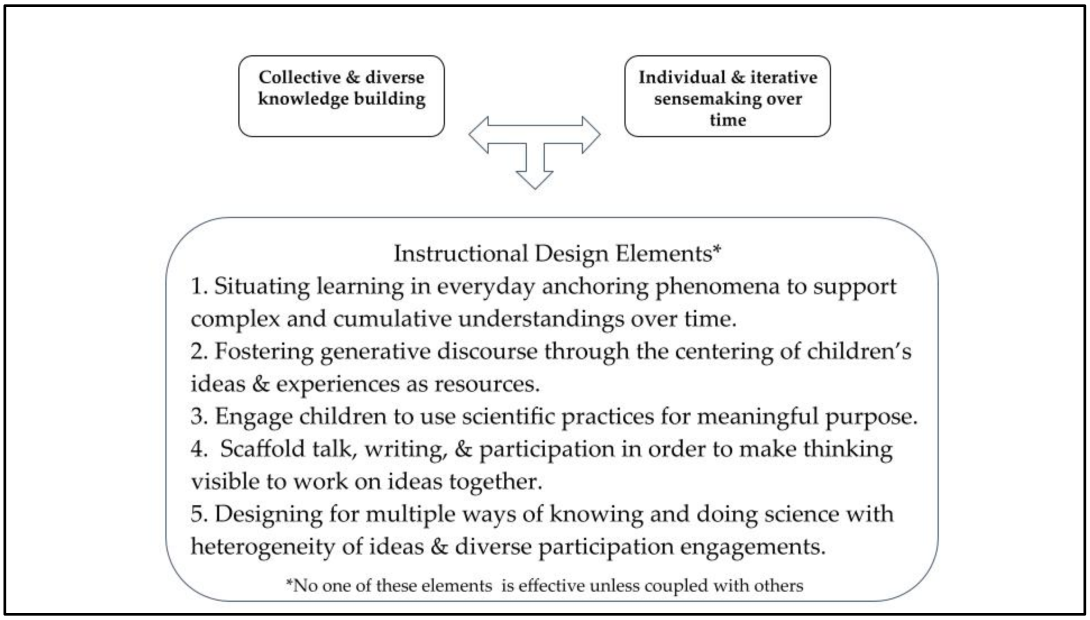


Figure 1. Conceptual framework of instructional design elements.

Element five is an addition to the adapted framework, taking a justice-oriented approach to designing for heterogeneity as a move to disrupt inequities, welcome multiple ways of knowing, and encourage diversity in modes of participation. Heterogeneity in this study being defined as the range of shared practices including everyday experiences, stories, ideas, ways of knowing, doing, and participating to "generate new understandings, extend navigational possibilities, and adapt meaning-making practices to new forms and functions" (Rosebery et al., 2010, p. 324). Element five is needed to disrupt the well-documented systemic injustices that occur in everyday classroom life including "otherization, conditional participation/belonging, and dehumanization"— events that occur so often they become "invisible" during daily routines (Calabrese-Barton & Tan, 2020, p. 1). Even with years of reform efforts, systemic oppressions continue to occur daily against children from marginalized communities (Milner, 2015; Tedesco & Bagelman, 2017) in particular their discourse practices being viewed from deficit perspectives (Bang et al., 2012; Gutiérrez & Rogoff, 2003; Ladson-Billings & Tate, 1995; Rosebery et al., 2010). These heterogeneous practices can be “mobilized” (Rosebery et al., 2010, p. 324) in generative and nurturing ways to support young children engaging in shared, disciplinary specific meaning-making practices.

Utilizing knowledge of learners and the communities in which they come from is an important factor in designing for the integration of historically accumulated skills, practices, and knowledge that children bring with them to the classroom from their home communities (Moll et al., 1992). We know from research the sophisticated modes of collaboration that children from Indigenous and Latinx communities bring from their everyday worlds into the classroom (Alcalá, Rogoff, & Fraire, 2018; Rogoff, et al. 2017; Correa-Chávez, Mejía-Arauz, & Rogoff, 2015). In this framework we sought to create the design of an intellectual space which values the well-developed listening, observing, and collaboration practices of our student population (Rogoff, 1994, 1995; Alcalá, Rogoff, & Fraire, 2018). Our design framework integrated multiple opportunities for children to learn through observation, listen to shared ideas, and engage in deep collaborative practices. Such examples include a focus on student centered discussions which encouraged stories and ideas from home communities and conducting investigations in student-led groups where children were given time and agency to employ a diversity of collaborative practices to collect data and solve problems. This framework supports science instruction with children from diverse communities by valuing and leveraging their communities’ skills, practices, expertise, and goals in relation with the rigorous, ambitious work meant to highlight the academic capabilities of multilingual learners from immigrant and refugee families.

Attending equitably and dialogically to both the individual and collective planes, aims to support the cultivation of an epistemic culture that is refined cumulatively and merges the everyday, scientific, and classroom discourses (Pickering, 1995). A culture where children's stories, ideas, and experiences can serve as a foundation for appropriating the disciplinary specific practices across the arc of a science unit of study. A culture where children learn the purposes for such practices as scientific modeling and meaningfully engage in the work of revision using feedback from peers. This framework will serve to cultivate dialectic interactions and heterogenous appropriation of practices between children as individuals and as members of a kindergarten scientific community over a period of time (Knorr-Cetina, 1999).

Method

Participants and Context

This is a qualitative case study and utilized purposeful sampling to select one classroom of learners and the classroom teacher, which represents a bounded system (Merriam, 2009). This study features a kindergarten classroom taking up the "Forces and Motion: Exploring physics through playground slide collisions" unit, which took place from February to May. In addition, I collected additional data on four focal students who were all identified as emergent bilingual and with diverse participation styles to document their engagement with models and the ideas of their peers over time. The unit goals were to 1) support students' participation in an intellectual community in which they contribute ideas and those ideas can be commented on and change over time; 2) use everyday and scientific ideas about force and motion to model, revise, and explain a complex everyday phenomenon; 3) apprentice students into modeling activities and explanations that support their understanding of these forces and motion.

This teacher was selected using criterion-based sampling (Merriam, 2009); she had extensive involvement in participating in instructional coaching support and participation in three professional development workshops prior to the start of the unit of study for this research. My role within this classroom setting is as an instructional coach with some bilingual language skills (Spanish) and to serve as a resource for both teachers and students. Both the teacher and I were raised in bi-cultural families and experienced the joys and challenges in navigating systems as women of color. In addition, I hold the responsibilities of researcher, curriculum developer, and professional development provider. I conducted participant observations for 9 months in a class taught by Ms. Mae Takeoa*. During the data collection, I continued to perform my role as an instructional coach while also engaging in reflexive practices to document my perspective and attention to social dynamics such as cultural, linguistic, and power imbalances in the classroom (Patton, 2015). In addition, I documented my interactions, personal observations, and emotions, to understand how my personal responses may shape the process of making observations and recording the lived experiences of the participants (Emerson et. al, 2011).

This study was conducted in a Title 1 elementary school within a progressive urban school district. The school's demographic composition: 39% Transnational Bilingual; 56% Hispanic/Latino, 21% Asian, 7% African American, 9% white. In addition, the school had 80% Free and Reduced Lunch student population. The selected class had 27 students, with 24 students coming from bilingual families; 19 students were from Spanish speaking households. This school identified emergent bilingual students through family intake forms and offers ESL programs for students. This classroom utilized a bilingual paraeducator for 1-2 hours per day. The target classroom is filled with round student tables, bookshelves and a small-carpeted area where the majority of student discussions take place. A typical day includes whole group instruction while students are seated on the carpet while their independent work time is dedicated to working at their table group desks.

The “Forces & Motion: Playground Slides” unit was designed using a situative perspective (Greeno & Gresalfi, 2008), with a sequence of activities that affords both discussion and use of conceptual ideas and methods that became more advanced over time. This unit took just over three months to complete. The science unit was developed by the researcher, which consists of hands-on experiments, an interdisciplinary approach to include math, art, and language arts, and group experiments. The focal point for each lesson resided in student scientific models and their participation within whole group sense-making discussions within a dialogic learning environment. Each lesson is anchored around student talk and models with a beginning and ending discussions lasting ten to twenty minutes depending on the topic and use of student models to guide the discussion.

Kindergarten Physics Unit Trajectory

Throughout this unit students were engaged in the science and engineering practices (NRC, 2012) of scientific modeling and explanation. The disciplinary core ideas and crosscutting concepts within this unit focus around interactions, relationships between energy and forces, defining engineering problems, and the causes and effects within forces and motion. The two performance expectations (Achieve, 2013) are as follows: 1) Students will plan and conduct an investigation to compare the effects of different strengths or different directions of pushes and pulls on the motion of an object and 2) Students will analyze data to determine if a design solution works as intended to change the speed or direction of an object with a push or a pull. These performance expectations were assessed using students' scientific models, but assessment is not part of the data analysis in this paper.

Phase One: The Eliciting Lessons 1-4. The beginning of the unit included observations and explorations of a variety of models and representations (student paper model, consensus poster, mini-slide, actual physical slide, ramps) both inside the classroom and around the school. This intentional access to models was done so that children would first get to experience the phenomenon on the actual physical slide and then be able to apply and record those experiences on their paper models. Student ideas were consistently elicited and publicly posted with their names alongside their ideas, which made visible and honored intellectual contributions.

Phase Two: The Investigation Lessons 5-8. Phase two focused on providing students with hands-on experiments, interactions with manipulating materials and variables to create data. Student groups were responsible for manipulating the materials to create data and record data on steep and shallow ramps, manipulated the size of the ball and adjusted the weight of the cup over a series of hands on, student-led investigations. At the end of each investigation, students come together for a class discussion where they think about the focal concept and practice using and applying their data as evidence to explain their ideas and reasoning around science concepts.

Phase Three: The Revising Models & Explanations Lesson 9-12. During the final third of the unit, students worked to integrate more abstract concepts, such as energy and gravity, into their models and discussions. Interactive read aloud opportunities were used as a method (Wright & Gotwals, 2017; Varelas, & Pappas, 2006] to explore concepts through the visual representations found in picture books. Students were given opportunities to consistently engage in small group and partner talk opportunities to generate student-created definitions and examples to explain these concepts to their peers in partner talk settings. Consensus modeling was utilized during discussions as well as referencing individual student models to support authentic engagement with revisions during the modeling process.

We positioned language diversity as a valued practice, provided dual language visual representations of concepts, and encouraged children to sense-make in the language of their choice with their self-identified friends during discussions. During our science discussions, students engage in whole group talk, partner-talk, student-teacher talk, or independent think time and their responses are usually recorded on chart paper that has been organized around a central question or topic for each particular lesson. Next to recorded student responses are student names, used as a method to build student ownership of ideas (Engle & Conant, 2002). In addition to dialogue, students collectively create consensus models, draw out examples of ideas on chart paper, or use individual student models to foster discussion. Children's stories, everyday ways of understanding the world, and even imagined play scenarios were elicited to transform science discussions into engaging opportunities to learn.

We provided multiple opportunities for students to interact with models and representations in ways that made sense to them across whole, small, and individual group settings. We worked to disrupt our "settled" science expectations and reductionist ways of knowing, communicating and interacting in science in order to create expansive intellectual spaces for participation and conceptual engagement in science (Bang et. al, 2012; Goldberg et al., 2009). This included identifying normed ways of contributing and relating to ideas in classrooms (e.g. verbally, sharing ideas whole group, IRE discourse) and working to disrupt traditional white, middle-class ways of engaging in the work of science to incorporate heterogeneity of ideas. (e.g. child-led talk, child generated questions, spontaneous child-initiated discussions). Children's models and representations were centralized as objects of inquiry and over time children learned how to use their ideas and models as sources of information in which to build knowledge from. Directions, expectations, and scaffolds were child-centered and occasionally playful as we sought to reimagine how not only children participate in science, but how we as educators participate with children in this work. Through connecting the situative perspective (Greeno & Gresalfi, 2008) with the fundamental need for heterogeneity (Rosebery et al., 2010) we made attempts to design for learning as a joyful, agentic, and ambitious process for children to experience as they develop intellectual and social relationships with each other and with the discipline of science.

Data Sources

The data corpus includes lesson transcripts, student and teacher interviews, as well as student artifacts. All twelve lessons were video recorded and transcribed (Derry et al., 2015). The recorded lessons captured both teacher and student talk during instructional times, transitions, and related events during non-instructional times. Discourse occurred in whole class discussions, small groups, pairs, and one-on-one with the teacher or the instructional coach. I followed video analysis protocols recommended by Derry et al., (2010); videos were transcribed in full. Videos and transcripts were examined for themes related to 1) Students creating and revising models 2) Students working with ideas 3) Students using models to explain conceptual ideas. I was attuned to the importance of producing transcripts that reflect the research goals for this study (Ochs, 1979). Transcription occurred in a four step process; 1) verbal communication from 12 lessons was transcribed and coded 2) events of critical significance were transcribed incorporating verbal and non-verbal data 3) Several transcripts were selected based on a timeline during the unit to utilize data from the beginning, middle, and end of the unit 4) Transcripts were chosen for this paper to demonstrate the diversity of ways that the students interacted with models and representations and shifts in engagement with models.

Analytic Methods

Using the entire data corpus, I developed a set of codes from the literature, some being focused around productive talk (Engle & Conant, 2002; Rosebery et al., 2010) and learning progressions of modeling (Schwarz et al., 2009). I added codes later that were emergent from the data during the analysis phase and that I felt might have explanatory significance. I used segmented transcripts to test the applicability of codes and tied closely with the conceptual framework. From the coded transcripts I developed themes related to the elements, actions, ideas, and artifacts that students were generating or creating during different phases of the unit. These themes were used to develop hypotheses, which were then tested against additional passes through the data.

Findings

I organize these findings by phases of activity that took place in the first, middle, and final thirds of the unit. The broad findings explore how children performed the work of modeling: 1) creating, understanding and revising models, 2) working with everyday and scientific ideas, 3) using models to explain. These three major areas help to provide a learning progression of working with models and ideas through the centering of children's knowledge and experiences through rich discussions guided by focused questions and impromptu demonstrations meant to introduce and collectively explore science topics such as ramps, pushes and pulls, and playground slides.

Phase One: Discussing Many New Ideas

As phase one begins, the entire class of students stood in line, waiting for their turn to race down the slide and bump a stuffed animal off the bottom. Students then gathered on their rainbow carpet, for a variety of science discussions in whole group and small group settings. Student voices can be heard in both Spanish and English describing their memories of slides at their neighborhood parks and on camping trips. During discussions, students' ideas and experiences are visibly honored using their magnetized photos to mark ideas during science discussions. The discussion web (Figure 2.) made visible the practice of listening to the ideas of others, evaluating those ideas, and understanding that there are a variety of ways to think about and represent concepts. Independent modeling time occurred as five and six-year old children worked at their round tables to apply the focus concepts using the model scaffold template printed on large sheets of paper. This is how our science unit began, amidst smiling, eager faces collectively experiencing the phenomenon first-hand and then engaging in modeling this experience.

Figure 2. Discussion Web

At the beginning of the unit, as students first interacted with their individual models, there was no cross-talk occurring between students or dialogue as they turned in their models to the teacher. Children's initial models contained both everyday elements (weather, flowers) and phenomena focused objects (people, teddy bear), and color (sky, grass). In addition, abstract phenomena focused symbols (arrows, lines), and phenomena focused words (phrases, sentences, narrations) were also included. Many initial models included design features to indicate time lapsing of the objects coupled with symbols or words showing how the person and/or stuffed animal sequentially moved throughout the slide "story".

All students were able to explain the relationship between two or more components of their initial models to an adult or during a whole class share out session, although some students had initial hesitation for how to respond to adult-initiated dialogue about their model. The focus of instructional work in phase one was characterized by supporting students as they learned to use this model as a tool for interpersonal and public communication.

Throughout phase one lessons, we observed students using the model to locate and communicate ideas through talk and accompanied gesture. Children used the model to communicate ideas and almost always combined their talk with gestures or explained ideas related to concrete objects, conventions, or conceptual language. We did not explicitly teach modeling conventions, such as adding arrows. Instead we worked over time and during discussions to elicit ideas and as a class discussed possible choices for considering a variety of modeling conventions that emerged across initial student models. Children took up modeling conventions they felt were relevant to their models and to their current understanding of the phenomenon. Student modeling conventions were often shared across the community, particularly when children displayed their models on the white board and listened to feedback and questions about their models.

In phase one, many students shared their initial model during a whole class share out session. A few students elected to talk about their use of modeling conventions to demonstrate a push but there were a few students who were hesitant to communicate their ideas verbally to the class even after engaging in a partner sharing session first. In those instances, the teacher and coach guided the share out process for some students, such as "I noticed you added an arrow at the bottom of the slide, can you tell us more about that?" This kind of model anchored questioning positioned the model as a mediator for talk and provided a focus for students as they learned over time how to view the model as a resource for communicating ideas.

In lesson three, students were provided with a new model and a focus on locating pushes and pulls on the slide. Students then were asked to trade models with a partner and find any places where a push or pull could be added using labeled sticky notes. In the image below (Figure 3), we see a model with suggestive revisions on sticky notes next to the ladder. Notice the use of an arrow in the model and the student's use of written language to describe the event first "you sit down" and then she wrote "you push yourself down". After the students received their models back from their partners, we observed the students adding those revision suggestions to their models. Revisions for many students occurred naturally and without direct teacher prompting. Every student utilized sticky notes to create revision suggestions, and while some students were not able to fully communicate their ideas to a partner in writing, they engaged in a process of learning or observing how one can engage in a modeling revision endeavor.

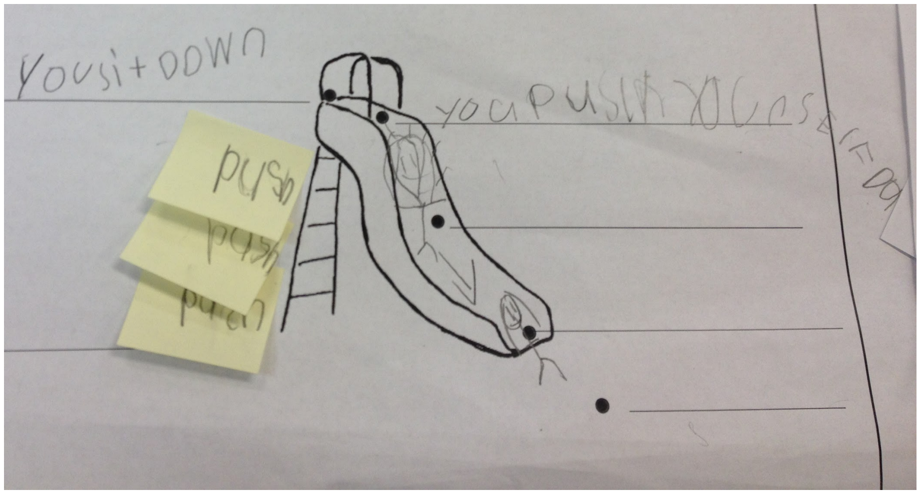


Figure 3. Partner revision model, lesson 3.

At the end of phase one, in lesson four, a *spontaneous scientific argument* emerged during an interactive science read aloud where students were questioning the authority of the book's statement and visual representations that "a slide is a ramp". The teacher and I saw this moment as an opportunity to explore the student's question—does a slide have a ramp? After several minutes of student talk Ms. Takeoa worked to synthesize student ideas and re-represent them for continued discussion:

> Ms. T: Think about what your friends are saying. So, let me restate what you guys said, so Carlos is saying that it is not a ramp because it looks like it has a filled in part and the slide doesn't have that. Andrew doesn't think that it is a ramp either because he thinks that it is too long to be a ramp. But Marisol and Natasha both say that it is a ramp and Marisol says that it has an up part and a down part.

A few minutes later students continued to make observations of the class consensus model and the slide photo in the book to draw comparisons.

> Maria: The slide doesn't look like a ramp.
>
> Ms. T: So, you are agreeing with Jose and Carlos?

Melissa: A ramp doesn’t have a ladder.

Jackson: [comes to the board to point to the model] It is not a ramp because it has a turn.

Students at this point in the discussion had all engaged in some form of talk contributions. There were partner groups forming and a few students appeared to have strong feelings about the topic, some shouted out their ideas. But in the next quote, the teacher responded to the intense waving of student hands in the air who wanted to share ideas. Ms. Takeoa recognized that there were so many children with their hands raised who wanted to share an idea publicly and communicated to them that ideas are continually built and can be shared as resources.

Ms. T: We are all thinking about this together, so just because I don’t call on your hand doesn’t mean that your idea is not important. It means I want you to keep building those ideas in your brain. We are always building, building, building so it might give you some new ideas to share. So, take a look at those ramps that we drew. Do we agree that these are both ramps? Now let’s take a look at the slide.

Melissa, a student whose ideas were seen as legitimate by other students, drew everyone’s attention to the ramp definition in the book. After a few more minutes spent discussing and arguing different viewpoints, student thinking shifted, we see Maria first sharing an initial wondering to her peers “The slide doesn’t look like a ramp” and then actively revising her thinking in a public setting. Also notice how Maria’s contribution is in connection to and in support of a peer’s idea:

Melissa: It is a ramp because it has a high place and a low place.

Ms. T: Maria how about you?

Maria: Slides are ramps, I agree with Melissa.

Ms. T: Ok so you agree with what Melissa said. So, we learned a little bit from the book?

After Melissa shared the “defining qualities of a ramp” and was supported by Maria it caused a cascade of insights as other students took up the notion that a ramp can be a variety of different real world objects such as a slide. In future lessons, students generalized the concept of a ramp to finding ramps to examples in their everyday lives such as a “hill”, “a roof”, and a “steep road”.

Supporting children in these kinds of intellectual shifts to learn to conceptually see “ramps” in everyday life and in the anchoring phenomena was part of the instruction design, where children would tangle with ideas first and then use evidence, such as from a text or home experience, to make emergent claims. This being illustrated as children were exploring “what counts as a ramp” in a whole group discussion. Implicitly, children were considering examples of how to look back critically at an authoritative resource like the definition in a book. The cognitive work involved in this scientific argument was illustrated in the transcript excerpts, as we saw Maria hold multiple viewpoints as she shifted her thinking publicly and reconsidered information as she listened to the ideas of her peers and decided that slides were indeed ramps. Over time we were working toward all children listening to, evaluating, and providing feedback to their peer’s ideas, while simultaneously considering the idea as a potential knowledge resource. While this example of a spontaneous scientific argument involved minimal structure, it did involve being responsive in the moment to a genuine class response. This “in the moment” design responsiveness by Ms. Takeoa required deviation from the lesson plan to initiate a space for children to engage in shared processing of ideas and evaluation of information to determine how slides can be ramps. In the next phase we will see excerpts demonstrating conceptual shifts as students collaboratively and earnestly generated complex discussion contributions utilizing models and material objects to mediate their thinking.

Phase Two: Sensemaking with abstract concepts through investigations

We see a shift in instructional activity in the phase two lessons as students were seeing concepts in action through group investigations. The learning conditions shifted to support student-led team investigations exploring both visible and abstract concepts in interaction such as weight, gravity, energy transfer collisions, and steep vs. shallow ramps. There were student groups spread out across the classroom, building different sized ramps and engaging each other in discussion about which kind of ramp would help the ball push the cup farther—rubber balls were to be rolled down the ramp and colliding with a cup placed at the bottom. During the middle phase of this unit every lesson focuses on student groups experimenting with different variables and then using that data to engage in sense making talk around concepts. The discussions in this phase shifted from eliciting general knowledge and experiences to gathering, collecting, and creating data in order to generate evidence supported claims.

Discussion supports such as the discussion web scaffold and interactional norms carried over from phase one helped create a series of connected dialogue where students were engaging in interdisciplinary, collaborative learning. In this phase, students had limited time with their individual paper models and focused more intently on the physical representation of the slide, the ball and ramp materials with focused concept application, and whiteboard modeling. In this phase, students begin to attend to the concepts in more complex and sophisticated ways as we observe shifts away from modeling as a traditional school task and engagement with models and explanations as a way to deepen conceptual understanding.

In phase two, students had been investigating the different variables such as steep and shallow ramps. The teacher engaged students in a discussion about energy and which ramp gives the ball more energy. A student, Đa Minh, comes to the board to model an idea to the class, he shares a narrative about how energy travels up the stacked boxes that hold up the ramp. His ideas touch on the science concept of an increase in gravitational potential energy at the top of a slide and then the transfer of energy to the cup. Ms. Takeoa asks all students to think about the energy on the ramp:

> Đa Minh: Um, um, its 'cause the box had energy. It goes up to another box, and to another box, and other box, and goes down to the ramp and then it goes up to the ball and it goes down to the cup.
>
> Ms. T: Okay, do you think you could draw that for me because it sounded like a lot of steps to me. And remember friends we are listening when other friends are talking so that we can build on their ideas. So Đa Minh is thinking that the energy is moving through the whole experiment.
>
> Đa Minh: [draws arrow going up the ramp] This is the arrow going up that means that uh:: the energy is going up. [draws a second arrow] This one [points to second arrow] goes from the boxes to the ramp." [draws a third arrow at the bottom of the ramp].

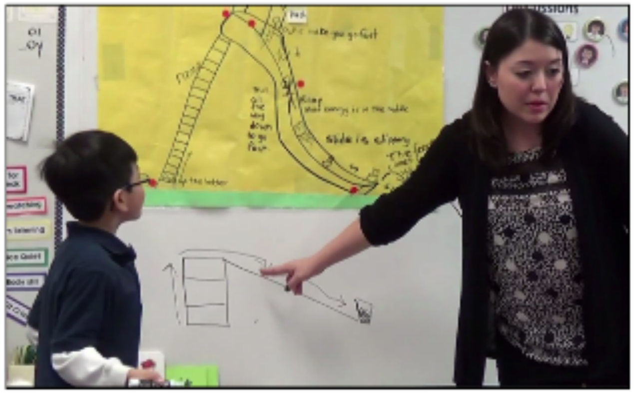


Figure 4. Teacher references Đa Minh’s modeling inscriptions for the class.

At this point, Ms. T turns to the class to reference the consensus model and then points to Đa Minh’s model (Figure 4). She then turns to Đa Minh to ask about the location of the energy. He viewed energy on the slide as always being present within this system, the mechanics of which always give the same results:

> Đa Minh: But if we do it again [holding the marker pointing to the model] then it will do it again and it will work the same again.

Đa Minh, in his own words, is referring to potential energy and transfer of kinetic energy in physics within an open system and as moving through the ladder, slide, and eventually into the cup as objects are placed onto the slide. It represents a kind of proto-theory that energy cannot be depleted; in practice, this energy being supplied from some source in the surrounding environment to ascend the slide. In this example and in the following transcript, Đa Minh is referring to the height of the slide as providing energy, anytime another object is placed at the top. It will work similarly, over and over. We see Đa Minh demonstrate conceptual understanding of force and energy well past kindergarten standards (Achieve, 2013).

If we observe his use of the model to inscribe, gesture, and communicate his thinking to an audience, we can see how the teacher then centers his modeling work as a focal point of attention for the class. This pedagogical move invites learners to make their thinking visible through modeling and also serves to legitimize and elevate their nascent ideas to the learning community. The following day, a peer of Đa Minh's, Raymundo, appeared to emulate this performance at the whiteboard (Figure 5) using the same concept of energy for several minutes while the class watched and whispered comments to one another.

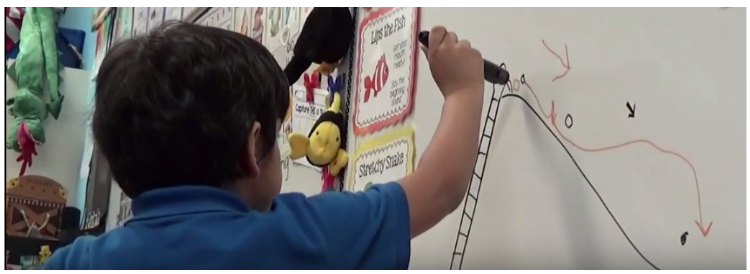


Figure 5. Raymundo's adding onto the community white board model.

But this time, Raymundo distinguished between the *different* kinds of energy between a ball rolling down the slide and a cube sliding down. Đa Minh and Raymundo both engaged in intellectual performances with audience of their peers and through the centering of children's public sensemaking at the board it allowed the community to observe scientific practices in action for future appropriation.

Investigations during phase two supported students in manipulating particular elements of the model (ramp height and weight of the cup and ball) to be able to see concepts in action and collect data for understanding the effects of those variables. During one such investigation, Maria was seated next to the ramp-building materials when she added on verbally to a peer's idea to explain how the energy is different on a shallow ramp, "*If it's kinda low* [removes two of three boxes from the ramp] *it kinda has a little bit* (energy) *but not like the big one*." As Maria manipulated the ramp, she used the props to understand the role of ramp height with regard to energy.

During a different episode we heard again from Maria during a partner talk how she visited a local park with her stuffed animals and voluntarily tested out her ideas, "*One day I went to this slide and I took my stuffy bear and I put it on the slide".* Maria's engagement with the concepts and activities was spreading beyond the walls of the classroom as she conducted an investigation out of school time and into her everyday home life. We see in this example the spontaneous nature of this student-driven work, occurring even outside of the classroom and traditional lesson time boundaries.

Phase 3:(Re)visionary practices

In phase three we saw a shift in how students are agentically interacting with the model both individually and collectively. As the unit progressed, focal children and many of their peers seemed to see modeling and its associated activities as more of an on-going and connected web of sense-making activity. Many children recognized, without overt prompting, when an occasion arose for questioning a model or adding revisions. We observed students engaging visually and physically during interactive scientific read aloud opportunities to explore abstract concepts, such as gravity. Then, in small groups, students can be heard applying such concepts to their own experiences as they articulated that gravity "is invisible" and "it is everywhere, even in China". The unit concluded with another ride down the playground slide, except this time students were enthusiastically locating the science concepts while they watched their peers and provided commentary; "right there, that is a push", and "see you bumped the bear, you moved it with your energy". We observed children using spontaneous dialogue around their models, holding up their work for others at their table to see, or initiating interactions with others using the model as a place for collective sensemaking and revisions. These forms of co-modeling were oftentimes unplanned occurring as students lined up for lunch or during a small group work session. This spontaneous joint work occurred without direct instruction and it is important to highlight its connection to the learning condition of grouping students by self-identified friends. In the images (Figure 6), we see two students working on model revisions during partner model check-in sessions and as their classmates were lining up for lunch. Clementina and Maria were friends and would often speak in their home language during small group discussions. We observed (Figure 6) one student reaching across to use the model to locate a

Figure 6. Spontaneous co-modeling revisions of individual and class consensus versions

conceptual idea for her friend. Allowing students to sense-make with friends is a learning condition we valued towards the development of an intellectually safe learning environment, where students could feel comfortable offering explanations in a language of their choice, while exchanging critique and feedback.

In preparation for final modeling, we positioned children as co-creators of a model checklist for ideas they wanted to include in their models. During this discussion, students shared ideas about using color in their models and the teacher responded to their thinking by posing the idea of using color to specify concepts in particular places in their model such as speed. Students agreed with this idea and they co-created a modeling reference poster to organize the inscriptions regarding concepts and corresponding color.

Maria took up this modeling convention using the color coding technique (Figure 7). Maria added conceptual language in her model and used those inscriptions to guide her explanations. By the end of the unit Maria had taken up a variety of modeling techniques such as the use of symbols, letters, colors, words and ideas to incorporate a range of concepts and their relationships. The colors represent particular places that she wanted to locate forces such as at the top and bottom of the slide; pushes are orange and pulls are blue. Yellow indicates that you can build up "speed energy" when you start moving on the slide, a term created by the children.

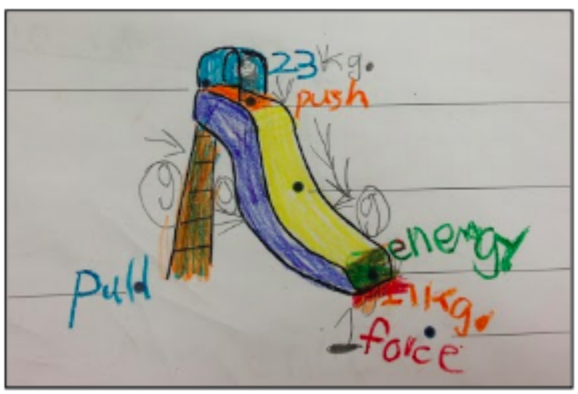


Figure 7. Maria's final student model.

Her slide ladder uses two different colors to show that both pushes and pulls are required to climb. Maria has used green to signify the moment of energy transfer from the moving child to the bear. Her arrows indicate that gravity is acting in multiple locations and in a downward direction. Prior to the final modeling lesson, in response to student generated questions about weight, each child had the opportunity to weigh themselves in kilograms as well as the stuffed animal. Maria, similar to many other students, included the weight of the objects (herself and the stuffed animal) in her final model. In the excerpt below, we see that Maria has no longer included concrete objects in her final model, instead we see her using concepts to explain the anchoring phenomenon.

> Coach: Can you tell me about your picture?
>
> Maria: Here is a pull [gesturing to the ladder] and here is a push [pointing to top of slide] because if you don't do a push, if you give a big push or little push you might not go down.

The coach pressed Maria to articulate more by asking "Can you tell me about what a push is and what a pull is?" to which Maria replied, "A push is when you move something, and pull is when you pull a flower out". A few minutes later, Maria begins to generalize the concept of gravity to objects beyond the slide. This next excerpt provides an example of a supportive learning condition and is typical of adult-student interactions around student models. The excerpt demonstrates the importance of one-on-one check-ins to gauge student understanding and can support dialogue with children as they begin to generalize concepts beyond the phenomenon they are exploring.

> Coach: What is gravity? You have the G right there on your paper [pointing to the G next to the slide].
>
> Maria : Gravity is, um, something that holds you up and it is in the floor and the table has gravity because it, it is holding itself down and that's how gravity is.
>
> Coach: Okay, so now tell me about if I were, if you were standing over here [pointing to the ground next to the slide] is there gravity over there?
>
> Maria : Yeah.
>
> Coach: Did you want to add anything to your picture? I wonder where else gravity

would be?

Maria : On the ground.

Coach: So how can you show that gravity is on the ground? What could you do in your picture?

Maria : Adding a G.

Coach: Okay adding a G.

Maria : [adds a G under the slide] Um so here [pointing to the slide] here [pointing next to the slide] it's all around.

Coach: It's all around.

Maria : And also in all the places in China, and in Spanish.

Coach: You said places like in China and places where they speak Spanish there is gravity too? Wow, so gravity is part of your science story?

Maria : [nods head yes]

Supporting children with one-on-one time and a listening ear was a learning condition that we provided regularly. In this example, we see how this student responded to the adult initiated questions. In this previous excerpt Maria shifts from locating objects affected by gravity to declaring that gravity is a phenomenon that is "all around".

Raymundo is a student whose teacher had identified him as having difficulty communicating his ideas during writing. Modeling however appeared to enable him to combine drawing, gesturing, and verbal comments to generate explanations. The following lesson (eleven) transcript highlights a check-in with the instructional coach about his final model. During this lesson, the coach brought an 8 inch, mini toy slide into the classroom to ignite child centered questions and discourse that could lead to students transferring the concepts across contexts. Using his final version (Figure 8) Raymundo shared ideas by locating concepts through gestures within the model which were all part of his sensemaking process.

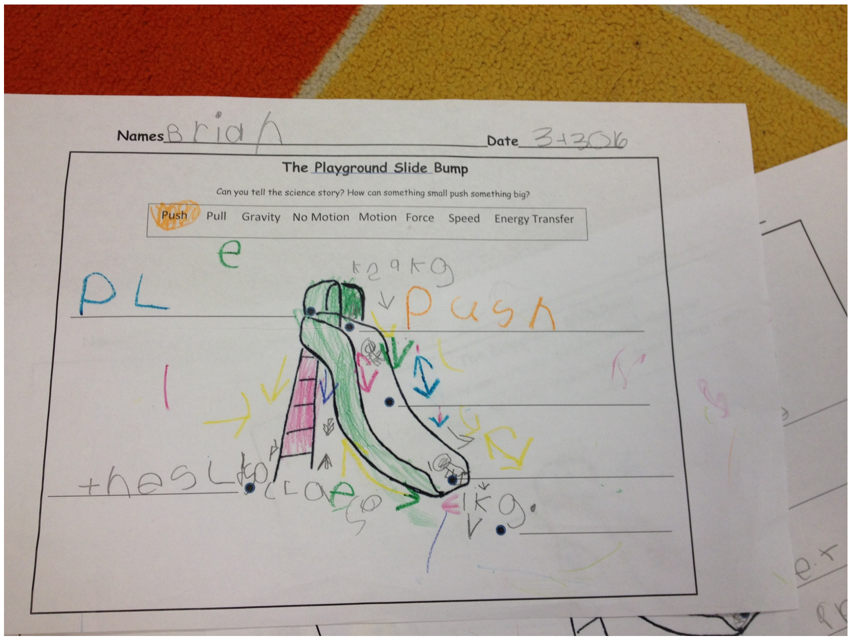


Figure 8. Raymundo’s final model.

Raymundo: If the slide doesn't have no push or pull, you can't go down because you need to have... you're heavy. And if you're heavy you need to have... you can still go down [pointing to model]... The slide can help you go down. There is something invisible pulling you down.

Coach: What is invisible that is pulling you down?

Raymundo: It’s... what did that say again? Gravity!

Coach: What pushes you down?

Raymundo: Gravity pushes. Gravity is right here [pointing to the ladder], Gravity is everywhere [pointing all around the slide model] around the slide. If this ramp [pointing to the mini toy-slide] can't move anywhere it can't...those dolls can get pushed down because it has energy, because the energy of the slide, it is low energy and it never goes away, the energy.

Coach: It never goes away? Where do you get the energy from?

Raymundo: From the slide.

Raymundo articulated a connection between concepts as it relates to the playground slide collision phenomenon. He concluded by mentioning the persistent presence of gravity and claiming that the energy comes from the “slide” that “never goes away”. Again, we see kindergarten children conceptualizing how these abstract concepts occurred in the phenomenon in sophisticated ways, beyond the scope of the grade level standards expectations.

Following the conclusion of the unit, all students had the opportunity to sit and reflect on their learning. In these interviews, students indicated that they saw Raymundo as a knowledge source that helped them learn. This integral design element of the learning environment “students as authors and producers of knowledge” were articulated in these interviews. During Raymundo’s interview the coach asked him, “Why do you think we want you to share your ideas with the class?” to which Raymundo begins naming particular elements of the anchoring phenomenon, “We can talk about how we go down the slide. How much speed it has, how much. If it is a steep ramp or a shallow ramp.” Here he named the various but connected phenomenological concepts that learners can explore during shared discussions opportunities.

Students increasingly began to see modeling as a way to explain ideas to an audience, particularly in later lessons. Clementina, the youngest student in the class, ignored snack time and initiated unprompted, drawing force and motion inscriptions on the toddler slide for several minutes. After snack time, other students cleaned up their desks and transitioned to recess, Clementina continued to add inscriptions to the slide. She paused when students approached her to ask questions about her labels, some even brought over their own final models and began comparing their ideas to Clementina's. Clementina went back to modeling on the slide until the teacher asked her to take a seat at her table. The formal instruction had ended for the unit and a few students, who had not shared their final model explanations, were meeting with the coach seated at a table. Clementina approached the back table and says, "I *really* want to do that with you." Clementina received permission from the teacher to stay in the classroom to continue modeling. This excerpt occurred after the last lesson of the unit:

> Coach: Do you like drawing science ideas?
>
> Clementina: [nods her head yes]
>
> Coach: Yeah? You're really good at sharing ideas.
>
> Clementina: And I also like sharing ideas because that means people learn.
>
> Coach: That means people learn. [silence 4 seconds]

Clementina remarks connect to a meta-strategic knowledge about learning and speaks to the larger classroom pedagogical culture.

> Coach: Alright keep going with your drawing because you've got to go to music pretty soon.
>
> Clementina: And I also wanted to circle gravity (on her initial model).
>
> Coach: What does the arrow mean again?
>
> Clementina: It means that there is gravity in the ground.

Clementina was prompted to finish her work because recess would be over in and she needed to be in music. Clementina received six requests during the next fifty-seven minutes to finish up her work—she never did make it to the specialist that day.

> Clementina: I'm gonna put energy in my slide [adds the work energy but the inscription is not easily visible]. What if people can't see it?

Clementina indicated that her representations of energy were meant to be shared with others and she was concerned that they may not see it. By phase three, modeling seemed less of a task and more of a way to communicate with an audience. During this interaction, Clementina questioned her inscriptions more than once as problematic because others may not be able to "see it".

> Coach: Is there anything else you want to add before you need to go?
>
> Clementina: I want to add 11 more stuffs.
>
> Coach: Could you keep drawing and keep drawing…do you think you will ever be finished do you think scientists are ever finished with their drawings?
>
> Clementina: No, and they just keep going and keep going.
>
> Coach: Why do you think they keep adding stuff?
>
> Clementina: Because they have a lot of ideas, so they put it in their papers, and um if they don't pick them it's okay because they can do it in their papers.

Clementina articulated that revisions to one's thinking in science don't end. She added that models are a place for ideas and was articulating that being in a classroom with twenty-seven students means you may not always get picked to share ideas. Modeling to these children appeared to become a visionary practice, allowing for new insights to be developed gradually over time through collective innovations towards an expanded conceptual understanding of the phenomenon.

Discussion

The discussion will focus on evidence that students began to transition between engaging in modeling as an instructional task to modeling as a (re)visionary scientific practice. The table (Table 1.) will be used to illustrate the shift from task to practice. Descriptions of supportive learning conditions, theorized to influence a shift in epistemic agency, will be included in the second half of the discussion.

At the beginning of the unit, all students created an initial individual model on paper. Working quietly and independently, their inscriptions included arrows, people, hearts, rainbows, and some objects not directly related to the phenomenon they then handed in their work to the teacher without discussion. While I do not have direct evidence from students that they perceived modeling as a task, their interactions with the models in the beginning of the unit were similar to traditional school assignments, in that they did not voluntarily return to their own initial models to revise or add new inscriptions or initiate discussion with peers about their work. Students appeared to orient to models as an assigned task doing the work as a private assignment with a focus of timely completion.

Children engaged with models in both planned and spontaneous ways and over time we learned more about children's capabilities as they demonstrated their capabilities to model, gesture, and sense-make simultaneously (e.g. Đa Minh's modeling, gesturing, and explaining this thinking to the whole class). We also learned that some children such as Clementina viewed modeling as a participatory act. Clementina articulated that even if you don't participate verbally, models can be a space to participate and that models embody ideas in a way that allows them to speak for you to an audience. In kindergarten we see the expansive uses for how young children have defined the practice of modeling for themselves in ways that serve their interests.

The model and related representations in this unit (playground slide) retains a simplicity needed for generative student innovations while the anchoring phenomenon incorporates complex and robust opportunities for knowledge building. Use of both abstract and concrete representations, advocated by Hapgood et al., (2004) afforded children diverse opportunities to locate, revise, and advance their reasoning of the scientific phenomenon. Model(s) were always displayed and usually referred to during discussions, investigations, and read alouds to provide a referent for the sustained intellectual work (e.g. physical models, paper models, mental models, white board models). These findings indicate the importance of student accessibility to a variety of models as well as opportunities to physically interact with the model through revisions. In addition, access to physical and cognitive manipulation of related representations (ramp), and experiencing simulations (playground slide) enabled the growth in sophistication of students' explanations and ability to generalize the concepts to other contexts.

Students' engagement with models shifted in phases two and three. Children began to use models as multi-dimensional, public mediators for sharing ideas with peers. Students oriented to models not just as representational tools having symbolic features but facilitating explanations and communication with others (Hapgood et al., 2004; Lemke, 1998). We observed students initiate intellectual activity such as spontaneous co-modeling sessions between friends at the whiteboard while their peers are lining up for lunch. Some were observed to return to their models during non-modeling activities to add new ideas or change existing inscriptions. Other times saw students creating varying representations of the model on the white board as they shared their explanatory thinking with the class. Students were not just creating a drawing, models became mediators for talk, thinking, and revision of shared ideas. Recall Đa Minh's public modeling in phase two "This is the arrow going up, that means...the energy is going up". Đa Minh's described the meaning behind the inscriptions and utilized symbols to represent how the abstract concept of energy moves through an open system. In many episodes similar to Đa Minh's example, we observed the model serving as a support for locating not just their gestures but a range of science ideas and experiences.

As the unit progressed, interactions with models became a more student-driven and student-initiated practice. By phase three, critiquing models also became a predictable routine for the community. Students regularly asked questions and clarified their understanding during discussions. Centering children, their ideas and models created opportunities for them to innovate on modeling inscriptions, allowing for greater agency and ownership of these products (Siry et al. 2012). This was further exemplified with Maria's playground teddy bear experiment as she transferred ideas from classroom experiences to their time in their neighborhood park. The trajectory of the unit culminated in students communicating revised ideas in their final models. During the final share out session, spontaneous revisions continued as Clementina would say that scientists' model revisions "*they just keep going and going*". These findings indicate the important role of an audience in the work of modeling as children engage in modeling revisions. Kindergarteners relied on the use of an audience as part of a purposeful routine (Danish & Enyedy, 2007) needed for iterative sensemaking work.

Through working with these students, I saw that modeling in this context was a set of interconnected public activities, motivating and informing other scientific practices, such as investigations. Public modeling led to peer feedback and shared sensemaking, with the findings demonstrating the importance of making thinking visible to work on ideas *together*. Students felt that models were for an audience, exemplified by Clementina who grew concerned with her modeling revisions that her audience may not be able to "see it". The act of creating a model can be a participatory act, because you are imagining an audience and how they will be understanding your thinking. Many children recognized, without overt prompting, when an occasion arose for questioning a model or adding revisions (Figure 5). The diversity of children's meta-representational competency (diSessa, 2004) contributed a rich array of possibilities for the community to utilize and student created inscriptions were publicly positioned by the teacher as innovative examples of making thinking visible.

There are few empirical classroom studies with kindergarten aged children creating representations and using models (Danish & Phelps 2011; Montiera, Jiménez-Aleixandre, & Siry, 2020; Samarapungavan, Tippins, & Bryan, 2015) and few to none which explore iterative modeling revisions and the evolution of kindergarten modeling. This paper provides evidence about the capabilities of kindergarteners work with models, ideas and innovative inscriptions when an epistemic culture is cultivated. Modeling as a practice, in which communities revise their work over time, has been well examined by the field, but there are few studies about modeling as a revisionary practice by kindergarteners that include inscribing and making sense across a variety of model types (individual paper, consensus model, white board models, physical 3-D representations). This study demonstrates how young children take up the practice of revision and are capable of understanding that models are meant to be revised in light of new ideas. This study confirms the research by Montiera, Jiménez-Aleixandre, & Siry,(2020) that young children's modeling becomes more complex over time given they are provided with supportive learning conditions.

Table 1
Modeling: From Task to (Re)visionary Practice

	Modeling as Task	Modeling as a (Re)visionary Practice
Broad Characterization of Students' Engagement	● Performative orientation: Focus on compliance & completion	● Cycles of learning experiences to generate shared knowledge, including diverse student-driven modeling innovations.
Activity Focus	● Time delimited. ● Children quietly turn in models without discussion.	● Children explore physics ideas both inside and outside the boundaries of the classroom. ● They begin to use models to initiate conversations about science with others.
Representational Work	● Children purposefully represent observable and concrete events or attributes in their models. ● Students show emergent capabilities for using models as tools for communicating ideas to others.	● Children embody increasingly abstract ideas in their models, using a range of words, meaningful symbols, and intentionally selected colors. ● Children begin to perceive models as representations of explanatory ideas for use with specific audiences.

Individual Versus Collective Learning	● Students interact with models as a private, independent task and are not observed to share ideas while creating initial models. ● Children respond to educator's prompts to offer feedback during model-sharing sessions.	● Models are publicly shared by children. ● Models serve as internal and external mediators for children to communicate, gesture, investigate, and sense-make. ● Students' ideas become objects of inquiry and they become more willing to engage in public thought experiments.
Revision Opportunities	● Students use scaffolded instructional prompts to practice making revisions, but do not independently revise their initial models.	● Children begin to revise models and explanations in response to cycles of investigative activity and prompts from peers.

Supportive Learning Conditions

We used heterogeneity as a lens for welcoming and fostering generative discourses and practices in order to cultivate an epistemic culture with and for kindergarten learners. Similar to the Rosebery et al. (2010) study, we designed for this work to unfold in both "planned and unplanned ways" (p. 351) (e.g. the spontaneous scientific argument "Is a slide a ramp?"). And this study documented children scientifically employing their ideas and experiences (e.g. Maria taking her stuffed animal to the park to conduct an experiment) and saw the work of sharing those ideas as part of the collective learning process (e.g. Clementina " I also like sharing ideas because that means people learn"). In order to support this collective work, I built off prior theory around learning communities (Boaler, & Greeno, 2000; Brown, 1997; Brown & Campione, 1994) and shifting student participation (Engle & Conant, 2002; Engle et al., 2012; Herrenkohl & Guerra, 1998; Rogoff, 1994, 1995; Rosebery & Warren, 2008; Rosebery, Warren, & Conant, 1992). Through these findings, this study provides information about the kinds of ideas shared by young children in science discussions. Examples include everyday science ideas, stories, and experiences from home as well as more modeling focused talk about representing science concepts (e.g. ramps, energy, gravity). The evidence points to the need for learning environments to view the diverse capabilities and everyday talk of young children as assets in building knowledge collaboratively.

Moving toward modeling as a revisionary scientific practice, defined by the collective nature of the children's intellectual and social endeavors which supported conceptual development across a range of participatory roles. As the lessons progressed, learners recognized a diverse range of possibilities of how, when, and why to use models. Students built an understanding of the range of purposes that models can serve (e.g. Clementina articulating that modeling is participating "if they don't get picked (to participate) then they can put it in their papers (models)." Over time we saw students demonstrate and innovate towards modeling as a revisionary practice with models being a crucial feature of their intellectual work. Returning to the transcript excerpts featuring Đa Minh and Raymundo, it appears that the centering of Đa Minh's initial work at the whiteboard allowed others to observe a novel public intellectual performance, listen to the dialogue, and resource the experience for future reference. Raymundo across three phases had emulated this public practice to build off the ideas of others (e.g. Đa Minh) producing conceptual innovations with and for an audience. Generative instructional strategies such as public modeling and sensemaking such as the ones that Đa Minh and Raymundo co-produced, were a regular occurrence in the science classroom as students had opportunities to exercise choice in their modeling and social sensemaking pursuits.

Our design emphasized the positioning of students as agentic authors and thoughtful producers of shared knowledge (Engle & Conant, 2002). Positioning for agency requires opportunities for personal choice in creating models, representations, and public dialogue. Positioning for agency and choice supported a diverse range of modeling innovations and this study found that students were heavily invested in this work. The benefits of personal choice were a key finding of a study by Danish and Enyedy (2007) suggesting that choice allows children to feel ownership and individuality over their representations. Our study took up personal choice and positioning for agency within discussions (e.g. children could choose which ideas and stories to share with others) and opportunities to model as children evaluated information and over time they determined the relevance of the ideas in relation to model revision. This positioning occurred across all activity structures within our lessons. Although a view of individual agency and positioning is important it is also necessary to hold space for the collective work of the community. Collective and diverse participation by students made visible the social dimensions of science, particularly within a unit where modeling is a central activity (Lehrer & Schauble, 2012).

Our design routinely utilized expansive framing for transfer in which the teacher, Ms. Takeoa, framed her expectations for setting the tone of the intellectual work that she expected of them while simultaneously positioning children as agentic learners (Engle et al., 2012). Prior to any discussion, group work, independent modeling or other activities, the teacher would carefully and succinctly outline the task, expectation, children's shared responsibilities, and respond to questions by the class. Ms. Takeoa's framing supported students with consistent messaging designed to encourage the shared nature of learning and intellectual risk taking. Framing occurred throughout the unit to invoke meta-awareness by students, oftentimes to engage them in considering the differing perspectives of others as they created and revised models and explanations. This is exemplified by Ms. Takeoa's whole class framing as she supported the class in considering the role of listening, "remember friends we are listening when other friends are talking so that we can build on their ideas".

Over the course of the unit as students engaged in modeling, their efforts were supported through strategic framing by the teacher (e.g. "We are all thinking about this together"), scaffolded talk moves which centered students' experiences and their ideas as resources, and routines (e.g. Discussion Web) to make visible diverse forms of participation (e.g. listening, verbal, kinesthetic-modeling) (Wright & Gotwals, 2017). This resulted in students creating a final model checklist in which *they* determined the concepts and inscriptions which would best explain the scientific phenomena, not to the teacher, but *with* an audience of their peers. The role of framing in authentic scientific work is undertheorized in the literature but our evidence points to framing as supporting young children in understanding the purpose, context, and significance of the disciplinary specific work. Through framing, positioning students as agentic authors of knowledge, and attending to heterogeneity, an epistemic culture was developed where revision became a normalized part of the modeling process as children engaged in opportunities to learn during discussions, interactions with concepts in books and media, and hands on investigations.

There is some evidence, that designed opportunities to learn (carrying out investigations related to the anchoring phenomenon, read-alouds about key science concepts, discussions treating students' ideas as resources, treating ideas as revisable/improvable, whole class consensus modeling, one-on-one conversations with teacher, etc.) were effective not only because of their cumulative nature and coherence with big ideas, but also because they are diverse and persistent features of the learning environment. Students are then likely to take advantage of different supports in varying combinations over time.

Some of these findings are consistent with other studies primary science classrooms, including Danish & Enyedy (2007) who found a balance between the "individual and collective representative work" (p. 32) and "collective scaffolding" as supportive to the work of young children's representational experiences (Monteria, Jiménez-Aleixandre, & Siry, 2020). In addition, these findings support the work of previous research in using read aloud books to support modeling and scientific understanding of complex topics (Hapgood et al., 2004; Manz, 2012; Wright & Gotwals, 2017; Varelas & Pappas, 2006). This study responds to calls by researchers of early learning environments (Samarapungavan et al., 2015) to determine how kindergarteners engage with modeling and model revisions over the trajectory of a unit. In addition, this study responds to calls for additional research as the findings provide examples of supportive learning conditions which enabled and positioned children to engage in interactive knowledge construction through scientific modeling of physics concepts (Samarapungavan, Mantzicopoulos, & Patrick, 2008; Wright & Gotwals, 2017; Suárez & Otero, 2013: Monteria & Jiménez-Aleixandre, 2015).

Implications

This study sought to better understand how students from institutionally marginalized communities participated and engaged in the practice of modeling both individually and as a knowledge building community. Given that this study sheds light on the experiences and potential that kindergarten science holds, it is important for us to think about the implications for practice and research. Through this study we have learned about the incredible scientific capabilities of kindergarten students engaging in knowledge construction in physics through scientific practices such as modeling. Modeling, in this study, played a central role in supporting student learning and understanding of complex scientific phenomena. These learners were provided with time to engage and diversely participate in a collaborative knowledge building enterprise around a high interest and accessible phenomenon while the classroom teacher was provided with a dedicated instructional coach. Future studies should examine the role of scientific modeling and instructional coaching in knowledge building communities across the primary grades. In conclusion, practitioners, school districts, and researchers must continue to collectively employ our disciplined imaginations in designing for equity and heterogeneity in elementary science education as we adopt strength-focused approaches to working with children from diverse communities.

Conclusion

This study allows the field of science education and learning science to gain a deeper understanding of emergent bilingual kindergarten students' engagement with scientific models and with the ideas of their peers under supportive learning conditions. Children's collective work with models occurred as a shared activity sustained throughout the unit. Models became a well-used tool for conceptualizing and theorizing at the kindergarten level. Modeling served to support the building of knowledge as students utilized models to generate and communicate scientific explanations. Models and representations enabled students to engage and understand a complex scientific phenomenon. Without the models and representations, it would have been difficult to sustain long term engagement or interest focused on knowledge building. Even in the absence of an actual model, we saw students gesturing in the air on an imaginary slide as they engaged in explanatory talk. The instructional design afforded children multiple and diverse opportunities to engage in cycles of model making, public sharing, noticing and wondering about the ideas in our models, critiquing models and ideas, and model revisions (Lehrer et al., 2000). The modeling cycle created a learning environment in which children can engage in learning about scientific phenomena revision of ideas and shifts in understanding. This enables the discipline of science to become a place where students feel comfortable participating diversely, taking intellectual risks, generating student-centered contributions, receiving feedback from their community, and engage in modeling as a process (Samarapungavan, Patrick, Mantzicopoulos 2011).

We now have an emergent, intersectional understanding of what both early learners and emergent bilingual students are capable of accomplishing during a unit on physics focused on scientific modeling within a supportive learning environment. These findings are an important contribution to the field, given the calls for research (Samarapungavan, Mantzicopoulos, & Patrick, 2008; Wright & Gotwals, 2017; Suárez & Otero, 2013; Monteria and Jiménez-Aleixandre, 2015) of needed studies about the early learning experiences within the science classroom. Specifically, we now have identified ways that students shift over time their interactions and perspectives towards modeling, which can guide further research that uses supportive design frameworks (Table 1). We have a more nuanced understanding of how kindergarten students interact with models and ideas over the course of a three-month unit and these findings can be tested in other contexts and student populations to determine their generalizability.

This study demonstrates that kindergarten students are able to collectively and progressively integrate rich scientific practices in order to engage in the enterprise of modeling. This enterprise encompasses not only individual work with models and ideas but engaging in a shared set of interactions within elements of an activity system (Greeno & Gresalfi, 2008). It appears that through a supportive learning environment guided by a set of connected design elements, kindergarten children readily engage in the highly demanding but engaging social and cognitive work of scientific modeling.

SECTION 2

"These powers walk...to all the parques": A multi-case study of diverse engagements in physics by emergent bilingual kindergarteners

Introduction

Primary science classrooms are filled with children who have rich foundational knowledge (Metz, 1995) and dynamically engage with the world through everyday competencies such as drawing, storytelling, questioning, playing, and observing (Keifert & Stevens, 2019; Gallas, 1994). Kindergartners have sophisticated ways of thinking about the world and draw on their lived experiences to engage in science learning (NRC, 2007; 2012). Research has shown that when children's natural capabilities are supported through equitable instructional designs, then they are able to engage in a wide variety of scientific practices. Such practices include making observations to generate claims (Monteira & Jiménez-Aleixandre, 2016), participating in purposeful science discussions (Gallas, 1995), creating scientific representations to demonstrate understanding (Danish & Phelps, 2010), revising explanatory models (Salgado & Windschitl, 2017; Salgado & Tomokiyo, 2018) and engaging in scientific investigations (Samarapungavan, Patrick & Mantzicopoulos, 2011). The findings from the aforementioned studies indicate that under supportive conditions, children in primary science classrooms are capable and motivated to participate purposefully in scientific practices across a range of meaningful contexts and topics.

Decades of research have documented limited time being devoted to science education in elementary school and with the quality of instruction being more teacher-led and directed (Buxton & Lee, 2014; Roth, 2014). Children from linguistically and culturally diverse communities, in addition to routinely being positioned from a deficit frame in education (Bang et al. 2012; Nieto, 2000; Calabrese Barton, 2001), are also experiencing science as a series of disconnected activities that lack a strong relational connection to big science concepts (Roth, 2014). Research indicates well-documented and significant gaps in standardized measures of science achievement (NRC, 2012), particularly among students from Latinx backgrounds (Santu et al., 2010). A shortcoming on much of the work reporting on science learning by very young children, is the infrequency of asset-focused reports on children from institutionally underserved backgrounds. In addition, researchers have reported on the importance of early learning environments which are designed to mitigate the cultural, linguistic, and socio-academic factors that influence the participation of linguistically diverse children in science (Buxton & Lee, 2014). Taken together, there is a need to provide the field with developing design knowledge about learning environments that examines how children participate under supportive learning conditions.

Few studies have examined diverse forms of participation in science by emergent bilingual children developing disciplinary specific knowledge through engagement in scientific practices. Motivated by the literature gap, this study aims to contribute research exploring how three emergent bilingual kindergarteners participated differently in a physics unit of study to examine forces and motion during playground slide collisions. In this study, I document how the instructional design elements create multiple and diverse opportunities to learn and participate individually and collaboratively in a knowledge building community. Utilizing a supportive instructional design to support linguistically diverse children, this study will examine how focal students participate across a science unit. In addition, this study seeks information to better understand how children demonstrate the process of knowledge construction as they participate in a knowledge building community. This study addresses the following questions:

1. Under supportive learning conditions, how do emergent bilingual children use resources and opportunities differently in order to learn to engage in scientific practices?
2. What disciplinary knowledge do children draw upon and demonstrate when their classroom and membership is conceptualized as a knowledge building community?
3. What roles do particular relational routines, activity structures, and discourse play in supporting kindergarteners to develop generative and equitable ways of talking together about science ideas in planned and unplanned ways?

Literature Review

This literature review will bring together three areas of research to highlight a vision for kindergarten science with supportive conditions for young learners in a linguistically diverse classroom. Research in the areas of knowledge construction, effective instructional strategies, and emerging bilingual learners intersect to conceptualize a kindergarten classroom of children as individuals and engaged members of a collaborative community (Brown & Campione, 1994; Engle, 2006; Gutiérrez, 1999; Rogoff 1994). The concept of knowledge building community is essential in order to cultivate the development of scientific understandings while simultaneously supporting diverse participation. For the purposes of this study, I will be using the terms emerging/emergent bilingual even though the literature I am citing uses the terms English Learners and English Language Learners. I acknowledge recent research which calls for rethinking these traditional terms. Scholars González-Howard & Suárez (2021) rightfully argue the need to problematize and move away from the term English Language Learners as a move toward "linguistic justice and asset-oriented framing".

The need for high quality science instruction is connected to the Framework and

NGSS which advocate a shift away from teacher-led and teacher-centered instruction with a focus on textbook learning, lectures, and students as recipients of knowledge. Instead we can view the framework (NRC, 2012), the three dimensional learning of the NGSS (Achieve, 2013) as providing the field with ample opportunities to engage in meaningfully, including language-rich learning opportunities (Lee et al., 2019). But this isn't only about providing opportunities, this vision of reform in science education is centered on a culturally expansive view of teaching and learning, including leveraging the full linguistic assets of children (NRC, 2012).

Emerging Bilingual Learners. Children from Latinx communities first entering school and who are emerging bilingual learners bring a wide variety of skills and practices from their families and communities which can be resourced to support their participation and learning in science (Buxton & Lee, 2015; NASEM, 2018; Salgado & Tomokiyo; 2018). Researchers have documented practices which include learning and participation through observation (Mejía-Arauz et al., 2005), sophisticated collaboration (Alcalá et al., 2018), and connecting everyday home experiences with school science topics (Buxton & Lee, 2010). Children's diverse everyday ways of knowing and talking about science are similar to characteristics and practices of scientific communities, and research has documented how young children use their everyday experiences as a contextual lens for understanding scientific phenomena (Rosebery et al., 1992; Warren et al., 2001). Examples include children's readiness to ask questions about observations of phenomena they see in the natural world and trying out investigations with everyday objects like blocks or toy cars to witness and influence cause and effect relationships. Such practices are part of a repertoire of cultural knowledge in which educators can use to better support and value the cultural contributions that children from these communities bring with them to the classroom.

Many U.S. classrooms are rich globalized settings where a diversity of languages, ethnicities, power, membership, inclusion and exclusions converge. Gutiérrez et al. (1999), argue that in designing classroom spaces to promote learning we must go beyond recognizing diversity of the language practices but how they can be used to support deep engagement and meaningful participation. Diversity includes recognizing the need to disrupt English as the power language of the classroom and going beyond acknowledging the existence of linguistic diversity in a classroom but encouraging children to sense-make in a language of their choice with their self-identified friends. Diversity includes recognizing cultural and linguistic differences brought to the classroom as valued added and marveling at children's unique participation journeys. Diversity includes considering who is teaching, designing, writing, and researching the tools and lessons for teaching and learning and also valuing the diversity in which children choose to engage and learn through those mediating tools. Diversity, being leveraged within the community to reform what has existed in science education for children learning English and to transform the space for meaningful learning opportunities. Such a space for learning would allow for the merging of storytelling, narratives, random chatter, listening, humor, everyday ideas and canonical science ideas which supports the maintenance of a "culture of collaboration" to enable "novel forms of participation" (Gutiérrez et al., 1999, p. 292). Students are then able to learn that they are not just participating to make an idea public but also emergently working to make their *reasoning* about an idea, *public*.

Despite the valuable knowledge and practices that such children bring to schools, it is well documented that children who are learning English as their second language, have less access to meaningful science learning experiences than their English speaking peers

(Callahan et al., 2010). The implicit institutional assumption of public education in America has been to respond to language diversity as a deficit (Ruiz, 1984) that needs to be remediated rather than an asset or an intellectual strength. As a result of the marked linguistic and cultural differences between a largely White teacher corps and emerging bilingual or multilingual immigrant students, these learners are often marginalized in classrooms and absent from time devoted to science in part because of external pressure to rapidly increase dominant language fluency (Buxton & Lee, 2015; Suárez & Otero, 2013). Gutiérrez et al. (1999) articulates that language practices which support and resource diversity are not always legitimized in formal settings such as classrooms and argues for use of hybrid language practices to mediate classroom communication through viewing language diversity as a resource for cognitive growth. In addition, deficit views of children learning English as their second or third language continue to influence how elementary-age children's knowledge and capabilities are undervalued. Such examples include research demonstrating that when elementary teachers are presented with video evidence of children drawing connections between home experiences with school science topics, the teachers are more likely to identify conceptual or linguistic limitations rather than acknowledging academic strengths (Buxton et al., 2013; Buxton & Lee, 2010). Given the history and research of linguistically diverse children being institutionally excluded or marginalized from science education we also must consider what strategies and approaches have supported this population of learners.

Learning science through meaningful engagement in scientific practices supports the building of linguistic and literacy skills, which can be achieved concurrently (Buxton & Lee, 2015; Lee, Quinn, & Valdés, 2013; Lee et al., 2019; NASEM, 2018). Recent research argues that the cultural, linguistic, and academic strengths of these children can "simultaneously promote academic achievement and strengthen EL's cultural and linguistic identities" (Buxton & Lee, 2015, p. 208). While linguistic growth in English is important, the incorporation of literature from English language learning is not solely to support children's English language development, but also to intellectually challenge and engage young learners in sustained intellectual work meant to highlight the socio-academic capabilities of children from linguistically and culturally diverse communities.

To offer an ambitious vision and equitable design for kindergarten science education would require a set of design principles and instructional strategies are orchestrated and revised over time in response to how children participate across multiple and diverse science opportunities to learn. Such a vision would encourage and cultivate a *community* where children see themselves evolving as increasingly central members, actively co-constructing science knowledge with their peers where language and knowledge building interactions take place both within and beyond the classroom walls (Gutiérrez et al., 1999; Lave & Wenger, 1991; Lee, 2019).

Knowledge Building Communities. Cultivating a knowledge building community is a foundational principle of this study because we are seeking to create a supportive and culturally responsive learning environment with young learners as they embark on meaningful participation for engagement in disciplinary practices. Boaler and Greeno (2000) articulate that "The social practices of a community provide an environment in which students can participate, and their ways of participating are adaptations to the constraints and affordances of the environment" (p. 173). These constraints and affordances, being influenced by the instructional design and culture of the classroom, support the need for a sustainable design where responsibilities and knowledge construction is a shared endeavor.

The fundamental purpose of such a community is to cultivate belonging, collaboration, and opportunities to participate in the building of knowledge and conceptual understanding within science.

Learning communities (Brown & Campione, 1994) utilize social practices (Wenger, 1998) which employ elements such as language, specialized tools, and representations to establish sustained, discourse-intensive sense-making. The emphasis on *sustained* intellectual work affords learners multiple and varied opportunities over the trajectory of a unit to engage in structured and unstructured discussions, small group investigations, and scientific modeling. Multiple opportunities to participate supports learners to practice, observe others, rehearse ideas with peers, and build capacity to communicate their thinking with their community by making their ideas public through semiotic modalities (gestures, embodiment) as well as through verbal or written form of communication (Buxton & Lee, 2015).

Conceptualizing classrooms as communities recognizes a need for classrooms to function towards facilitating and sustaining a nurturing, developmentally appropriate, and metacognitive learning environment (Brown, Metz, Campione, 1996). The teacher assumes the role within the learning community to model, frame, and facilitate discourse and disciplinary specific practices while placing student talk, interests, and reasoning at the center for designing effective instruction. In addition, teachers work to intentionally engage with students, their ideas and their productive and very necessary struggles to support the learning process through culturally diverse norms and routines (Engle & Conant, 2002; Brown & Campione, 1994). The children assume responsibility for employing their skills and resources such as listening, collaborating, and innovating during their learning experiences. Together, the children and their teacher orchestrate a series of dynamic learning opportunities in which people are engaged in an array of cultural and academic interactions narrated through talk, gesture, responsive listening, movement, giggles, and learning (Ash & Kluger-Bell, 1999; Gallas 1995). Such learning environments contain an ebb and flow of information, questions, distractions, silence, stories, feedback, and sense-making moments necessary for learners to engage in deep meaning making work with peers (Schultz, 2003). The knowledge building community in this study functions to move beyond "effectiveness" and "accountability" reaching instead for communal responsibility and relationality. Relationality occurring socio-academically as they construct intellectual relationships with each other and with the discipline of science. Next, I discuss why talk in science classrooms is a central and foundational component for the establishment of a knowledge building community.

Supporting Everyday Ways of Knowing and Communicating in Science. Students, including emerging bilingual learners, benefit from design principles that employ cultural, relational, and socially oriented views of learning within discourse rich learning environments. In science classrooms, discourse is a foundational element of sharing knowledge, critiques, and revising ideas (Scardamalia & Bereiter, 2006). Learning communities function as communities of discourse, as children's ideas become a central guiding focus for discussions serving as explicit objects of knowledge ready for collective critique and revision occurring over time (Windschitl & Calabrese Barton, 2016; Mercer, 1996). Not only are ideas then "seeded for migration" (Brown & Campione, 1994) but the skills associated with communicating those ideas become public and ready for appropriation by others.

Language is used to bridge the social aspects of discourse with the cognitive work that encompasses knowledge construction (Cazden, 1991) and talk is one of the central components of the meaning making system of communication in formal classroom settings (Mortimer & Scott, 2003). Dialogic talk in learning settings is distinct from traditional lecture-listen or questions-answer routines. Instead this orientation to language is focused on shared and sequenced communication towards understanding and meaning-making (Bakhtin, 1981). Dialogic talk can occur across a variety of formal and informal settings and across all cultures (Nasir et al., 2006; Heath 1983) and occurs as a value-laden, active process. Wertsch and Rupert (1993) describe social interaction as a necessary component for the ability to determine word meaning and to generalize during dialogic talk. “Participating in dialogic classroom discussions seems likely to change students’ conceptions of themselves as learners, especially when the discussion highlights reasoning and gives students opportunities to explain their ideas.” (Resnick et al., 2015, p. 446). Learning and language development, therefore, can occur within social situations in which the relational building of all learner voices exists within an invoked, active space of social language (Lee et al., 2019). Researchers examining science learning environments at the kindergarten level found that dialogic teaching played a central role in young children’s science learning (Monteira and Jiménez-Aleixandre, 2016; Montiera, Jiménez-Aleixandre, & Siry, 2020)).

With the advent of the Next Generation Science Standards (Achieve, 2013), engaging students in disciplinary specific talk is at the forefront of science education reform (NRC, 2007; NRC, 2012). Whole-class discussions are a dominant practice across a variety of classrooms and have potential for fostering learning (Cazden, 2001) and act as a mediating tool (Black, 2005) allowing teachers and students to engage in meaning-making within collective talk experiences. It is these collective talk experiences which enable the co-construction of knowledge and language development as students experience science as a "social enterprise" (Lee et al., 2019, p. 319) through engagement in scientific practices (e.g., creating and revising models or constructing explanations). Discussions can engage students as active participants through verbal or performative contributions or more reserved participation such as listener and observer. These cumulative experiences support an equitable instructional design allowing students opportunities to participate diversely in sustained intellectual engagements where their development of conceptual understanding and linguistic skills occurs in context and in community.

Whole class discussions can allow for a diversity of students to share responses in a particular spatial-temporal setting (White, 2011) if there are equitable opportunities cultivated within a safe intellectual environment. Some scholars question whether the benefits of whole class discussions have translated to institutionally underserved students (Chu & Kim, 1999; White, 2011), "the use of class discussion can be effective or ineffective based upon the classroom culture, the students in the class, and the interactions between students and teachers" (White, 2011, p. 261-262). Whole class discussions often take the form of traditional IRE discourse patterns (Cazden, 2001; Mehan & Cazden, 2015;) with seemingly unproblematic knowledge transmission as the result of passive student involvement (Myhill, 2006) both socially and academically (Alexander, 2010; Cazden, 2001; Lemke, 1990; Mehan, 1979; Lehesvuori et al., 2013). IRE favors particular ways of knowing, hindering authentic sense-making practices, and which can support deficit-oriented perspectives of students and constrains learners' abilities to participate, engage, and contribute to disciplinary specific discourses built during classroom learning experiences.

The process of cultivating a knowledge building community includes awareness of IRE as a "default" discourse pattern in classrooms, and educators must consider how they are participating in that discourse with children. Understanding the construct behind the privileging of particular ideas is to consider the "settling of expectations" (Bang et al., 2012), which in classrooms translates to deeply entrenched, hidden social and academic enclosures which "control the borders of acceptable meanings and meaning-making practices" (Bang et al., 2012, p. 303) thereby systematically and consistently excluding students from institutionally nondominant communities and their ways of knowing (Bang & Medin, 2010; Nasir, 2000; Warren et al., 2001; Rosebery et al., 2010). We therefore must consider the impact of the design of classroom discourse and sense-making experiences, which have been shown to influence student's achievement, participation, retention of knowledge, and identity formation (Mortimer & Scott, 2003; Resnick et al., 2015; Dweck 2007, Steele, 1997).

Research indicates that elementary aged children appropriate scientific discussion strategies from their peers (R.C. Anderson et al., 2001; Lee, 2017) and kindergarten children have been documented to work productively through partner talk opportunities (Fuchs et al., 2002). Young learners think in complex and sophisticated ways (Metz, 1995, Lee 2017), have skills necessary to engage in complex reasoning, can work constructively and intensively (Fuchs et al., 2001) with peers, and benefit from shared talk that focuses on constructing explanations (Resnick et al., 2015; Mercer et al., 2009). When young learners engage in partner talk, they are exposed to social interactions, where the potential for sense-making can emerge as students work in low risk settings to refine and build upon their ideas (Fuchs et al., 2002). Therefore, designing for the process of creating a collaborative science learning environment through multiple and varied shared discourse opportunities supports early learners, particularly emergent bilingual learnings, not as learning in isolation, but as learners who meaningfully engage within a community (Lee, 2017).

One study (Lee et al., 2019) examined how researchers co-designed to support the development of a conceptual framework for science and language integration. That study incorporated well-structured, and purposeful whole class discussions but in addition included partner and small group discussion settings. This allowed children to move across the settings utilizing diverse talk registers such as everyday conversations about science ideas to more specialized scientific discourse. In addition, learners participated more often in lower risk settings with a smaller audience to check comprehension by observing, evaluating, and appropriating the articulations of their peers prior to testing their ideas out with a larger audience. Lee et al. (2019) argue that including multiple opportunities to engage in disciplinary specific practices and evaluate which linguistic registers to use during specific discussion settings for learners supports children in using “language to learn science” (p. 325). As children become more comfortable with specialized scientific discourses and engaging in increasingly public talk, the focus remains on the content of children’s science ideas rather than on the accuracy of their linguistic competence.

In thinking about the design features and particular activity structures for shared talk, the literature is understudied for kindergarten children engaging in specialized talk about science concepts and scientific practices. We know from the research in kindergarten classrooms (Patrick, Mantzicopoulos, & Samarapungavan, 2009) that sustained and meaningful participation in science can promote children’s motivation, perspectives, and self-efficacy in relation to their science experiences, girls’ interest in science in particular benefited. We know that through appropriate scaffolding, that young people are capable of authentically taking part in a wide range of scientific practices such as engaging in productive scientific investigations; carrying forward previous experiences and conceptual understandings from past lessons and can communicate ideas and visual representations to an audience (Samarapungavan, Patrick & Mantzicopoulos, 2011). Samarapungavan et al. (2011) suggest that the integration of science and literacy nurtures children's interest and with that interest their motivation can be promoted by integrating students' experiences with classroom content, classroom discussions, and fostering student agency. It seems that apprenticing students into an ensemble of discursive oriented activities supports student understandings of how to use whole group and small group discussions to share ideas, take intellectual risks, and view peer ideas as resources.

Theoretical Framing

We want children to not only learn science content through disciplinary specific practices but also to develop meaningful relationships with each other and science. In particular, we want them to feel and believe that their everyday ways of knowing and doing science *belongs* in these spaces. This idea connects to a defining characteristic of participation, summarized by Lave and Wenger (1991) as "ways of belonging" (p. 35) and being located in the joint work by members of a community. Lave and Wenger's (1991) framework has been instrumental to acknowledging the positioning of individuals in relation to one another (interpersonal) and membership within communities of practice. Consistent with these "ways of belonging", this design accounts for diverse participation engagements interacting with one another in a social community which collectively builds and revises their understandings.

Within Rogoff's (1994) community-of-learners model which views learning as a “matter of how people transform through participation in the activities of their communities" (p. 226), children’s engagement can be focused on organizing and participating in joint work such as supporting, navigating, or leading others. Many studies exploring valued ways of participating, including discourse practices within classroom settings (Engle & Conant, 1998; Herrenkohl & Guerra, 1998; Rosebery & Warren, 2008, Rosebery, Warren, & Conant 1998). These provide insight into how children and their teachers have engaged in shared intellectual journeys within classroom contexts. The current study provides insight into the interactions among emergent bilingual kindergarten children who engage in cognitive work using a variety of tools, representations, and communicative methods to share and revise ideas.

The design of this study emphasizes talk in social contexts, which centralizes discursive practices within the community as a foundational element for individual and collective learning (Vygotsky, 1978). In addition, the design of the curriculum was situated within a scientific phenomenon on playground slides (Greeno & Gresalfi, 2008). In this study, the materials and intellectual resources occur within the scientific modeling process where children’s ideas and models are being actively shaped, reshaped, and supported by tools, representations, ideas, and shared languages. Learning within the modeling process is bound up in activity that provides students with varied opportunities to learn, to actively change ideas, and to meaningfully engage in a nurturing community of learners. The analysis will examine the participation engagements created by focal students as they navigate joint intellectual activity, materials, and information to produce material artifacts and discursive interactions. Participation being defined as diverse (linguistic, cultural, academic) shifts, transformations, or consistencies in an individual’s trajectory between elements of activities occurring over time within disciplinary practices and activities that are valued to a community (Greeno & Gresalfi, 2008; Lave & Wenger, 1991; Rogoff, 1991;1994). A community in which authority figures in the classroom actively problematize the assumption that participation and understanding are solely attributes of the student. This problematizing work will be outlined in the conceptual framing which outlines effective and equitable instructional design, bringing together theories and perspectives that align and support children's engagement in science education from a strengths-based approach.

Conceptual Framing

In this study, I documented how the design elements of the learning environment supported the children as they participated in various kinds of joint work. The five elements (Figure 9) are meant to generously support students as they experience modeling and explanation as a process involving *collective and sustained* intellectual engagement on a complex phenomenon. To design the instructional elements, I started by adapting a framework of principles informed by a literature review and summarized in Windschitl and Calabrese Barton (2016). These were drawn from research studies that focused on science learning in classrooms, and drew upon a subset of investigations that employed well-articulated theoretical frameworks to guide the instructional design, documented learning and the conditions that supported learning over an extended period of time, took learning to be both conceptual and participatory in nature, and attempted to develop student understandings that went beyond the reproduction of textbook ideas (Brown & Campione, 1994; Engle & Conant, 2002; Lehrer & Schauble, 2004; Magnusson & Palincsar, 2005; Metz, 2004; Rosebery et al., 2010; Smith et al., 2000). In these studies, students' ideas became the central focus of discussions and they served as explicit objects of inquiry which could be collectively revised by the learning community (Scardamalia & Bereiter, 2006). This outcome is particularly salient to a vision of teaching for centering cultural and linguistic heterogeneity (Rosebery et al., 2010) within a science classroom as children learn to share and revise ideas for sensemaking purposes.

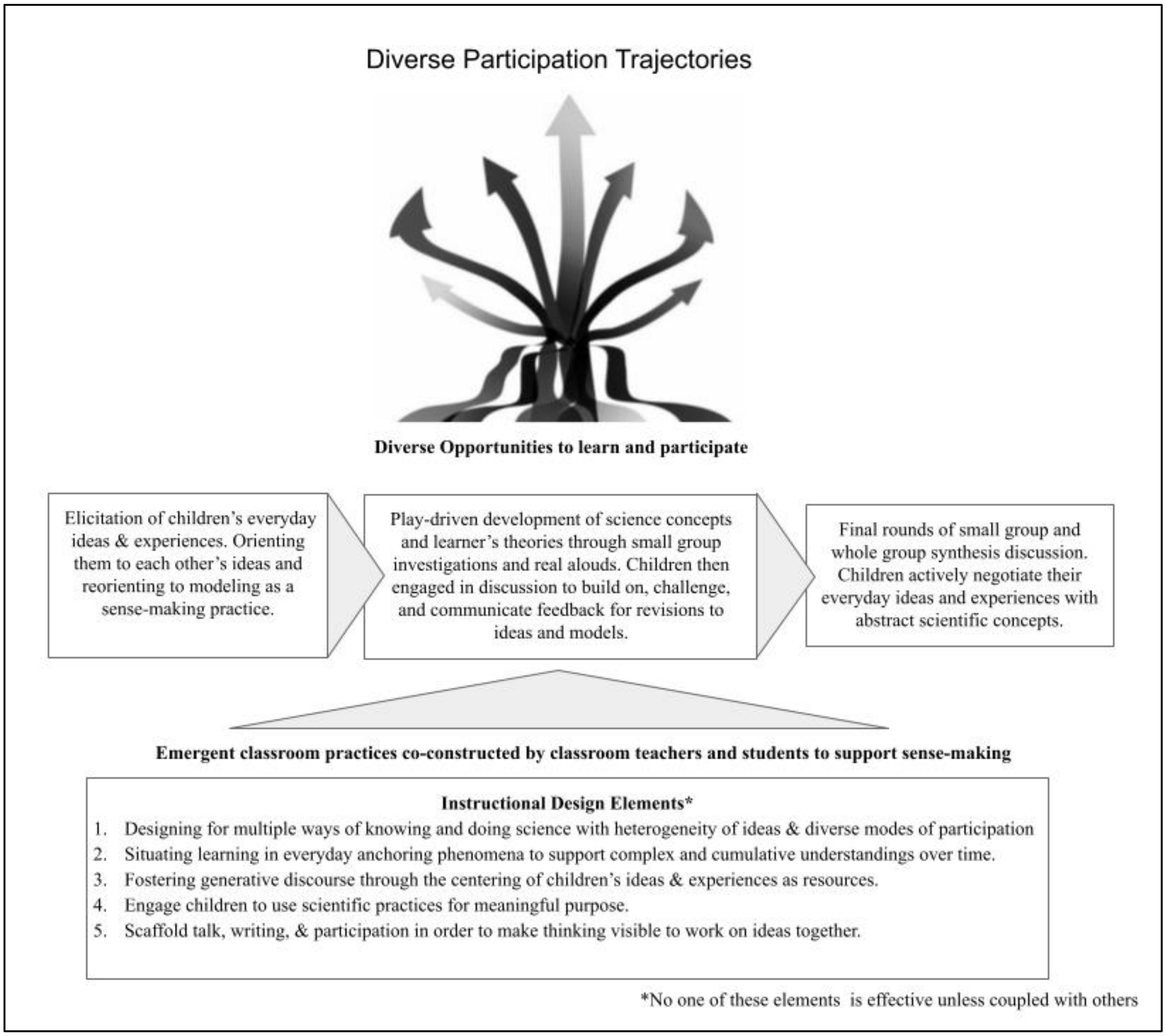


Figure 9. Section 2 Conceptual Framework.

As the community in this study engaged in science learning, there were emergent classroom practices which were co-constructed by students, their teacher, and the instructional coach to support the cumulative development of physics-related ideas and explanations over time. In order to support diverse and dynamic participation engagements, the instructional design elements provided children with multiple and diverse opportunities to interact, rehearse, and learn (Greeno & Gresalfi; 2008) both as individuals and members of a community that values collaborative scientific inquiry (Rosebery et al., 1992). This work begins with different types of discursive interactions mediated by student-generated artifacts such as models. Examples of these classroom routines include the use of participation talk scaffolds (e.g. Discussion Web, Figure 2) and public consensus modeling by children. Such modeling interactions occur both in private settings and across different group structures. Children contribute to the collective endeavor by sharing their everyday experiences and ideas, creating initial, revised, and final models, providing feedback to each other, leading group investigations to collect data, and synthesizing information to create final models and explanations.

Connecting the instructional design elements, participation, and a knowledge building community requires framing as an instructional practice to promote scientific discourse (Engle et al., 2012; Kelly & Breton, 2001). Framing serves to introduce disciplinary specific practices, content, and social expectations to the community as they undertake joint or individual work. Windschitl et al., (2020) articulates that in planning for a discussion rich learning environment, there are strategies for supporting sense-making talk in classroom discussions. First, framing the activity provides active guidance for students in understanding the task, instructions, and expectations. Engle et al., (2012) discusses how teachers can frame for transfer in order for learning to take place, placing an emphasis on expansive framing (positioning students to use what they have learned to participate across spatial-temporal contexts) rather than bounded framing (in which learning is meant to be applied in single or narrow contexts with a restricted set of participants or contexts). Engle et al. (2012) argues that expansive framing results in greater transfer of facts, concepts, and principles from one context to another as "students are positioned to actively contribute to larger conversations that extend across time, places, and people (p. 215)." This positioning connects directly to engaging learners in the meaningful and authentic sense-making work in which students can thrive. The knowledge building community becomes a place where children learn to see their own ideas and the ideas of their peers as not only legitimate but as necessary to building knowledge about science phenomena.

With this design, we sought to encourage and welcome children to pose questions, revise models, and critique the ideas of others as they co-participated with each other. With a focus on co-construction of intellectual relationships, this framework works to leverage and resource the skills, stories, strengths, and everyday science ideas that young learners bring to school (Lee, 2004; Warren et al., 2001). As children share their insights, questions, and wonderings during discussions and investigations, the adults used framing, questioning, and prompting strategies during discussions to validate and visibly legitimize children's contributions (Gutiérrez et al., 1999) to the community. Thoughtful questioning and prompting strategies, remain one of the hallmark principles for fostering productive disciplinary engagement (Engle & Conant, 2002) but situated within that productivity is the need to be mindful that we don't reproduce evaluative discourse practices (Cazden, 2001). And in this framework, I replace the wording of *productivity* to *generativity* in order to support cooperative, positive inter-community relations (Cohen, 1994) focused on rich sense-making discourse outcomes (Noddings, 1989) towards equitable, humanizing interactions. We see that agency, in this study, is constructed through resourcing both heterogeneity of ideas (Rosebery et al., 2010) and a place for participation to occur outside of the traditional lesson boundaries (everyday home and classroom experiences) thereby opening for an expansive view of participation, a space for scripts and counter-scripts (Gutiérrez et al., 1995) so that diverse learning engagements could be dynamically shaped and supported.

This design seeks to cultivate diverse participation through support from the instructional design elements. The design elements aim to foster robust and generative discourse within the community as children's everyday ideas, home experiences, and scientific explanations were centered, elevated, and valued (Moll et al., 1992). But these elements occurred in conjunction with the educators working to actively desettle our expectations (Bang et al., 2012) so that adults work to actively disrupt deficit perspectives and inequities largely created by educators (Buxton & Lee, 2010; Buxton et al., 2013). This desettling work includes science professional development (Amaral et al., 2004, Cuevas et al., 2005) and instructional coaching (Anderson et al., 2014) for educators focused on understanding how to design instruction for multiple ways of knowing and doing science while incorporating children's cultural and linguistic skills as intellectual resources (Lee 2005; Rosebery et al., 1992; Warren et al., 2001). The design elements require that educators teach within an intellectual space ready to interact with children's diverse ways of participation and everyday science ideas then their knowledge and skills can be fully incorporated into the community.

Through the positioning of students as authors and leaders of discussions and use of language development strategies to support linguistically diverse classrooms (Buxton & Lee, 2014) it allows children to see themselves as active participants with multiple opportunities to "join the conversation" across spatial-temporal contexts (Engle et al., 2012; Yore, Bisanz,

& Hand, 2003). The instructional elements afford children the agency to participate within different modalities, across both public and private activity structures such as through gestures, orally, pictorially, and textually (Buxton & Lee, 2015; Rosebery, et al., 2010). In addition, generous opportunities across time and contexts to support diverse student participation cumulatively across the unit and in single points in time. This positioning of children and their everyday ideas as scientific, supports the cultivation of a "culture of belonging" allowing for ordinary classroom interactions and discussions to catalyze participation as different children take advantage of different opportunities to participate. The effect on individual participation may then influence future modes and modalities of participation. Children engaging in this design, would co-construct a series of legitimate ways to participate across both social and intellectual dimensions using increasingly more sophisticated modalities (Lee, 2002; Lee & Stevens, 2020). And yet children's choice and agency of when, where, and how participation will occur is still unpredictable and spontaneous in nature, characteristics embraced by this design (Gutiérrez et al., 1999; Lee, 2005). Taking this framework into account, my hypothesis is that when provided with a learning environment that integrates these core instructional design elements, emergent bilingual kindergarten students will resource a variety of opportunities in which they can learn to participate and participate to learn.

Methodology

Participants and Context

This is a qualitative multi-case study and utilized purposeful sampling to select one classroom of learners and the classroom teacher, which represents a bounded system (Merriam, 2009). This study features a kindergarten classroom taking up the "Forces and

Motion: Exploring physics through playground slide collisions" unit, which took place during spring quarter. The unit goals were to 1) support students' diverse participation in an intellectual community in which they contribute ideas and those ideas can be commented on and change over time; 2) use everyday and scientific ideas about force and motion to model, revise, and explain a complex everyday phenomenon; 3) support students' growth in disciplinary specific practices through diverse opportunities to participate.

I selected a classroom site that provided an information rich case setting (Merriam, 2009). The teacher, Ms. Takeoa, was selected using criterion-based sampling (Merriam, 2009), she had involvement in participating in job-embedded instructional coaching support and participation in three professional development workshops and weekly instructional coaching support during science for nine months prior to the start of the unit of study for this research. These coaching sessions included live support during instruction and debrief reflection. My role within this classroom setting is as an instructional coach with basic bilingual language skills (Spanish). In addition, I hold the responsibilities of sole researcher, curriculum developer, and professional development provider. I conducted participant observations for 9 months in a class taught by Ms. Mae Takeoa*. This classroom was the second of four cohorts I researched over the course of four years. During the data collection, I continued to perform my role as an instructional coach. In addition, I documented my interactions, personal observations, emotions, to understand how my personal responses may shape the process of making observations and recording the lived experiences of the participants (Emerson et. al, 2011).

I conducted interviews with Ms. Takeoa in order to support the focal student selection process. We selected these students based on their wide range of participation styles and assessed final models from an earlier modeling unit on puddles. We wanted to make sure that the instructional design framework could meet the needs of a variety of students and afford opportunities to learn for a range of participation styles. All student participants showed a willingness to be interviewed and filmed. The school labeled these focal children as English Language Learners but we will continue to use the term emergent bilingual. All three focal children primarily spoke Spanish at home with their families. During this study the focal children received additional support in English and had a middle to higher range of English proficiency. These children contributed to whole group discussions in English and often used both Spanish and English in small group discussion and student-led investigations.

Maria is one of the older students in the classroom being six years old. Her family primarily speaks Spanish at home. In a previous unit on puddles, Maria participated across whole group and small group discussion and shared ideas with others when prompted. Maria is described by her teacher as focused and on task during class and does not need reminders to follow classroom norms or rules. Raymundo is also six years old and his family primarily speaks Spanish at home. Raymundo regularly participated during class science discussions vocally and publicly shared his everyday and scientific ideas and explanations during the puddles unit. Raymundo's teacher described that writing (forming words and sentences) was challenging and he was referred for special services by the end of the year. Clementina is the youngest student in the class having turned five years old in August. Clementina's family only speaks Spanish at home. Clementina's mom describes her as "siempre observando, siempre mirando y pensando en las cosas, y le gusta estar en movimiento" (always observing, always looking and thinking about things, and she likes to be on the go, moving around). Clementina attended a bilingual preschool for two years with the majority of the instruction taking place in Spanish and had very much looked forward to starting "real" school like her older sister. During the previous unit on puddles, Clementina raised her hand often during whole group discussions but when she was called on she often did not share any ideas verbally.

This study was conducted in a Title 1 elementary school within a progressive urban school district. The school's demographic composition: 39% Transnational Bilingual; 56% Hispanic/Latino, 21% Asian, 7% African American, 9% white. In addition, the school had 80% Free and Reduced Lunch student population. The selected class had 27 students, with 24 students coming from bilingual families; 19 students were from Spanish speaking households. A majority of the students in this classroom were part of families from Mexican, Guatemalan, and El Salvadoran immigrant and refugee communities. This school identified emergent bilingual students through family intake forms and offered English Language Learner pull-out programs for students. This classroom utilized a bilingual paraeducator for 1-2 hours per day several times per week. The target classroom is filled with round student tables, bookshelves and a small-carpeted area where the majority of student discussions take place. A typical day includes whole group instruction while students are seated on the carpet while their independent work time is dedicated to working in their seats surrounding the large round tables.

The "Forces & Motion: Playground Slides" unit was designed using a situative perspective (Greeno & Gresalfi, 2008), with a sequence of activities that affords both discussion and use of conceptual ideas and methods that became more advanced over time. The phenomenon "playground slide collisions" is grounded in children's everyday experiences at school and home communities (Lee, 2019). This unit utilizes an interdisciplinary approach to include math and language arts, and group investigations. In addition, interactive science read aloud books are consistently used to illustrate concepts, narrate concepts through everyday human experiences, and resources as evidence for discussions. Lessons are anchored around student talk and models with beginning and ending discussions lasting up to twenty minutes each depending on the number of children who are participating.

We positioned language diversity as a classroom norm, provided dual language visual representations of concepts, and encouraged children to sense-make in the language of their choice with their self-identified friends during discussions (Gutiérrez et al.,1999). During our science discussions, students engage in whole group talk, partner-talk, student-teacher talk, or independent think time and their responses are usually recorded on chart paper that has been organized around a central question or topic for each particular lesson. Next to recorded student responses are student names, used as a method to build student ownership of ideas (Engle & Conant, 2002). In addition to discursive practices, students come to the board to publicly and collectively create consensus models, draw out examples of ideas on chart paper, or use individual student models to foster discussion. Children's stories, everyday ways of understanding the world, and even imagined play scenarios were elicited to transform science discussions into engaging opportunities to learn. These examples of the kinds of experiences and engagements children participated in which exemplifies the logistical work of the instructional design elements (Figure 1) that was used to work towards a transfer of the intellectual work from teacher to student (Herrenkohl & Guerra 1998).

Data Sources

The data corpus includes lesson transcripts, student and teacher interviews, as well as student artifacts. All twelve lessons were video recorded and transcribed (Derry et al., 2015). In addition, due to the nature of some children's participation occurring outside of the traditional lesson boundaries, the cameras continued recording while children were transitioning to other activities such as recess, lunch, or specialist classes. On occasion, children would ask to stay in from recess to continue doing science and in these instances, with teacher approval the cameras also recorded these conversations and interactions.

Children engaged with the instructional coach as a member of the community increasingly over time (Rogoff, 1994) both within and outside of science lesson time and these interactions were also recorded and transcribed. The recorded lessons captured both teacher and student talk during instructional times, transitions, and related events during non-instructional times. Discourse occurred in whole class discussions, small groups, pairs, and one-on-one with the teacher or the instructional coach. I followed video analysis protocols recommended by Derry et al., (2010); videos were transcribed in full. Videos and transcripts were examined for themes within the activity system 1) Student's ideas, experiences, and interactions with each other 2) Students working with models and ideas individually 3) Consistencies and changes in the participation attempts, mode of participation, and mediating artifact by focal children. I was attuned to the importance of producing transcripts that reflect the research goals for this study (Ochs, 1979). Transcription occurred in a four step process; 1) verbal communication from 12 lessons was transcribed and coded including gestures (Alibali & Nathan; 2012) events of critical significance were transcribed using Ochs' (1979) conventions incorporating verbal and non-verbal data 3) Several transcripts were selected based on a timeline during the unit to utilize data from the beginning, middle, and end of the unit 4) Transcripts were chosen for this paper to demonstrate the diversity of ways that the students interacted with models and representations and shifts in engagement with models.

Analytic Methods

A time-ordered matrix was performed and analyzed on the three focal students (Miles, Huberman, & Saldana, 2014). This matrix included participation data from each student during different activity structures (whole group talk, small group talk, partner talk, student initiated talk with an adult, adult initiated talk with a student) during each of the 12 lessons. This matrix was used to distinguish participation trajectory similarities and differences between the focal students in conjunction with corresponding elements of the designed learning environment. Using the entire data corpus, I developed a set of codes from the literature, some being focused around participation (Herrenkohl & Guerra, 1998), productive talk (Engle & Conant, 2002; Rosebery et al., 2010), elementary science engagements (Manz, 2012; Montiera, Jiménez-Aleixandre, 2015; Montiera, Jiménez-Aleixandre, Samarapungavan, 2020; Samarapungavan et al., 2015) gestures (Alibali & Nathan, 2012) and learning progressions of modeling (Schwarz et al., 2009). I added codes later that were emergent from the data during the analysis phase and that I felt might have explanatory significance. I used segmented transcripts to test the applicability of codes and tied closely with the conceptual framework. From the coded transcripts I developed themes related to the elements, actions, ideas, and artifacts that students were generating or creating during different phases of the unit. These themes were used to develop hypotheses, which were then tested against additional passes through the data.

Kindergarten Physics Unit

Throughout this unit students participated in the multiple and diverse opportunities to engage in the science and engineering practices (NRC, 2012). The disciplinary core ideas and crosscutting concepts within this unit focus around interactions, relationships between energy and forces, defining engineering problems, and the causes and effects within forces and motion. Throughout this unit students were engaged in the science and engineering practice (NRC, 2012) of scientific modeling, which incorporated both student technical drawings paired with explanatory talk. The disciplinary core ideas and crosscutting concepts within this unit focus around interactions, relationships between energy and forces, defining engineering problems, and the causes and effects within forces and motion. The two performance expectations (Achieve, 2013) are as follows:

- Students will plan and conduct an investigation to compare the effects of different strengths or different directions of pushes and pulls on the motion of an object.
- Students will analyze data to determine if a design solution works as intended to change the speed or direction of an object with a push or a pull.

These performance expectations were assessed using students' scientific models, but assessment is not part of the data analysis in this paper.

Findings

I organize these findings by focal children's participation across a unit of instruction. The broad findings explore 1) how children used opportunities to learn and participate in different ways and 2) highlight particular relational routines, activity structures, and discourse norms supporting focal students to develop generative and equitable ways of talking together about science ideas in planned and unplanned ways. In these excerpts we explore both individual focal participation and their interactions across a range of discussion and activity structures.

Beginning of the Unit

During the first moments of this unit, children watched with laughter and surprised expressions as their teacher quickly moved down the playground slide and sent the stuffed animal flying into the air as she was the first to demonstrate the phenomena they would be studying (Figure 10). All the children then took turns down the slide, bumping the stuffed animal. Children also were actively making observations and creating (comedic) commentary in Spanish and English as their classmates all went down the slide. Playground slide experiences were designed to allow the community to collectively experience the phenomenon through embodied action in order to be able to make thinking visible to create an initial model. After this outdoor experience children independently created their initial

Figure 10. Collective Playground Slide Experience.

models and then shared them publicly with each other and asked questions about particular modeling features. During these first four lessons, children were being socialized to engage with science practices utilizing partner talk, small group discussions, and public conversations with the whole class. During discussions, students' ideas and experiences were recognized using their magnetized photos to mark their contributions during science discussions. These ideas and partial understandings were treated with equal status of science ideas, and became, themselves, objects of inquiries. A discussion tool (Figure 2) as introduced at the beginning of the unit in order to mediate participation and to hold the adults accountable for monitoring participation and ensuring that children had opportunities to share, listen, and respond to the ideas of the community.

During the first four lessons of the unit, focal children all participated in partner talk, small group, whole group discussions and activities. However, the ways in which they engaged in discussions and activities was different. There were situational differences across focal participants as the contexts of participation enabled or constrained their ability to engage as central actors during discussions and activities. As we explore the narratives of each focal student in the beginning of the unit, details about learning conditions are interwoven throughout in order to provide a contextual frame for the experiences of these children. Clementina's participation trajectory shifts over time as she resourced representations and initiated opportunities to discuss ideas with adults occurring outside of the science lesson schedule. Maria participated consistently throughout the unit and conducted investigations at her neighborhood park to explore thought experiments. Raymundo relied on the role of an audience to engage in public sense-making and modeling to spontaneously produce dynamic conceptual innovations.

Clementina

During the beginning of the unit we saw Clementina engage across a range of activities through both adult-initiated prompting and learner-initiated participation. Clementina appeared hesitant to speak in whole group and one-on-one episodes. When she did speak her voice was often barely audible. Clementina's modes of participation, however, shifted and transformed across the trajectory of the unit, as will be illustrated throughout these findings.

During the first lesson, children were asked to share slide stories and experiences in a small group rehearsal prior to a whole group share out. During the small group discussions both the teacher and the coach traveled from group to group listening to children, working to identify everyday stories from their home experiences. We wanted to center stories from outside the classroom in order to support the conceptualization of science ideas as existing in places such as home and community settings or beyond. During small group talk, Clementina shared a family camping story about a slide she described as "big" and "fast." She was asked by the teacher to share this same story in a whole group setting. In this excerpt we notice some initial hesitation to share out a story previously rehearsed in a small group. But this hesitation provided adults with an opportunity to exercise solidarity with Clementina by exhibiting visible support, wait time, responsive dialogue, and ultimately public idea elevation.

> Ms. T: So friends, we were talking about the slipperiness of the slide, Clementina can you share what you talked about with your group?
>
> Clementina: (no response)
>
> Ms. T: (wait time 3 seconds)
>
> Clementina: (no response)
>
> [Coach provides additional prompting but Clementina did not respond. Coach asks Clementina to share the specific camping story from her small group to which she responds].

Clementina: (barely audible) I went down a big slide and I went super fast.

Ms. Takeoa then revoiced the story to the class and made two different attempts for Clementina to elaborate on her story, "What did you say it made you do?". But Clementina's voice volume remained inaudible. Instead of putting the responsibility on Clementina to speak up, Ms. Takeoa responded by sharing the responsibility to listen among everyone in the community:

> Ms. T: So, when one friend shares [gestures to Clementina with her hand] your job, remember [points to class norms poster] is to listen when someone is speaking. And some friends have a really quiet voice, so you have to be really really good listeners.

Despite this initial hesitation, she shared a story with science ideas across contexts (e.g. family camping, classroom). We see that in addition to revoicing, the teacher names the expectation of the community to listen as a "job" in response to the differing voice levels of the community members and this positions moves to build a particular kind of community culture. This framing was intended to set a foundation for the community to accept and legitimize different ways that children may engage in discussions (e.g. quietly, assertively, hesitantly). Despite the quietness of Clementina's contribution, her "big slide" and "I went super fast" idea was then taken up by peers and referred to in discussion for several minutes. It was also referenced in future discussions.

Several days later, in lesson two, we saw a similar whole group interaction as all children took turns sharing their initial models with the whole class. Clementina shared her observations about a cause and effect relationship in a voice that was again barely audible: "so if you put the bear on the slide, [pointing to model] and then you go on the slide and then you go down the slide then the bear falls down". The community responded, adding ideas about "slippery slides" and the effect of "wet slides" on speed. Clementina, for the first time in whole group discussion, responded to the ideas of one of her peers by quietly stating "The bear is going to fall down from the slippery". The coach responds to Clementina's comment as an opportunity to highlight that children's ideas are essential and support one another:

> Coach: The bear is going to fall down because it is slippery. So, Clementina added on to Carlos's idea and ideas can be connected and *todos los ideas son importantes,,* all of your ideas are important. So sometimes your ideas can be connected.

This was an attempt to elevate Clementina's ideas and create an early invitation for joint activity, an invitation to recognize everyone's ideas are worth considering and that the community can build ideas together.

Interestingly, Clementina then attempted to continue to engage in sense-making talk, after the traditional scheduled lesson time had ended. After the end of the lesson, children were getting ready for recess and Clementina approached the teacher, saying "Ms. Takeoa, on the slide, the first thing I wanted to tell you—", but the commotion of children gathering coats drew Ms. Takeoa away from responding to Clementina's slide ideas. It would not be the last time that such an event would occur.

In lesson three, the coach initiated an independent modeling revision check-in and Clementina hesitated again to share ideas; she paused for long periods of time while holding the floor, occasionally failing to respond, even as the coach and teacher used extended wait time in order to stimulate dialogue. In this one-on-one excerpt, Clementina's hesitates to respond to the coach's questions:

> Coach: So, you wrote "push" right here Clementina [pointing to her push label on the model], can you tell me why you put that there?

Clementina: [pause, no response]

Coach: Is there a push at the bottom of the story? When you were going down the slide and the bear was at the bottom? Was there a push?

Clementina: [nods head yes]

Coach: So, tell me about that push [pointing to the bottom of the slide].

Clementina: [Clementina puts the pencil in her mouth, leans back in her seat, away from the coach, no response]

Coach: What happened when you went down the slide?

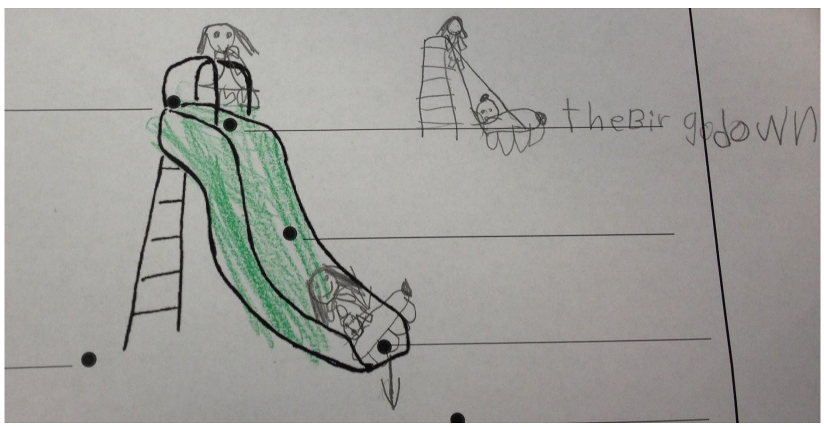
Clementina: (5 second pause) Mmm:: the bear fell down because we did a push.

In this talk episode we notice Clementina literally leaned away from the coach's puzzling attempt to generate conversation around the "push." After the coach rephrases the question Clementina replied by again, articulating a cause and effect relationship that occurred during the slide simulation.

In the beginning, the teacher and coach recognized Clementina's unique participation which included hesitation, quiet voice, and her ideas as opportunities to communicate through framing with the classroom community social expectations, personal responsibilities, and the importance of sharing and building on ideas and stories from children's home lives.

Maria

In contrast to Clementina, Maria raised her hand only a couple times per whole group discussion but often added onto ideas previously shared. Maria added on to the ideas of others, and this was done largely without intervention from adults. Maria participated across all the discussions and activities in the beginning of the unit, she shared ideas and stories and created an initial model of the playground slide simulation. Maria's initial model (Figure 11) incorporates her simulation experience as she includes herself and the bear being pushed down and included a symbol (arrow). Maria was one of two students in the class who drew a second slide in addition to the slide on the model. Maria shared that her hand-drawn slide was “steeper” and to show that the “bir go down” on a big slide as well. During lesson one, Maria shared her model in a one-on-one setting with the coach and responded without hesitation to questions about her inscriptions (bear, person, arrows) that she included in her model. Jackie also used gestures to locate her talk in the model “[points to the top of the



slide] you go down then [slides finger down the slide to the bottom] you push it”. Later during lesson two, in a whole group setting, Maria chose to speak about her modeling inscriptions with a class of her peers using a barely audible voice she described that she used an arrow to show that “the bear fell off the slide”.

Figure 11. Maria’s initial model.

The teacher then revoiced so that everyone could hear this idea. Maria’s choice is important to note because it is early in the unit and Maria’s decision to attend to modeling inscriptions with an audience of her peers indicates that inscriptions such as color and symbols are focal points of interest for young children. Immediately after Maria shared her model, the coach then emphasized Maria’s ideas and a focus on the arrow as a particular drawing convention to consider in a model.

> Coach: So, she wanted to show that the bear fell off the slide, so she put an arrow. Did anyone else do that on their picture and she even *wrote*. In science you can also write your ideas. You don't just have to draw them.

This elevation of an idea was done to support the framing of modeling activity was an essential instructional strategy. The teacher and coach were consistently framing the connections between different science concepts because we wanted children to notice and take up some of these ideas in their talk or modeling inscriptions.

Towards the end of lesson two, after children shared their models, they then gathered into small groups to engage in conversation about potential places that they could locate pushes or pulls in their models. As the coach approaches a small group (Maria, Yereli, and Clementina) and asks them in Spanish "Where do you think there are pulls in the slide event?" Notice how children, including Maria, eagerly responded with different linguistic and gestural modalities.

> Maria: Yo se.- (I know.)
>
> Yereli: -Yo sabo.- (I know.)
>
> Maria: -A donde estar las escaleras [gestures with hands to show pulling up the ladder]- (Where the ladders are.)
>
> Clementina: Yo pienso cuando te vas a levantar, yo pienso um, um, a bajo de las escalera um puedes um [gesturing a pull with arms] (I think that when you are going to lift yourself, I think that um, um below the ladder um you can um)
>
> Coach: Jalar? (Pull?)
>
> Clementina: [nods head yes]

In this excerpt, Maria shared her ideas in Spanish and gestures to demonstrate the concept in action. What is significant about this short multimodal exchange is the multitude of translanguaging demands that Maria and other students engaged with, in order to engage in small group talk in a language of their choice. Some of these demands included Maria and others listening to directions in English, discussing ideas in Spanish with their small group about locating pushes and pulls in a model, and demonstrated through embodied action (gestures) where they experienced these concepts on the actual slide. These children engaged in the shared generativity and multi-modal participation in a small group and their participation (linguistic, gestural). This kind of small group dialogue occurred across the unit with focal students as they were observed to translanguage to communicate their thinking in response to questions from both adults and their peers.

In lesson three, children then were asked to trade their models with a partner and offer revision suggestions using labeled sticky notes. In figure twelve, we see two models from Maria and Clementina with revision suggestions labeled “push” and “pull”. Notice the drawing on the left, Maria did not include concrete objects and instead focused on conceptual labeling. On the left, we learned from a student interview that Clementina’s model shows a time lapse drawing of a friend “Kazzandra” climbing the ladder and traveling down the slide. After Clementina and Maria gave each other back their models, we observed Maria wrote a “push” just above the peer revision suggestion (blue sticky note) at the bottom of the slide. Revision for Maria in this instance occurred naturally and without direct teacher prompting. Clementina did not incorporate any revision suggestions on her model.

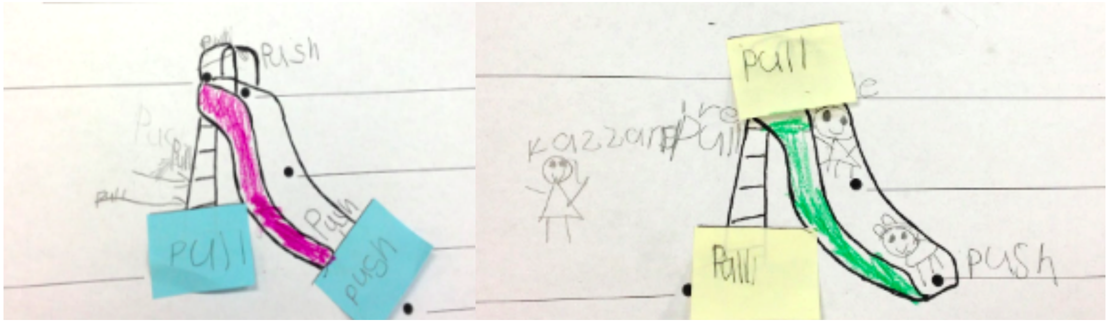


Figure 12. Partner Revisions with sticky notes. Maria (right) and Clementina (left).

In addition to sharing ideas in small group discussions Maria would initiate participation by adding on to the ideas of peers. This occurred in many whole group discussions, one example during a lesson four whole group discussions such as “Slides are ramps, I agree with Melissa” and projected her voice across the classroom. By lesson four, children began integrating scientific ideas about concepts into their everyday talk such as in a conversation between Maria “Slides are like ramps” and with her self-identified friend Clementina “I am thinking about a, a mountain and a ramp that I draw and also [gesturing with pencil down the slide ladder] ladders are ramps.” During this brief exchange, we see these children take up physics conceptualizations of ramps using Euro-Western conceptualizations and generalize the concept of ramps to three different but everyday examples.

Raymundo

Raymundo’s participation is slightly different than Maria and Clementina across the first four lessons. In the beginning of the unit we see Raymundo participating publicly in whole group discussions with a robust voice as well as readily communicating ideas with others in small group and one-on-one settings. In addition, he responds immediately in conversation with his peers and adults, particularly after being prompted to describe his ideas or his model. Raymundo stands at the front of the room to share ideas with others and relies on an audience (of any size) to communicate and mediate his thinking.

Before Raymundo began to model on his paper, he began using the blank model to communicate ideas with the coach. After he has drawn his ideas into the model, he used it in the same way to anchor his thinking as he shares aloud his ideas, this example occurred in lesson two during a one-on-one check in with the coach, Raymundo used gestures to locate his talk within the model and makes a choice to describe his arrows as a modeling inscription to represent the bear being pushed down:

> Coach: So, tell me about your picture.
>
> Raymundo: [points to a little slide he drew] I was, I was going down and um [points down the little slide] and I made arrows to (slides pencil down little slide to the bottom] to push it down [sweeps finger off quickly to indicate a push].
>
> Coach: Okay, so the arrow shows something going down and then.
>
> Raymundo: [points to the bottom of slide with pencil) And then I dropped it down. I bumped it...and when it, when [points to drawn slide and sweeps finger down the slide] when you go down the pressure of your shoes makes it hard, so you can [sweeps middle 3 fingers down the slide] so you can push it.

Raymundo included the word “pressure” to make attempts at describing this cause and effect relationship between the “pressure of your shoes” and the effect on the bear. During conversations with peers and check-ins with adults, Raymundo used the model to gesture and communicate ideas. But in addition to access, he had time with an adult to share the meaning of his inscriptions and begin to create explanations about the simulated phenomenon. In this excerpt we saw how Raymundo used the model conceptually to share ideas and gesturally in order to demonstrate concepts such as motion and direction. During lessons in which students did not add or revise to their individual models, the class model was always displayed on the board and remained a place where children could continue to anchor ideas, gestures, and stories. Models served as an anchor and provided opportunities to locate gestures and talk for all of the focal students at the beginning of the lesson.

In a lesson three discussion children were sharing ideas about forces and began to brainstorm different examples of forces through joint work. In this example we see how Raymundo listened to the idea of one of his peers and then extended on their idea during a whole group discussion:

> Kaia: What else is a force?
>
> Melissa: Any moving thing.
>
> Coach: Any moving thing? I wonder about that one.
>
> Raymundo: When you push a ball, you use a force. When you push it slow it will stop. If you, like, stop it and you push it again- something makes it stop because it is a force.

Raymundo elaborated on the idea of force by introducing a concrete example and initially he was in agreement initially with Melissa, taking up her statement and elaborating on the idea of motion. But he then introduced a new idea and differentiated between pushes to start and pushes to stop. In Raymundo's talk both kinds of pushes seem to be forces. The teacher recorded the student's ideas on chart paper, "Okay I am going to put pushing and stopping [writing on the chart paper]." Additional prompting questions are attempted to allow children to extend their thinking:

Coach: So, you are using a force, yeah? When you are pushing and stopping? Melissa was listening to Raymundo, Melissa what did you just say?

Melissa: If you, normally when you kick a ball, normally when you kick all, normally either if it's fast or slow kicking, slow still makes the ball move because it is kicking because kicking makes things move.

Coach: So, kicking, we can put that up there (Discussion Web). I like that she was listening and then she responded. So, I would put her name next to adding on to Raymundo's idea (magnet faces), we can use each other's ideas to think about new things.

Melissa then incorporated different strengths of pushes "fast or slow" as she started talking about different kinds of force application. In this instance, we want to remember that the sense-making that is occurring is about an abstract concept and elaborating on it or differentiating between variations on it, which Raymundo and Melissa are both generating. Raymundo elaborated on the basic definition of what is a force and he is adding more nuance to the idea of force as moving. So does Melissa after Raymundo's comment and she took up his example and extends it further providing the community with additional information to consider about forces (slow kicking and fast kicking). This conversation is a typical exchange that occurred within the knowledge building community and was one of many which have the cumulative potential to enable additional conversations about how we are understanding how forces work in everyday events.

During his interactions with the coach Raymundo used specialized science terminology such as "pressure" and fluidly innovated on his ideas and on the ideas of others in public discussion spaces. Raymundo initiated participation across different settings and responded to questions and prompts with extended utterances. Raymundo seems to readily be *playing with* science ideas whether he is holding up a blank science model to exchange dialogue or extending ideas and offering examples to explain his thinking.

Middle of the Unit

Over the middle of the unit, Raymundo continued to innovate on conceptual ideas in very public ways, Jackie took ideas from school and experimented at home, while Clementina engaged robustly in small group investigations and conversations, but not in whole group. The middle of the unit combined a series of lessons focusing on conceptual development through hands-on investigations, interactive read aloud lessons, whole group consensus modeling, and discussion rich opportunities to share ideas. In small group investigations children worked to manipulate materials and variables to create and record data. Children engaged in informal conversations in small group settings as they explored concepts through hands-on investigative trials. They then used this data to make claims with evidence during whole group discussions. Investigations enabled children to see and discuss cross-cutting concepts in action as they observed the effect on the distance a cup could be pushed using different variables that supported talk and thinking around cause and effect, energy, and scale, proportion, and quantity. During this time children were also utilizing text from read aloud books and a variety of modeling opportunities to use during sense-making discussions.

Lesson five was the first of a series of investigations in which children worked jointly in small groups to take turns manipulating variables, recording data, and sharing ideas and observations. Again, the teacher provided framing for children during the initial demonstration and discussion prior to the group investigations. An important point is that

Ms. Takeoa transferred children's ideas *into* her framing such as in the upcoming excerpt when Raymundo's earlier assertion about forces was included for the whole class. The teacher worked to make visible the connections between activities explicit parts of the instruction as the classroom community engaged in what sounded like "joyful blurting" of a focal science concept:

> Ms. Takeoa: So today we are going to do an experiment that will link our ideas about a ramp. We have our ramp and then we have our ideas about the pushing with the bear and the pulling. We are going to link all of these ideas with the experiment that we will be doing today. So today I am gonna read just a little bit of this (holds up book about forces) to get our brains warmed up okay.
>
> Class (blurting in unison): Force!
>
> Ms. Takeoa: Good remembering! Forces get things moving. Forces also make things stop. Forces also make things speed up or slow down. [read aloud part of the picture book on forces] So I just wanted to read that to remind you that pushes and pulls are forces and that forces can make things go, but also make things stop. Now we have to really be thinking about our special science words and I am going to add a special science word up here [pointing to the force poster].
>
> Class: (blurting in unison) Force!

After the framing, demonstration of how to set up materials, and questions were asked and answered, children went into different locations around the classroom that were set up with a stack of materials for each group during lesson five.

Next, we look more deeply at excerpts from focal students as they participated in investigations and whole group synthesis discussions to first work through procedural challenges and later engage in conceptual understanding. Transcripts feature focal students individually participating in activity and co-participating with peers or other focal students.

Clementina

During the middle unit lessons, Clementina does not raise her hand during whole group discussions and had withdrawn from whole group participation attempts. But Clementina consistently participated in small group structures. Clementina's utterances increased over time during small group discussion as she shared responses to her peers, one of many examples are when children are discussing concepts they see outside of the classroom "Did you know that a road can be a ramp?" and Clementina responded in agreement " Oh, oh in my house when we go down the hill but it's a ramp road".

Across the investigations many children were supported by the use of the visuals in the data collection worksheets, Clementina consistently referenced these worksheets.

Figure 13. Small Group Investigations, Data Collection Worksheet.

Sometimes she was able to reference the worksheet visuals (Figure 13) to persuade her group to follow specific directions such as how many boxes to use to make a steep ramp or how many cubes to put in the cup to add weight. In addition, Clementina also referenced the materials in the investigations and used the material objects from investigations to explain ideas about energy, speed, and distance.

In lesson five, small groups of children investigated the question "How far does the ball push the empty, half-full, and full cup?". Clementina's group initially had trouble taking turns with materials, so the coach approached the group to check in on them and provide support with the *procedural* aspects of the investigation. Children needed to create a full weighted cup with cubes and are deciding on an exact number to add, Clementina counts in Spanish " Uno, dos, tres, cuatro, cinco, seis, siete, ocho." The coach asked them to count the number of cubes that it takes to fill the cup half-way full. After that counting Clementina notices that the number of cubes in the worksheet visual is different than what it takes to fill up the cup "Si, pero aqui hay muchos." (Yes, but here there are many.).

Maria: Ready, set, go. [ball is released and rolls down the ramp]

Coach: Okay, what do you think? Que piensan?

Maria: No se movio. (It didn't move)

Coach: No se movio mucho? Y, what are you going to write then? (It didn't move much? And,)

Clementina: Estaba aqui y se movio aqui un poquito. (It was here and it moved here a little.)

Coach: Un poquito? Okay, nada mas? Un poquito? (A little? Okay, nothing more? A little?)

Yereli: Si, luego cuatro. (Yes, then four)

Coach: Okay so cuatro (four).

Clementina: Is it a lot?

As this small group counted the distance the weighted cup was pushed by the ball, Clementina stopped to ask about the measurement amount and if it was "a lot" of distance to be pushed. After a couple of minutes of discussion, the group decided that they would know once they finished and measure the empty cup and the full cup.

One of the supportive learning conditions that took place in this excerpt was time spent being supported by an adult to overcome procedural difficulties to begin thinking about what their observations mean in relation to the focal question. In addition, the coach both asked questions and responded to children in both English and Spanish as all members of the group were from Spanish speaking households. The use of Spanish and English was used not only to communicate in the home language of the children, but to support the preservation of their emergent bilingualism, and to establish a culture of linguistic freedom in sharing science ideas as the coach often said to the class "*Science is done all over the world in many different languages*."

In this next small group transcript excerpt from lesson seven, we see Clementina, Maria, and Marisol engaged in an investigation designed to support students in making direct observations of a cause and effect phenomenon resulting in a ball and cup collision. The focus for this particular lesson is to determine which ramp height allows the ball to push the cup farther, with data being created as students measure the distance a cup is pushed when a ball is rolled down a shallow ramp and a steep ramp. The ramp served as a representation that can be manipulated by students to demonstrate the concepts they have read about and discussed in previous lessons.

In this transcript segment, Clementina was working in a small group with three of her self-identified friends, all of whom speak Spanish, to build different sized ramps and test the effects of how far the cup is pushed. Ms. T joins the group on the carpet and sets the expectation for considering conceptual ideas within the experiment by saying "Okay so remember we are thinking about energy so which ramp do you think has more energy."

Maria then physically used the ramp in her response with Clementina supporting her idea:

Maria: The tall one [lifting the ramp to show the tall ramp]

Ms. T: How do we know it has more energy?

Clementina: Because it is more bigger and it makes it slide a little farther.

Clementina's response to Ms. Takeoa's question, used data as evidence from previous trials that the cup is moved farther away from the ramp "makes it slide a little farther" to support the claim that taller ramps have more energy.

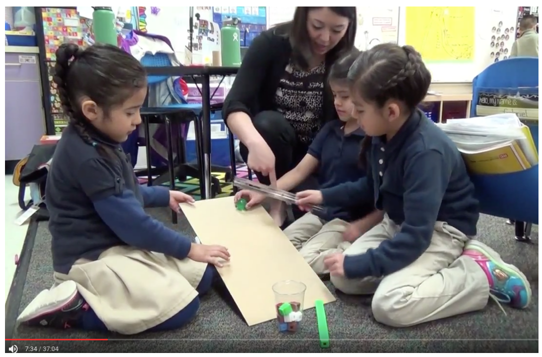


Figure 14. Small Group Investigation.

Ms. T: it makes the cup slide farther

Maria: and the little one like this [moves ramp to a shallow position]

Clementina: I am going to try and do it like this [moves ramp to demonstrate]

Marisol: it didn't work because it was too low

Marisol and Clementina then used a combination of gesture and talk to communicate that there is a connection between the ball having energy and the height of the ramp's boxes. They make continued attempts to provide ideas to engage in scientific thinking.

Clementina: [takes the ball from the Ms. T's hand] It has energy because it's round [rolls the ball between her hands].

Clementina then is seen holding the ball as she articulated that the shape of a ball is a reason that a ball may have energy. Her reasoning connects to the scientific principle of rotational kinetic energy of round objects. Student contributions and responses to adult initiated questions often took the use of materials for demonstration in this excerpt. Learning environments in which children can materially handle and manipulate during discussions enabled focal children in this study to further explain their understanding in both talk and demonstration.

By the end of the middle phase of the unit, Clementina had not yet taken up public modeling and her verbal participation during whole group discussions decreased during this phase of the unit. During lessons five through nine she was observed to be consistently and intently looking at the speaker and transferring information from whole group discussions into settings which included partner talk. She was also observed using materials from the physical representation to explain conceptual ideas and specifically, she is observed to have engaged and contributed in every partner talk opportunity. In addition, Clementina is observed to have identified and corrected procedural problems and manipulates variables to create specific conditions to generate data as she refers to the ideas of others. This evidence indicates that she participated by listening during whole class conversations in order to be able to participate verbally in partner talk and small group investigations. She is participating in different but generative ways in a small group with materials in this phase of the unit.

Maria

Maria continued to initiate participation in discussions and investigations across lessons five through eight and shared rich contributions, one example which will be shared in this section. Maria worked collaboratively with her small group doing investigations and consistently engaged in whole group and small group talk in response to sense-making talk about connecting conceptual explanations to the model. One example happened during lesson five as she described the ball going down a ramp and replaced the word hill for ramp, "the hill makes it go faster." There are several instances where Maria interchanges objects (e.g. hill for ramp and stuffed animal for bear) in her talk within small groups. In the middle part of the unit, Maria offered thought experiments and a story from an investigation that she conducted outside of school. In lesson six, after having experienced just one hands-on investigation, Maria shared a thought experiment with the coach and her partner about a hypothetical situation with a real bear and a cub as she describes how she took the investigation from class to her local neighborhood park.

> Maria: If there is a big bear and it is a mother and you push it, it will not come down because it's heavy. If there is a baby one and it is a toy one it will go down because that is because the fake bear can fall off and the real bear cannot fall because they are heavy, and the toy bear is not heavy.
>
> Coach: So, it matters if something is heavy at the bottom of the ramp. [turns to Toloai] What do you think about what she said? Do you have any new ideas that you want to share?-
>
> Maria: -The real bears, they are heavy, and they can't fall. One day I went to this slide and I took my stuffy bear and I put it in the slide and I pushed it and then when I was pretending she was a real bear and it tried pushing it but I couldn't. But if there were a big person and they pushed a big bear, I don't know if it *might* fall?

During her descriptions of an actual material experiment, Maria theorizes about real objects and if it were a real bear that it would be too heavy to push.

> Coach: What if you are on a really big ramp, a really big slide and there is a real bear

at the bottom, like a huge bear, what would happen?

Maria: If there is a really big bear that pushes and you push really hard on the slide and there is a really big bear you *might* push it on the ground.

Coach: Why do you think it makes a difference if the ramp is bigger?

Maria: The small ones, the small ramps cannot push hard but if you put the big bear and you push hard, but on a big slide you *might* push the bear.

In this talk episode notice how Maria incorporates evidence from investigations done at home. During this excerpt we see the longest documented set of extended utterances from Maria that were recorded on camera as she created and responded to hypothetical trials with a variation on manipulated variables. She conceptually retried actual physical experiments and responded to adult questions with possible outcomes framed with conjecture. Maria is very intentional in the way that she does not make claims about these hypothetical experiments (e.g. “might”) but instead offers her ideas as *potential* outcomes. This points to her awareness that physical trials are needed in order to make a claim with evidence. Maria responded with an insightful comment using the work “might” to illustrate her caution in making claims. This use of the word “might” appeared to be picked up from different children throughout the unit as they publicly shared ideas with others. By lesson six, Maria had used the model to hypothesize about the relationship between multiple connecting conceptual ideas (e.g. The weight of the object placed at the bottom of the slide, height of the ramp) while incorporating relevant experiences from outside the classroom.

Maria also used the investigative materials to apply concepts to gesture and locate ideas about concepts during times when adults initiated questions within her small group. An example of this occurred in lesson seven as the teacher approached the small group to ask about the differences in energy between steep and shallow ramps. Both Maria and Clementina were working in a small group with Yereli to understand the effect that a steep or shallow ramp had on the distance a cup was pushed. The teacher checked to ask questions related to their conceptual understanding "Okay so remember we are thinking about energy so which ramp do you think has more energy?" and Maria responds by physically holding up the ramp at a steeper incline and says "the steeper one" with Clementina adding on " because it is more bigger and it makes it (cup) slide a little farther". After a few additional turns of talk, the episode concluded with additional shared ideas about the ramp height changing as the three students take turns manipulating the ramp with Maria sharing a concluding statement "Yeah and if it's (ramp) kinda low [removes two of the three boxes from the ramp] it kinda has a little bit (energy) but not like the big one (ramp). Throughout this episode the teacher continued to press on children's ideas to make their thinking public related to the relationship between the ramp height and the distance the cup was pushed while the children used the available investigative materials within their explanations. The shared nature of language across this episode highlights that Maria's participation was in relationship with the participation of her peers in a small group.

Raymundo

Throughout the middle of the unit Raymundo consistently initiated talk during partner and whole group discussion. Raymundo initiated this talk, using abstract concepts such as gravity in small and large group discussions to create working definitions and examples for his peers in small and large group discussions. His ideas are *referred to by his peers* and used in discussion in combination with consensus modeling. Raymundo seems to publicly use the designed learning environment to his advantage to assume the public role of sharing his ideas, making his thinking visible, and continue taking intellectual risks. Increasingly through the middle of the unit, Raymundo took advantage of the space we have created for students to assume roles of agency within whole group discussions and is afforded more public opportunities to share his thinking throughout the unit. Raymundo is a robust contributor and is usually called on by the teacher to contribute to whole class discussions. Raymundo continues to make attempts in the middle of the unit to take public intellectual risks by engaging in thought experiments during whole group discussions and used whole group modeling as a sense making practice.

During lesson six, children engaged in a whole class discussion and listened to the teacher read parts of an informational science book. During the read aloud, students were pulled out of science class for English language testing (ELPA), this included Raymundo who would miss the entire lesson which formally introduced the topic of energy and a read aloud book focused on a person pushing down a rock placed at the top of a hill and discuss ideas as this lesson had formally introduced the topic of energy. Raymundo returned to class as students were lining up for recess with their teacher. When Raymundo returned, the coach created a space to share the pages from the book that he missed and had planned to teach Raymundo about the topic of energy. But Raymundo ended up “teaching” the coach about how much he knew about the energy in the book scenario. The evidence for this occurred when the coach asked Raymundo “where the energy came from for the rock to move” and Raymundo used the images in the book to locate his talk and gesture:

> Raymundo: [points to the picture in the book] From him to the rock...and that one (points to the picture of the boy trying to push the rock up the hill] you can’t push it down because there is no ramp so now the force of the rock. The energy of his hands

[points to the boy] are now like tired, so the rock it's big and hard so it can like not go. If there is no ramp it will just stay there but if there is a ramp it will, like move.

In this excerpt, Raymundo took advantage of an opportunity and treated the coach as an audience for which to communicate his thinking. Raymundo is using the illustrations in the book to describe the transfer of energy from the boy to the rock. He is conceptualizing the word force for energy but articulates that energy can travel from object to object. He includes the ramp as a necessary component of being able to move the rock due to the size of the rock. He also considers the importance of the role of the ramp in being able to move the big rock and hypothesizes that without a ramp the rock could not move. He returns to this idea of energy transfer in other lessons through the unit and shares ideas with peers about energy transfers on the slide and does so with a single thought partner as well as a whole group of his peers.

In a new form of participation, Raymundo engaged in public modeling and sense-making during a whole group discussion. This occurred in lesson eight, as Raymundo picked up one peer's conceptual contribution and another peer's modeling inscriptions to share his ideas related to energy transfer. Raymundo raised his hand, he was called on and immediately he stood up and walked to the board (without an invitation) to spontaneously begin using the ideas of his peers as a focal point of discussion "and then the ball stays there only there when it rests right there [points to the black ball] the slide gives it more energy". Raymundo continued to locate concepts within the model as he used a gesture-talk system of communicating in order to respond to questions generated by the teacher. He engages in modeling and revisions for several minutes in front of the class as they add commentary to his ideas (Figure 15). Then the teacher pointed out to the class that Raymundo was *using an* *idea from a peer*, which Raymundo critiqued:

> Kaia: Okay, so I hear that you are kinda adding on to that idea that Đa Minh had. Where the slide itself has energy. Like it is not just the thing itself, but the slide also has energy. Because no matter what we put on it, stuff can move-
>
> Raymundo: - But not cubes, cubes just stay there [pointing to the top of the slide] up there sitting [moves pen down to the bottom of the slide].

Figure 15. Raymundo describing modeling inscriptions.

Raymundo critiqued the teacher's response and created an alternative situation to support his argument that only balls roll downhill, cubes can't get going and roll like a ball. Raymundo continued to articulate that because of the shape of the ball it can more easily move down the slide because they can roll. This discussion continued for a few more minutes as Raymundo added inscriptions to the model and the teacher asked the class to discuss some of his ideas in partner talk "I think that it is a really interesting idea, thinking about different things that are at the top of the slide and whether or not they can get energy from the slide". During this exchange, Raymundo was referring to the idea of rotational energy that a ball has from being able to roll down the slide. These kinds of spontaneous thought experiments emerged across different settings and Raymundo regularly engaged in this kind of intellectual performative work.

Throughout the middle part of the unit, Raymundo is seen integrating skills across scientific practices as he actively works with ideas to revise a model while simultaneously using the model to explain his ideas. Raymundo initiated public modeling during discussions, created modeling conventions to represent concepts, continued to revise the model in response to public questions, tried out conceptual ideas to explain a hypothetical experiment to distinguish between kinetic energy of a sphere versus a cube. He provided rich intellectual contributions in which the community could take up and use for knowledge construction. Raymundo was not only actively sense-making he was teaching, he was modeling how he thinks about concepts and their relationship with the slide, he incorporated hypotheses and engaged in thought experiments. He uses modeling conventions, and intentionally included what he believes is part of the modeling story. He referred to the ideas and comments of others, sometimes disagreeing with those ideas and incorporated certain concepts or innovations into the model. Later in the end of the unit, his style of public modeling is then taken up by Clementina but within a private one-on-one setting where she uses similar styles of modeling conventions and discourse to continue revising a collection of three models.

Final Lessons of Unit

During the final part of the unit (lessons 9-12), children continued to engage in a range of discussion structures (e.g. whole, small, partner) to share their ideas around increasingly abstract concepts such as gravity and energy transfer. In addition, children worked in small groups to share and negotiate ideas through language to synthesize their investigation experiences by engineering a Rube Goldberg machine. Focal children engaged in spontaneous public modeling more than in previous lessons . Often students initiated conversations as they sought out to create opportunities to share their ideas and model revisions with others. Throughout the unit, children were provided with time to discuss and engage with non-fiction and fictional stories with science topics to visually illustrate abstract concepts. During the final lessons, the community worked in collaboration to create a final model checklist as they reviewed all of the charts from the unit and voted to discuss and determine which concepts should be included in their final models. The community discussed how to represent ideas in their models and determined that a color-coded system to represent and locate the different concepts in the model would help the audience be able to understand their ideas. Children then created their final models using their checklist and shared them during a whole group share out session.

Clementina

During the end of the unit lessons, Clementina's participation shifted as she began to think aloud about modeling in front of the whole class and engaged in sustained modeling in a one-on-one setting for extended periods of time with the coach. Clementina returned to a strategy used earlier in the unit–initiating *conversation* with adults after the science lesson has ended. She made attempts to initiate one-on-one talk with her instructional coach during both instructional and non-instructional times, creating a space where she engaged in sense-making talk and modeling with an audience of one. During the end of the unit in the one-on-one conversations with the coach, Clementina began to engage in more metacognitive activity such as discussing her own ideas and models while also considering other people's ideas during the trajectory of the unit. There appeared to be particular conditions in which Clementina engaged and up until the end of the unit, Clementina had participated differently in whole group discussions.

The shift towards more public sense-making in lessons eleven and twelve took place as Clementina used models and representations to communicate her ideas to the whole class. One example occurred towards the end of lesson eleven as children were finishing their final models and the coach and teacher checked in with children around the room. The coach was seated on the floor speaking to Raymundo, Clementina approaches, sits on the floor next to the coach and whispers “I know where is gravity...there is gravity in the whole slide”, this being a non-normative ontological claim. The coach responds by asking how she will show that in her model and Clementina says, “by putting a G in um, um in all over the slide”. Clementina moved to the whole class consensus model (Figure 16) and began inscribing “G’s” in specific locations. During this time children headed out to recess, the teacher collected the final models, and the coach approached Clementina to ask about these inscriptions and to prompt further explanations of her ideas:

Figure 16. Clementina adding inscriptions to the class consensus model.

Clementina: I am doing g, g, g....because um, every time I am doing a g [traces her marker down the list of g’s under the slide] because there is gravity in the whole slide.

Coach: What if I was standing over here and I wasn’t on the slide, would there still be gravity?

Clementina: Yeah there is gravity because it holds you.

Coach: Could you show me? How would you draw that?

Clementina drew a stick figure of the coach with a big arrow pointed down and added that it was to show “gravity pulling you down” and that “the gravity is holding you down”. For the next few minutes of this interaction Clementina continues to talk and gesture about forces across different contexts “the *up* forces are in the airplanes because it makes you go up” and added representations while simultaneously discussing the inscriptions of other students. During this interaction, Clementina responded to questions without hesitation and engaged in explanatory talk and modeling. This was a *shift* from her interactions with the coach in lesson three (e.g. increasing hesitation to respond to coach’s questions, barely audible voice volume). We see that Clementina used the model as a resource to generate inscriptions which in turn seemed to support her characterization of gravity.

In lesson twelve, children gathered on the carpet with their initial and final models to think aloud together about their learning over the course of the unit and respond to each other’s ideas. In the center of the room is a toddler slide which was used to stimulate conversation and transference of concepts from paper models to real world objects. The coach prompted Clementina to share her ideas from the previous lesson. She addressed the class multiple times during this forty-five minute long, student-led class discussion, oftentimes positioning herself in the center of the perimeter of her peers (Figure 17) and using the pointer tool to describe her modeling conventions as well as locating conceptual

Figure 17. Clementina participating in whole class discussions.

ideas both on the toddler slide and the yellow consensus model. As Clementina spoke publicly about her additions to the consensus model, students could be seen making unprompted revisions on both their own final and initial models. Her voice is audible and her ideas about gravity unfolded spontaneously as she spoke. During Raymundo's turn to share, he took up one of her ideas about gravity and spoke about it as others contributed by centering Clementina's contributions.

Towards the end of lesson twelve, as children are heading out the door to recess, Clementina initiated yet another sense-making session, fifty-seven minute long, in which she continued doing science. Clementina began this session by describing the added inscriptions (arrow, colors, words, objects) on her individual paper model. A few minutes later, Clementina moves from her individual model and walks to the board to speak about the class consensus model. During the next twenty minutes, she engages in sense-making to compare concepts, ideas, and experiences across the yellow class consensus model, the toddler slide, and her individual student model for the next twenty minutes:

> Clementina: So, this one um slow energy [pointing to the toddler slide] and [pointing to the yellow model] this one is fast energy. This slide has eleven pieces [writing on toddler slide]. This one [pointing to the yellow model] has 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,

12, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 27, 29 pieces.

Clementina compared and theorized about the two representations and counted the number of steps in the ladders. In the moment, she created a system of measurement "pieces" (steps) and used proportional reasoning to distinguish the differences in energy between the two slides. She continued to talk while moving between the toddler slide (Figure 18) and the class model:

Figure 18. Clementina describing inscriptions on the toddler slide.

> Clementina: This is all of the words that we have right there [pointing to yellow model] so that means this is the energy. Also, the force and there's pushes and also the pulls [pointing to ladder]. And the energies and the gravities, all of the powers, all of what are here [pointing to class model] are right here [pointing to toddler slide] and the slide and then they walk to all of the parques um: to all of the parks."

At this moment in the interaction, Clementina created a verbal summary of ideas and concepts and how they compare across models but also how, "they"—the forces—occur at all of the parks. For her, forces and powers have now become objects, which she is referring to using the term "they." She has also generalized the forces and motion beyond the anchoring phenomenon and has extended her understanding of these concepts as occurring in “all” parks. Her explanatory talk then ended abruptly and she moved on to discussing a kind of scientific synthesis of personal self-expression sharing ideas related to *emotions* “I am so happy. And I make people learn and then they say the same ideas what I say, so I can write them here [points to class model]” and *transferring ideas across time*, “I like sharing ideas because that means people learn...these ideas are going to go to Ms. Bear’s (first grade) class from kindergarten” and *transferring ideas across contexts*:

> Clementina: I like doing science because that makes me learn science. And I can tell my parents. I can tell my mom or dad or my big brother or sister um um what did, I did for science that’s how they can learn a new thing.

We can see a trajectory of Clementina’s participation beginning with revisions on her individual model to applying science concepts and conventions across three models, while responding to questions, engaging in proportional reasoning to distinguish between models, and using sense making talk to hypothesize and generalize phenomena to other circumstances. And her participation continued even after the last camera had been put away, the school bell rang, and the yellow poster rolled up for analysis. Clementina climbed onto the bookshelf so she could begin creating a new model on the whiteboard, but this time she changed the variables. Now there would be three people going down the steep slide and as she modeled she was explaining her inscriptions aloud to herself, because models for Clementina were never finished “they could keep going and going”.

Maria

Throughout the unit, Maria is observed to be a consistent participant across all activity structures. She is selective about when she raises her hand during whole group discussions and when that occurs she shared well-formed ideas which were often connected or built off previously shared ideas of her peers (e.g. "I agree with Melissa, a slide is a ramp"). During the beginning, middle, and end lessons, Maria is routinely observed to publicly build knowledge in response to comments shared by peers. One example occurred in lesson ten during the beginning of a small group discussion she indicated that didn't know what gravity was but after *listening to other children* provide examples and characteristics of gravity for several minutes she then remarked "is in the ground, gravity is always there for all the days, forever." Maria also is observed to expand on ideas publicly such as in lesson eleven when she builds upon her initial idea of gravity being in the ground and transfers that concept across contexts and shares that gravity is "in the places like China" and in countries that speak "Spanish".

Maria was able to engage in multiple discussions across various discussion structures (class, small group, partner talk) to engage and re-engage in thinking about concepts such as gravity more than once. Supportive learning conditions includes the opportunity for children to rehearse ideas, listen to the ideas of others, and return again to discuss previous concepts. Contributions from students during discussions is an important component to a community's ability to build knowledge collectively. Maria consistently contributed rich ideas and everyday examples to the community about scientific concepts such as forces "A force is something that makes you move, like when we go to the slide it makes us move" and "a pull is when you pull a flower out". During whole group discussions Maria was observed to use her individual paper model and the class consensus model to reason with ideas and explain her thinking to others (e.g. Maria explaining to the class why she wrote some G's on the model "Gravity is everywhere and also on the slide and everywhere". Similar to Raymundo and Clementina, Maria also takes up abstract concepts in her talk such as energy and can reason with this concept in light of the phenomenon. This example (lesson 11) is from an adult initiated final model check in during a partner talk episode:

> Coach: Okay so tell me about the energy [pointing to her inscription in the model] from the slide.
>
> Maria: Energy comes from the slide.
>
> Coach: Ok, so where does it go? So, you said you have the energy when you [pointing to the top of the slide]-
>
> Maria: -The slide gives you the energy and the slide has the energy and you have the energy.
>
> Coach: And you have the energy to do what at the bottom?
>
> Maria: You give the push like this [pushes up with her body]. If it is a real bear we cannot push it, but it is a fake bear we can push it. But not the big bear but the little we can push it [points to her model and slides her pencil up and down the slide] cause it go down.

Maria's statements to the community which include embedded everyday examples, characterizations, and definitions of concepts seem to be building towards the development of intersubjectivity as shared meanings about science ideas are continually revised and expanded upon over time in this knowledge building community (e.g. Maria stating that gravity isn't just for people but "everything"). Throughout Maria's participation engagements, the ideas that she shared were consistently and earnestly focused. During a final interview, Maria remarked that Raymundo is a student who she has learned from and said that it was good to share ideas otherwise "if you don't share ideas that means that you were not listening". The public nature of the work in this unit by this community of children is supported with a range of practices, listening being a particular and important action identified by students such as Maria and Clementina and which also emerged during family interviews of the messages that parents shared with their children “Tienes que escuchar” (You need to listen).

Maria’s consistent participation endeavors occurred largely as self-initiated during discussion as she engaged collaboratively in discussion with the ideas of others. Maria also responded to adult-initiated requests to elaborate on ideas, modeling inscriptions, or to share everyday experiences from home. The model also served as a resource for Maria as she applied and located concepts on models, used sophisticated modeling techniques including letters, symbols, colors to distinguish between different concepts on her final model, and engaged and reasoned with abstract concepts in increasingly complex ways over time.

Raymundo

During the lessons occurring at the end of the unit, Raymundo continues to participate actively across activity structures and most notably continues to engage in public sense-making and conceptual innovations. Sometimes after these public episodes, Raymundo received hi-fives from his friends after he sat back down from modeling on the board. One interesting development towards the end of the unit was that Raymundo continued to explain his thinking in whole class settings, we saw several students also take up this practice such as Clementina. Raymundo was often seen to introduce innovations with others in discussions as he creates definitions and examples to illustrate concepts with his peers. He also referred to the ideas of others publicly (lesson 11) when Clementina was sharing ideas to the whole class about energy transfer:

Clementina: When we are on the slide. Um, when we are on the slide, the slide has energy and when we get on the slide the energy gets on us.

Raymundo: Yeah, and we get that energy from the slide to us.

Raymundo's addition to Clementina came at an important time as this was the first time that Clementina had extended utterances while standing and explaining her thinking. After Raymundo elevated Clementina's ideas, other students began adding on and elaborating on how to represent the energy from the slide getting on us with one student blurting that they would color it "green".

These examples provide evidence that Raymundo is not just describing concepts such as energy or gravity acting in a singular place, but he included talk about gravity acting on the Earth, moon, and stars. Like Maria, also transfers this concept across contexts and planetary situations; "Gravity keeps us on the ground on the planet [points downward]", "it makes all the people stay on the planet", and "There is gravity, invisible gravity that you can feel it it keeps us on the ground for the whole time". Raymundo routinely is one of the first students to share ideas in a whole group or small group setting and students such as Clementina and Maria were seen to benefit from those ideas as they followed by contributing their own diverse examples and conceptual reasoning. Sharing ideas through student-led and student-centered discussions supported conceptual innovations being expanded and revised within the community.

Raymundo's approach to working in investigations with others was one of a leadership role, but also control (resources, procedures) while he worked with his small group. Raymundo was with the same group of peers in small groups throughout the unit. During the middle and ending phases of the unit, Raymundo directed group members to coordinate materials in a demanding way and often the resources were not distributed or shared equitably. The group investigations in which Raymundo was a part of remained fixated on procedural aspects of the investigation and rarely engaged with the conceptual aspects of the investigation during their dialogue. Raymundo was often seen in command of materials, directing others and his group often ran out of time to record data. By the end of the unit, Raymundo continued to direct and control materials as his group engaged in the procedural work to construct a Rube Goldberg machine in lesson nine:

> Andrew: I need tape.
>
> Raymundo: You grab it and I will tape it. Stop moving it!
>
> Natasha: Raymundo look [pointing] we need that one.
>
> Raymundo: Okay, next. Tight, tight.
>
> All the students continued working together in pairs to tape rolls together
>
> Raymundo: [Takes away the tape from Andrew] This is tricky, it is like we are doing math.
>
> Andrew: Yeah, like we are doing math.
>
> Raymundo: [Snatches tape away from Natasha]
>
> Natasha: We tried our best to make it work.

This excerpt demonstrates that focal children working in small groups in this study engaged in joint endeavors differently. While Clementina and Maria were part of groups in which no one person took a strong commanding role in their group they moved from procedural to conceptual work and dialogue during investigations. While Raymundo's actions in small group investigative settings differed as he took more aggressive command of the procedural aspects of leading his group. We did not observe or document his group to make the transition from discussing procedural to conceptual aspects of investigative work.

Raymundo’s modeling engagements included the addition of creative inscriptions that demonstrate his ability to locate concepts using color, symbols such as vector arrows, and rich conceptual language. Raymundo’s final model includes labels from concepts across the unit such as push, pull, gravity, and energy transfer. He also began to seek out adults towards the end of the unit to show and explain his model “This arrow means that you are climbing the ladder” and described gravity in the model with a gesture of large widespread hands “it’s everywhere on the slide”. Raymundo engages in spontaneous modeling conversations with others during the final modeling sessions and is seen offering revision suggestions to his peers. Children were afforded time, agency, and freedom to move around the room to share ideas with others, lay or sit on the ground to spend time thinking and making modeling inscriptions, all important learning conditions to support young children in scientific practices.

At the beginning of lesson twelve the children gathered on the carpet and discussed the sudden appearance of a toddler slide in the center of the carpet. After the coach told them it wasn’t just a toy but a tool, Raymundo was the first to grab an expo marker and begin adding inscriptions to the slide. Children took turns sliding down the toddler slide and adding concepts to it with index cards and expo markers. Raymundo added commentary to the whole group as children are sliding down and he verbally locates inscriptions, actions, and concepts while describing the events “So that arrow means that Aidan went down” and “Your shoes...they’re hard. They can push the bear”. This addition of including an actual slide in the class was resourced by many students such as Clementina and Raymundo as they transferred their modeling experiences from paper onto this slide. The community worked across a range of representations and models which were accessible throughout the unit and as students increasingly developed dynamic ways to engage in the work of modeling and sense-making with these tools.

Discussion

Diverse and Generative Participation Pathways

These findings illustrate the agency and creativity that children used to engage in opportunities to sense-make in diverse, non-traditional, and conceptually progressive ways. Through examination of these diverse participation profiles, the findings support previous literature (Hokayem & Gotwals, 2016; Samarapungavan, Patrick, & Mantzicopoulos, 2011; Metz, 1998; 2004; 2008) indicating young learners' capabilities for sophisticated cognitive work within unique learning engagements. The focal students engaged differently but generatively within and beyond curricular activity; most notably we have Maria who recreated investigations and conducted advanced thought-experiments at home about force and motion, Raymundo who consistently took public intellectual risks to sense-make in front of peers, and Clementina who initially participated in a more reserved and hesitant manner but increasingly progressed to intensive public modeling work as she engaged in meaning-making across three different representations of the same phenomenon. Throughout the unit it appeared that these three students took advantage of different opportunities to engage in sense-making about ideas or models, and occasionally to disengage or participate in puzzling ways. But taken as a whole, findings suggest that focal children benefited from doing this work within a community, within a classroom culture that valued linguistic freedom, as they observed the engagements of others and participated in scientific practices in their own ways across whole and small group settings.

We learned in this study that children's participation is not always a linear process, that participation for some can shift, transform, or remain consistent over the course of a unit. In addition, the notion of one's participation can be expanded beyond an individual's performance to include co-participation endeavors that support both the community and the learner. Participation and learning through joint activity is supported by the research in which children build upon the ideas of others and which can be common in designed learning environments (Samarapungavan, Patrick & Mantzicopoulos, &, 2011).We didn't assume that all students would participate in similar ways, or that the instructional design would benefit all students in a uniform way, but we recognized that all students did not benefit uniformly from the same activities. We anticipated some of this, designing for a variety of activity structures (e.g. discussions, demonstrations, read alouds, playground field work, modeling, investigations, data collection, explanatory model sharing) and modes of participation across the unit so that students could benefit from a diversity of talk and modeling opportunities. As the unit progressed, each of the focal students appeared to take advantage of different combinations of sense-making opportunities to reason with others, leading each of them to take unique pathways toward understanding both the practice of modeling and the science ideas embodied within those models.

Children in this study were documented to not only build scientific knowledge but also build a relationship to that content in ways that disrupted traditional spatial-temporal, lesson boundaries such as when Clementina said that the ideas from her experiences in kindergarten can go into first grade. Children saw the importance of this (scientific) knowledge and “learned a different relation to the subject matter” (Rogoff, 1994, p. 211). This community of learners approach, articulated by Rogoff (1994) describes this model as “based on the premise that learning occurs as people participate in shared endeavors with others, with all playing active but often asymmetrical roles in sociocultural activity.” (p. 209). Clementina, Maria, and Raymundo all took on active but diverse roles in the community and the findings demonstrated that even though their participation profiles differed, they each expressed conceptual understanding through their own unique means. The development of (scientific) understanding occurred through shared language as children co-participated in scientific practices with others by coordinating activity with peers (e.g. Maria’s small group investigations to manipulate variables to record data), listening and responding to the ideas of others (e.g. Raymundo and Melissa building ideas off each other during a discussion on energy), negotiating consensus about an idea or concept (e.g. Raymundo’s critique of the teacher’s idea that “anything placed on the slide will roll down”), other times to explore and innovate inscriptions and conventions during the modeling revision process (e.g. Clementina adding “g” to the community consensus model to show that gravity is happening all over). The meaning making becomes visible as a social practice when we consider the role of shared language.

Co-participation (Gutiérrez et al., 1999; Tobin & McRobbie, 1999) allows for the inclusion beyond participation as an individual process to include communities of learners engaging in joint socio-intellectual activity (Gutiérrez et al., 1999). Where over time children have the agency to develop new emergent modes of participation with others (e.g. Clementina’s one-on-one conversations with the coach). The nature of this work varies as multiple opportunities to learn (e.g. modeling activities, investigations, discussion structures) are offered throughout the lessons in a unit providing members a menu where children can assume different forms of participation (e.g. leading or contributing to discussions, actively observing or listening, offering feedback on ideas or models). Co-participation within a community of learners model appeared to open up the space for more expansive and inclusive perspectives into the question of "What counts as meaningful participation?" (Gutiérrez et al., 1999; Stromholt & Bell, 2018). Considering participation as a collaborative endeavor in which both students and teachers define, helps us to rethink both what it means to participate and also how to understand diverse and unique participation engagements for individual students.

Many of our students attended bilingual preschools and played together after school, in their heritage languages and we wanted to continue those relational and language patterns in the classroom by encouraging students to engage in partner discussions with self-identified friends and to sense-make in a language chosen by the student. In small and whole group settings the instructional coach would speak to students in Spanish and English as well as providing framing in both Spanish and English "*es importante que todos estamos escuchando* (it is important that we are all listening to each other)". Instead of moving all students through staged and undifferentiated modes of participation, we acknowledged and legitimized their ideas and stories and over time designed for the possibility that children would be able to recognize particular opportunities in which they wanted to participate peripherally or more centrally, enabled by their positioning as authors, teachers, and collaborators in building knowledge.

Guided by the findings of the focal students, can we call this class a knowledge building community? Knowledge building communities have particular features, such as collaborative idea improvement and iterative development of artifacts (Scardamalia & Bereiter, 2006; Tobin, & McRobbie, 1999). Students in this study had opportunities to build knowledge collectively through the creation and revision of "epistemic artifacts" such as models as well as "conceptual artifacts" such as thought experiments (Scardamalia & Bereiter, 2006). The use and revision of such artifacts allowed children to continually work on emergent ideas such as Maria's efforts in the middle of the unit to conjecture that the ramp with the most energy is "the steeper one". But as children were presented with multiple opportunities to work on the development of these ideas, future growth was enabled (e.g. Maria: "The slide gives you the energy and the slide has the energy and you have the energy."). Models provided a foundation for emergent ideas to develop and for information from different sources (discussions, text, investigations) to be organized and stored. The shared nature of the epistemic artifacts was centered around a community engaged in collaborative modeling endeavors and discourse through predictable instructional routines (Hapgood et al., 2004). In responding to the opening question of this paragraph, the evidence in this study suggests that very young children not only participated in scientific practices but they also collaboratively built understanding as a community. What follows are specific examples from focal participants in which they engage diversely in the knowledge building endeavors of idea development and model revisions to explain the complex phenomena of playground slide collisions.

Clementina: Third Space Participation

Clementina's participation over the unit was not as consistent or predictable as other focal students. Over the course of the unit, findings demonstrate how Clementina transformed her participation through a positioning shift, particularly during the end of the unit as Clementina used multiple models to create one-on-one conversational opportunities with the instructional coach to engage in explanatory talk which included sophisticated conceptual reasoning. Clementina's role remediation created action towards "Clementina as teacher and synthesizer" to a range of audience sizes. What was unique and unexpected about Clementina's participation is that she took advantage of two educators being in the classroom and the iterative work of knowledge building to create a momentary third space (Gutiérrez et al., 1999) in which she could continue engaging in the work of model revisions with an audience of one. Clementina's construction of this third space extended the object of activity (modeling revisions), reorganize the activity (Clementina leading the conversation and inscriptions) and this resulted in new opportunities for learning (e.g. Clementina articulated after a long sense-making conversation that the physics concepts in the model were also at all the parks). In addition, Clementina used models for multiple purposes including as mediators for talk, participation and conceptual innovations. We learn through her participation that it was not only possible for a five year old child to engage in sustained intellectual work with models for an extended period of time (Fifty-seven minutes) but that conversations around models and revisions can be extraordinarily motivating for young children such as Clementina.

Clementina's model-mediated *conversations* increased dramatically during the course of the unit. She used them to enter into interactions with adults who are typically not able to spend long periods of time with individual students during classroom instruction. Conversations as a discourse approach in are discussed in the community of learners model (Rogoff, 1994) which emphasizes that conversations can serve as supportive dialogue and as a resource for building knowledge. Findings on Clementina's participation demonstrate that she drew freely on her authentic competences which included model mediated conversations, which she could employ during whole group, small group, and one-on-one interactions.

Maria: Conceptual Engagements Across Contexts

In contrast to Clementina, Maria's participation trajectory was consistent throughout the unit. At the beginning of the unit Maria spoke about her modeling inscriptions to adults and the larger community when prompted. But unlike Clementina, Maria did not initiate talk about her model with adults during non-instructional times. Maria, however, was engaged in numerous co-modeling engagements with Clementina that occurred spontaneously throughout the unit. In addition, Maria was observed to add onto the ideas of others such as during a scientific argument when children were working to identify ramps in everyday places such as playgrounds, Maria remarked in a whole group discussion "Slides are ramps, I agree with Melissa". In the middle of the unit, Maria engaged in a thought experiment during a partner talk conversation where she took on increasingly complex ideas as she interchanged her stuffed animal for "a real bear" and carried these conceptual ideas to her local park where she carried out her own investigations. Maria's participation extended beyond the classroom as she was driven to recreate investigations at home with the material objects (neighborhood slide, stuffed animal) that she had available. This example of continually working on and investigating ideas is a key principle of a knowledge building community (Scardamalia & Bereiter, 2006) in which ideas are continually being developed. And is a sign that deeper interest has been established when children voluntarily engage in further investigation. At the end of the unit Maria applied abstract concepts such as energy transfer in her talk. Then without hesitation when prompted by a discussion question she responded with her own characterization of how energy traveled through the objects in this phenomenon, "The slide gives you the energy and the slide has the energy and you have the energy." Many of Maria's peers, including Clementina and Raymundo, contributed ideas to discussions that included self-created definitions, examples, and characterizations of concepts in their own unique and legitimate ways. In these instances, we were not teaching for English language development but created opportunities for language(s) to be used routinely by children in purposeful and meaningful ways (Lee et al., 2019). Providing young children with engaging, everyday phenomena coupled with robust content which is contextually connected to their lived experiences appeared to enable emergent bilingual children such as Maria to develop sophisticated conceptual understandings.

Raymundo: The Role of an Audience

Raymundo's participation trajectory stands out as distinct from Clementina and Maria. Starting early in the unit, Raymundo used his peer audience to support a unique form of participation, public sense-making with an audience. Throughout the unit, even with an audience of one, Raymundo often shared emergent ideas and developed them further through interactions within the presence of others and oftentimes with a model (even a blank model). Raymundo's use of gesture and meaning-making in relation to objects is a fundamental arrangement of reasoning in considering a distributed cognition view. These findings indicate the role of an audience in the work of modeling, where kindergarteners relied on the use of attentive others as part of a purposeful sense-making routine (Danish & Enyedy, 2007). Toward the end of the unit, Raymundo was creating and publicly sharing his own definitions of concepts and examples "invisible gravity that you can feel it. It keeps us on the ground for the whole time". Raymundo's openness to sharing ideas, even emergent ideas publicly provided opportunities for the larger community to take up his definitions, revise them and add onto them.

The participation pathway distinctions among the focal students are important to highlight and consider as the field builds an understanding of how young learners engage with scientific concepts, participate in a community with a growing and shared repertoire of practices, and learn under supportive conditions. Their differences became more pronounced over time as sequenced learning experiences enabled focal students to take advantage of varying combinations of individual and collective work, hands-on experiments, sense-making discussions, independent modeling assignments, public sharing of revised models and ideas, and private conversations with teachers. Findings indicate that these learning opportunities did not serve to simply aggregate knowledge over time or to support each student in the *same way*. Rather, students engaged differently across a range of interconnected activities, both student-led and teacher facilitated, occurring across school and home contexts. The scope of these participation profiles extended into interdisciplinary arenas of work including quantitative data collection and analysis (student-led ramp investigations) and obtaining evidence from literary sources (interactive science read aloud opportunities). The teacher encouraged routine student-led discussions where they were invited to invoke everyday and specialized discourse in support of evaluating their current thinking, engaging in investigations, generating new relationships among concepts and iteratively recrafting their models—all evidence of ongoing knowledge construction (Siry & Maz, 2013; Samarapungavan, Patrick, Mantzicopoulos 2011; Engle & Conant, 2002). The findings suggest that sustained intellectual engagement in a complex set of ideas allowed for both deep learning and different —but not always linear—learning profiles to emerge.

Instructional Design Framework

Designing a learning environment in which children are positioned to collaborate and build knowledge, requires designed and spontaneous opportunities to publicly share thinking across different audience structures (whole class, small group, partner talk). Part of this design means that the organization of the learning environment is responsive to students their needs, interests, and ideas. The possibility for lesson resequencing was always present as we redesigned in order to best mobilize the everyday intellectual resources of students (Bang & Medin, 2010; Warren & Rosebery, 2004) to support student self-efficacy and participation as individuals and as valued members of a knowledge building community. The kinds of interactions that take place within these structures engages different linguistic skills from children (Lee et al., 2019). For example, the role of an audience enabled the community to take turns making their thinking visible while revising and working on ideas, even beyond the boundaries of the classroom (e.g. Clementina describing that she will tell her family what she did in science so they can learn new things, Maria discussed gravity being in places like China). In this way children learned science through purposeful interactions with shared language (English, Spanish) and through engagement in the science and engineering practices children practiced exercising disciplinary specific discourse. Similar to suggestions from Lee et al., (2019) this study also found that *over time* as focal children developed science knowledge their use of specialized vocabulary and innovative conceptual thinking (e.g. Raymundo's cube vs. ball episode) permeated their language as they worked together to make sense of phenomenon. These design choices created a learning space where students' linguistic backgrounds were honored, where they heard their language being spoken by educators (e.g. "*Todos los ideas son importantes,* all of your ideas are important"), and where they could express their learning and growing understanding over time across different activities occurring both during outside of traditional lessons (e.g. Clementina asking to stay in from recess to model and share ideas “the energies and the gravities, all of the powers... walk to all of the parques”). These findings illustrate that the use of rich scientific language and vocabulary were present across all three focal student participation engagements (e.g. focal student descriptions of energy). These findings are consistent with the recommendations for designing learning environments which support diverse participation within a community of learners for emergent bilingual and multilingual students (Lee et al., 2019). The findings suggest that opportunities to develop specialized science language and interact with complex scientific phenomena occurred as a product of using language(s) within the socio-intellectual interactions of a community.

Similar to other frameworks (Lee et al., 2019), these findings indicate that a necessary learning condition for kindergarten science and for supporting emergent bilingual learners is *time* spent building intellectual relationships. Time is a fundamental resource for deep disciplinary engagement to transform emergent understandings into knowledge (Siry, Zeigler, & Max, 2012; Lehrer & Schauble, 2012; Engle & Conant, 2002). Time matters because, as our findings suggest, students participate in diverse ways. They took advantage of activities and resources differently and sought to agentically determine how they would participate through multiple opportunities afforded to children by the menu of intellectual activities. When kindergarteners are provided with adequate time for sustained intellectual work, such as in connected discussions over days, the learning can be cumulative and subject to revision. Samarapungavan, Patrick, and Mantzicopoulos (2011) describe time as being an important factor in offering kindergarten learners with diverse entry points to engage in scientific practices that benefit from time for elaboration, explanation, and revision of models

(p. 872). Time allows both educators and children with extended opportunities to use their observational skills to listen carefully, observe concepts in action, ask questions, re-evaluate ideas, and respond thoughtfully across activity structures.

While we learned a great deal about emergent kindergarten modeling practices in the first paper of this dissertation, we also identified some of the work that we as educators needed to take up in order to design for agentic and equitable participation by all students. We (teacher and researcher) designed for multiple and diverse opportunities for collaboration in small groups (e.g. investigations, small group discussions) to attend to the Funds of Knowledge (Moll et al., 1992) that children bring with them to the classroom which can be used to support learning, one such example from the research being fluid collaboration (Alcalá et al., 2018). We worked to disrupt problematic expectations (Bang et al., 2012; Heath, 1986) about how students should participate and shifted towards cultivating heterogeneity of contributions to discussions (Rosebery et al., 2010). We also co-designed activities to support student agency and creativity with modeling innovations and revisions that supported knowledge building (Engle & Conant, 2002; Danish & Enyedy, 2007; Scardamalia & Bereiter, 2006; Tobin, & McRobbie, 1999). In addition, we recognized the disruptive force of English as the dominant language in the classroom and worked to open the space for more diverse sense-making through the use of hybrid languages practices (Gutiérrez et al., 1999).

Summary

The design of this study found the importance of purposeful routines and meaningful interactions to mediate participation with models and representations (Danish & Enyedy, 2007; Montiera, Jiménez-Aleixandre, & Siry, 2020). Modeling findings are consistent with previous research pointing to the revisionary nature of modeling endeavors supporting the development of complex scientific understanding through engagement in this practice (Manz, 2012; Montiera, Jiménez-Aleixandre, 2015; NRC, 2012; Schwarz & White, 2005; Windschitl et al. 2008). However, this study adds to the literature gap on modeling by emergent bilingual kindergarteners engaging over the course of a unit. The modeling findings from this study support the work by other researchers (Samarapungavan et al., 2015) in primary grade classrooms which demonstrate that young children are capable of engaging with scientific modeling in order to support the development of more sophisticated and robust scientific understanding.

This study contributes to a deeper understanding of participation pathways over the course of a science by emergent bilingual children. The participation profiles of the three focal children were unique in the opportunities they chose to take advantage of as they engaged deeply in the work of knowledge building. All focal children developed sophisticated conceptual understanding of the slide collisions phenomenon and utilized models and explanations to communicate their knowledge. This design framework provides a new model for science instruction and education at the kindergarten level and acknowledges work by other scholars which detail the need to disrupt traditional learning dynamics between teachers and students in order to build a community which supports more agentic student participation in science classrooms which includes deep conceptual meaning making (Cornelius & Herrenkohl, 2004; Engle & Conant, 2002; Herrenkohl & Guerra, 1998).
The findings support calls by other researchers to recognize the scientific capabilities of young children as their everyday ideas, stories, and lived experiences are resourced for supporting complex scientific understanding (Hokayem & Gotwals, 2016; Metz, 2011; Monteira and Jiménez-Aleixandre, 2016; Siry, 2013). The learning conditions used in this

study support findings by researchers which found the importance of designing for multiple opportunities for children to engage iteratively in epistemic talk, inclusion of models and representations to represent built knowledge, and positioning children as knowledge producers (Lee et al., 2019; Montiera, Jiménez-Aleixandre, and Siry, 2020). In addition, similar to the Montiera et al. (2020) study, our findings suggest that cultivating diverse and generative participation in science can be supported through dialogic interactions combined with asset focused views by teachers of young children's capabilities to engage in sophisticated scientific reasoning. Overall, this study contributes to better understand both supportive learning conditions and diverse participation engagements of kindergarteners engaged in the work knowledge building as a community.

Implications

This study sought to clarify how emergent bilingual learners participate in a kindergarten science unit under supportive conditions. Time, multiple opportunities to participate across different activities, inclusion of children's everyday ideas and stories, and sustained intellectual engagement are central to the work of designing for knowledge building. The design of a learning environment for the purpose of collaborative building knowledge is challenging and requires support for educators in ways that are responsive to both the Framework for K-12 Science Education (NRC, 2012) and to the linguistic and cultural backgrounds of diverse learners. Some of those challenges required spontaneous co-designing such as the regular occurrence of more than twenty hands being raised during discussions and the resulting waves of disappointment for some students at not being chosen to share their ideas with the class. On a few occasions these moments of strong disappointments while they were disruptive to the lesson, provided the teacher and coach with valuable feedback. While these instances occurred more at the beginning of the school year, there were a few occasions when a student became physically violent because they were not able to immediately participate in the discussion but had to wait while others shared ideas. The tensions inherent in learning environments can be viewed in different ways, but sites of rupture can be generative (Gutiérrez et al., 1999). These moments of rupture were reflected upon by the educators and through metacognitive conversations with the children and we concluded that the ruptures spoke to procedural, organizational, and conceptual questions and concerns of equity within whole class discussions. In a subsequent study with a new cohort of students, these issues of equity and rupture in whole group discussions were taken up by the researcher. Whole group discussions were repurposed as sites for synthesizing information while children spent more time sharing ideas within small group conversations. Future research should consider the high motivation of kindergarteners to engage in science discussions and consider how to design with the affordances and constraints of whole group science discussions.

In this study, the teacher received support such as co-designing opportunities with the instructional coach/researcher as well as access to high quality professional development to better understand and implement three dimensional learning (Achieve, 2013). Some notable supports included allocating time for science (e.g. 2-3 times per week, 30-45 minute lessons), access and funding to attend ongoing high quality science professional development, instructional coaching needed to implement equitable instructional practices and actively work to disrupt and desettle normed expectations of whose knowledge counts in science and whose participation is valued in the classroom. It is important to note that this was the second year the teacher had been piloting the curriculum. During this time Ms. Takeoa provided invaluable revision suggestions for the curriculum and instructional design and was willing to make her instruction transparent within the research practice partnership so that we could better understand the kinds of learning conditions that best support multilingual classrooms and encourage agentic participation by children. Her participation in this study enabled us to better understand how to support and conceptualize a knowledge building community at the kindergarten level. This kind of inclusion of teacher skills and knowledge into shaping curriculum and design of a learning environment in elementary science stands in contrast to some educational trends which focus on "teacher proof" curriculum (Samarapungavan et al., 2015). I argue for an educational climate in which teachers are valued and their perspectives and experiences support curriculum and instructional decisions, particularly educators of color. Our understanding of knowledge building communities in science education would benefit from additional research to determine what we can expect from children in first and second grades who collaboratively engage with model revisions and idea development within a knowledge building community.

I join other researchers who call for meaningful and high quality science instruction in the early grades particularly with interdisciplinary engagements (Mantzicopoulos et al., 2008). In conclusion, families, educators, and researchers must continue to advocate for the equitable teaching of science in primary grades and provide legitimate forms of ongoing support for educators so that we can continue to learn more about how to improve instructional designs which complement the scientific capabilities of emergent bilingual children.

Conclusion

This multi-case study contributes to the literature in several ways. First, it illustrates the generativity and complexity of diverse kindergarten participation by emergent bilingual students across a complete unit of science with an emphasis on engagement in disciplinary specific practices such as carrying out investigations, modeling, and communicating explanations. Second, the findings also support the perspective that participation is not just an individual engagement but a collaborative endeavor in which children co-participate to develop complex ideas and models over time. Third, the learning conditions provide the field with a broad set of supports including; positioning of children and leveraging their natural capabilities; centering of students' everyday ideas, stories, and experiences in discussions; use of hybrid language practices to support multilingual classrooms; and employing a community of learners model in action during a kindergarten science unit which sought to build knowledge collectively.

Through this analysis we have a better understanding of the varied forms of participation that kindergarten students develop. Our findings also highlight the importance of providing multiple and diverse opportunities for students to participate in the discussions, small group talk, and one-on-one conversations that are anchored around student created models. One particular design element focused on multiple ways of knowing and doing science. This element was incorporated not only to support scientific knowledge building through language use, but also to intellectually challenge and engage children in the ambitious work meant to highlight the academic potential of emergent bilingual learners from immigrant and refugee families.

SECTION 3

Back to School Essentials: A scientific knowledge building community

It's back to school time when children are busy shopping for supplies and teachers are decorating classrooms. But don't forget about one of the most important back to school essentials that all teachers should consider getting, a knowledge building community. A knowledge building community can be generally thought of as a collaborative group of people working together to share ideas, engage in joint meaning-making activities, and improve their understanding of a central question, problem, or project (Scardamalia & Bereiter, 2006). Idea improvement is a key feature, where all members of the community generate ideas, pursue the development of that idea or concept, and engage in sustained intellectual effort over time to revise their thinking and explanations as they gain new evidence or information (Scardamalia & Bereiter, 2006). Let's examine how one kindergarten teacher structured learning opportunities for her students in ways that allowed them to build knowledge as a community and explore the four strategies for supporting knowledge building (Table 2):

- Sustained Intellectual Engagement on a complex but relatable question, problem, or project
- Equitable Embodied Discussions
- Scientific Modeling as a central science and engineering practice that organizes the work of other practices.
- Establishing a Culture of Collaborative Knowledge Building

It is the beginning of the school year in a vibrant kindergarten classroom, tucked away in the Pacific Northwest. A group of five and six year-old children sit with their teacher and discuss forces, energy, and motion. The unit they are exploring was designed by the teacher in response to her student's complaints about playground slide collisions occurring during their recess. The teacher, Ms. Tomogado, wanted to respond thoughtfully to children's concerns and use the opportunity to engage them in learning about the physics of slide collisions, an everyday phenomenon for children. The anchoring phenomenon explored an engaging, everyday event on crowded playgrounds, slide collisions. The unit she wrote consists of twelve sequenced lessons which all connected back to understanding the question "Why can we move down slides and bump objects?". This unit was designed to provide children with ample time to explore the phenomenon and engage in sustained intellectual engagement in order to develop deep understanding of scientific concepts such as the different strengths of forces acting on our bodies when we are moving down a slide and bumping a stuffed animal off the bottom of the slide.

The emphasis on *sustained* intellectual work, means that teachers can design and provide multiple and varied opportunities to engage different kinds of participation to happen over the trajectory of a unit. This may look like having a class discussion outside standing next to the slide or asking families to contribute stories from home about playground slide experiences. Multiple opportunities to participate supports learners to practice, observe others, rehearse ideas with peers, and build capacity to share, revise, and refine their thinking with their community by making their ideas public. Research suggests that all young children, particularly emergent bilingual children, benefit from being provided with consistent sustained and meaningful engagement and scheduled time for science (Lee et al., 2019). Children in Ms. T's class were able to engage in science two to three times per week and between thirty to forty-five minutes per lesson and this allowed for all children to contribute ideas to discussions which were a primary focus of activity.

Equitable Embodied Discussions

Discussions are an important part of supporting the work of a knowledge building community as children's ideas, everyday stories from home, and questions are central to the work of building understanding about the phenomenon. Ms. Tomogado's instructional skills for facilitating equitable classroom discussions include a few different elements which are pulled together to support all children, including neurodiverse populations, developmental classrooms, and multilingual learners. First, discussions that build knowledge rely on a variety of discussion structures such as whole group, small team talk, partner conversations, and one-on-one talk with an adult. These structures allow children to rehearse ideas in lower risk settings prior to a whole group discussion which is a higher risk setting. Ms. Tomogado worked to acknowledge the presence of intellectual risks that children take when they offer discussion contributions and regardless of whether or not the idea was scientifically accurate, all ideas were charted on poster paper. Then over time, children return to these ideas to determine if they are generative or not to understanding the phenomenon. In this way children are engaged in the work of sense-making rather than the teacher telling them information that is more easily forgotten. Within the cultivation of a knowledge building community, the teacher in this context focuses on paying attention, listening acutely, and observing students during science discussions as they use both oral, written, and kinesthetic language to describe and explain scientific phenomenon. Part of these observations should consider who is participating and to visibilize different forms of engagement including gestures, movement, and the use of the white board to model ideas and concepts.

Second, Ms. Tomogado created a "Discussion Web" tool which uses children's photos to better understand who is participating and whose ideas are being attended to by other students. The discussion web tool allows the teacher to recognize different forms of idea sharing and to identify those that have not had an opportunity to share ideas. There are numerous variations of this tool that can be used to support participation such as the figure on the right which shows children's small group's while the figure on the left identifies individual student participation. Consider what kinds of visual supports would motivate children to participate while also attending to the intellectual work occurring during class discussions.

Third, discussions required Ms. Tomogado to be truly present with students and their ideas and always find ways to view student contributions from a strengths-based approach to avoid deficit perspectives. This includes the ongoing development of interpretive power (Rosebery et al., 2016) as a move to build intentional awareness of the wide range of intellectual potential in children's diverse sense-making discourses and ways of engagement in science. This intentionality allows teachers to "desettle" their expectations (Bang et al., 2012) of what counts as a science idea and who can have science ideas. Desettling expectations of "what counts" and "who counts" in science classrooms is a move to disrupt historical and present day injustices to encourage children from linguistically and culturally diverse communities to engage fully in science learning. This practice of desettling expands on the kinds of ideas being shared and privileged, encourages diverse participation, and values knowledge and the lived experiences of institutionally underserved children. This may mean that children are sometimes grouped with their self-identified friends or that children can choose to share ideas in their home languages with others who also speak that language.

This practice of “desettling expectations” allows the teacher to move away from a largely evaluative perspective and instead consider the diverse knowledge, stories, and experiences that children bring to the classroom as an asset. Thus, opening up a space for multiple ways for knowing, valuing, and being. This practice allows teachers to listen for diverse ways of knowing the world and identifying partial understandings that emerge during whole group, small group, and one-on-one conversations with students. In this way, educators have permission and encouragement to step away from an ingrained instructional pedagogy of “correct, and incorrect” and allow the community to build knowledge inclusively. Instead, this practice allows teachers to lean towards a type of formative assessment that makes children’s thinking visible as their understanding develops over time to inform ongoing instruction. In this way, diversity is embraced enabling and enhancing the potential for student learning through providing high-quality opportunities to share and build knowledge (NRC, 2012). Let’s explore one discussion at the beginning of the unit to show how children’s ideas are centered and are supported to build on their ideas as a community.

Rosa: Slides are fun.

Miguel: The slides are fun because you go fast.

Ms. Tomogado: What makes you go fast on a slide?

There is a long pause, with no student responses, so the teacher decides to rephrase the question.

Ms. Tomogado: What kinds of slides make you go fast?

DeAndre: Big slides, not the baby slides.

Esperanza: Yeah, the bigger slides means that you can go down faster. It gives you like 10,000 bags of more energy.

Ms. Tomogado: Can someone tell me more about the 10,000 bags of energy?"

Carlos: "She means like, because you go faster you are stronger.

Ms. Tomogado: So we are starting to use words that we don't want to forget, like energy, stronger, and faster…let's write them down on our chart paper. We will be thinking about these words as we draw our slide models. I would like everyone to take a moment to think about what Carlos and Esperanza said and think about how you would draw someone going down a slide getting faster and stronger. Who would like to share how they would draw one of those ideas?

At the beginning of this discussion children were describing their emotions about slides "fun" and little by little as children contributed ideas, their focus of discussion shifted to include specific science concepts (energy) and one student applied a numeric quantity (10,000 bags) to the amount of energy a bigger slide gives a person. The teacher then connected the community's ideas back to modeling as children were prompted to think about how they would draw those shared ideas on their models. In addition, the teacher's next move was to elicit ideas about how to model particular concepts, this positions children as capable of creating modeling inscriptions and during discussions, activities, and investigations. Ms. Tomogado always connected back to the model and phenomenon as a routine for reminding young children that they are working iteratively to better explain and understand a scientific phenomenon. Then over the course of the unit, children began connecting back to the model on their own as a place for locating their changing understanding and questions during discussions. Their own models are locations for diverse sense-making approaches to representing the science content, processes, and relationships they believe are important to include in their final model. The diversity of and in children's models represents their multiple ways of knowing and is a desired outcome of their engagement in scientific practices.

Models and Modeling

Knowledge building communities also create and revise different kinds of artifacts such as scientific models. The list of distinguished practices in science and engineering (NRC, 2012; Achieve, 2013) identify models and modeling as a key practice to develop and explain the scientific events and phenomena occurring all around us in our everyday lives. Models are just one of the four key features that this article will explore for cultivating a knowledge building community in primary science classrooms. Modeling in the early grades has been found to support young children's participation, anchor their scientific ideas, and provide a place for children to revise their thinking over time in light of new information and evidence. The framework for K-12 Science Education stresses the need for students to be more inclusively involved in the sense making aspects of learning science (NRC, 2012) . This includes the conceptual material and epistemic work of developing and revising models and generating evidenced-based explanations for complex phenomena (NRC, 2012).

There are many different ways to approach modeling in the early grades, but one of the most important features of modeling is that models support children in making their thinking visible and where they can learn from the ideas of others to revise their models and explanations. Positioning children as "authors of knowledge" (Engle & Conant, 2002) enables them to use their natural capabilities for drawing, creativity, and curiosity to add and make changes to their models over time. Children in the early grades can create modeling inscriptions to represent different science concepts, one example (Figure 19) with the use of the letter "G" to show that gravity is in many different places in this phenomenon. Models can be used for both whole class modeling as well as individual and partner modeling depending on the focus of activity for the day. A key feature in this story is that the whole class model was always on display during science lessons and could be referred to by

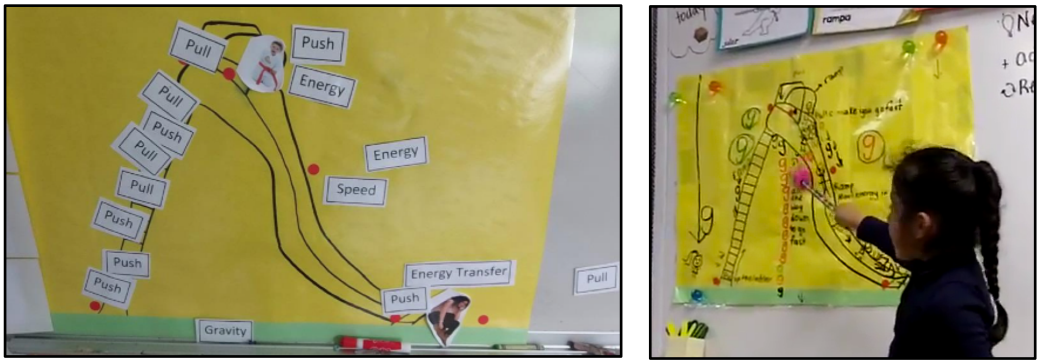


Figure 19. Whole Class Consensus Models.

children as needed. Whole class models can be laminated for use with expo markers (Figure 19) while children can use a range of tools such as magnetic word labels, pencils, markers, and even construction paper can be used to model concepts, processes, and relationships between ideas. Ms. Tomogado would build in time during lessons to do one-on-one modeling conferences with students to learn how they represented concepts and to identify observable and unobservable features of their model. During this unit, students modeling innovations were very diverse as they found different ways to represent concepts such as color coding the slide to designate certain areas as fast, medium-fast, and slow speeds or using symbols to locate pushes and pulls on the ladder. Finally, one of the most important routine learning opportunities for the community is to schedule time for children to share their models and inscriptions to the whole class. Model share outs can occur during opening or closing discussions as well as during partner talk opportunities as children give and receive peer feedback and critique. During science, the sharing out of students' models provided students with the opportunity to both learn from each other as they listened to their peers use the model to explain their thinking. Oftentimes children were seen going back to their desks to add revisions during the share out sessions as children recognized that they wanted to change or add something to their model. Models for children became more than just a traditional school assignment as children earnestly continued revising their ideas, sometimes spontaneously and without being prompted by the teacher. Models and modeling can bring certain features into focus while obscuring others and it is important to be mindful of the limitations that exist within each kind of model. Students' beginning models rarely incorporate a complete explanation of the phenomenon. But over time, students will individually model key pieces of the phenomenon puzzle, which can be displayed and used to add their diverse inscriptions to create a whole group model that incorporates the expansive range of children's inscriptions, ideas, and ways of understanding the science concepts and ideas. During the share out process, students can be given the option to go back and add to or revise their models as they learn new ways to model processes or sequence ideas. This strategy is part of creating a responsive classroom where we are showing students that we value their time, ideas, and efforts towards building knowledge collaboratively.

Establishing a Culture of Collaboration

In order to cultivate a knowledge building community, it is important to start developing these intellectual relationships early in the school year. Ms. T strives to design a learning environment in which her primary roles are as a facilitator and mentor for the community as children develop both social and intellectual relationships with each other. She recognizes that this is a shift away from the traditional authoritarian role of the teacher to one that seeks to be liberated from "managing behavior". Establishing a culture of collaboration at the beginning of the school year allows for children to develop agency as they share the responsibility of establishing expectations and consensus about how they would like to be in relation with each other. One strategy for supporting the shared nature of responsibility is to engage children regularly in metacognitive activities (Bransford et al., 2000) to better understand the purpose behind the science activities and discussions. Ms. T calls it "talking about our talk" and children pause from lessons to sit together and have conversations about questions such as "*Why do you think it is important to share our models with each other?*" or "*Why should we be good listeners when others are talking?*". These opportunities provide time for the community to engage in reflective conversations to establish the purpose for intellectual activity and troubleshoot issues that may arise. One such episode occurred as children worked in "science teams" to discuss ideas about energy, as children shared out from their teams one child shouted "Hey! You stole our idea.". In that moment the teacher paused the lesson and the children sat to discuss how different teams might have similar ideas and asked children to think if all ideas belonged in the circle of learning. The teacher facilitated the conversation and posed the questions "Is it okay to have the same idea as another team?" and "Is it okay to a different idea than others?" children shared out their feelings and ideas and after ten minutes of discussion they decided that teams can share the same idea. Then one by one, students were invited to move their magnet pictures inside the circle of learning to represent themselves as members of a community (Figure 20). The issue of "copying ideas" did not emerge again after that conversation, instead children learned and used the sign language symbol for agreement during discussions.

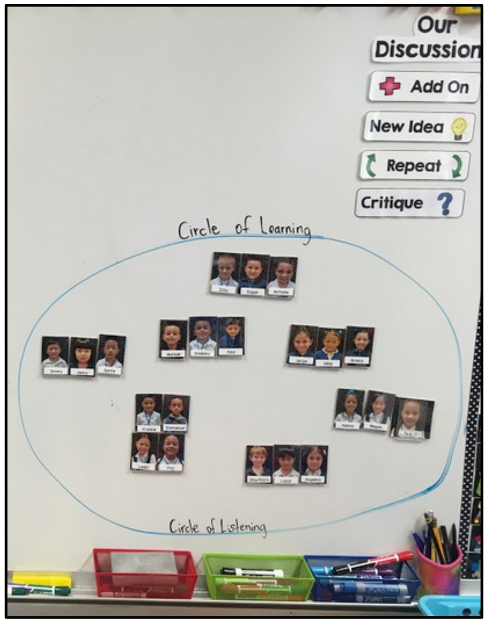


Figure 20. Tools for supporting equitable and inclusive participation.

Table 2

Key Features of a Knowledge Building Community

Four Key Features of a Knowledge Building Community
Sustained Intellectual Engagement on a complex and relatable question or problem: Time is essential for supporting all children to engage in meaningful science learning. The discussions and activities should connect back to answering and understanding a central question, problem, or engineering project. Teachers may need to be creative with their schedule, particularly in the early grades to ensure there is enough time for rich sense-making discussions and investigations. There are many examples of rich phenomena that are part of our everyday lives that can be used to engage students in deep conceptual knowledge building. Examples include: ● Weather Events: snow days, icy roads, atmospheric rivers, seasonal changes. ● Kitchen Events: pressure cookers, heating and cooling foods, pop can freezer explosions, baking foods that rise with yeast. ● Playground Events: Ziplines and simple machines, swings and motion patterns, wet slides and increased speed. ● Outdoor Events: Crows and garbage, seasonal bird nesting behaviors, insect

behaviors on plants and in different places.
Equitable Discussions support all children in participating diversely and collaboratively while encouraging multiple ways of knowing, doing, and communicating science ideas. Valuing diversity in discussions requires that educators be present with children and their ideas as they consistently seek opportunities to view children and their contributions from an asset-based perspective. Examples include: ● Use children's magnet faces and the discussion web to visiblize who has shared ideas and what kinds of ideas they have shared. ● Consider planning to check in or make close observations of 4-5 students each discussion, take notes about what you observe. Over the course of 1-2 weeks you will have some additional data that will help you inform your instruction or that you can use to follow up with particular students to ask questions and build rapport.
Modeling is a key component for children to build knowledge if they are provided with multiple and diverse opportunities to revise their ideas, share their models, give and receive feedback, and collaborate with others to engage in the modeling process. Examples include: ● Use a range of models and representations to support student engagement. Models can be on paper, laminated into a large chart paper, actual representations such as a toddler slide can all be used to support diverse participation. Allow children to use a range of tools such as markers, pencils, construction paper. Some children enjoy acting out the phenomenon with costumes or simple hand held puppets.
Establish a Culture of Collaboration: Early in the school year in order to co-construct expectations for science learning and share the responsibility across the community to build intellectual relationships with each other. The teacher's role shifts away from authoritarian to facilitator and mentor who guides and supports the community in sustained science learning. Examples include: ● Design for multiple and diverse opportunities for children to participate both indoors and outside of the classroom. Consider asking children to take a walk around the schoolyard or with their families to look for science concepts such as ramps, forces, and motion. Then include those stories in classroom discussions. ● Look for inequities in participation- "who do you notice not raising their hands or appearing hesitant to engage in discussions". Consider grouping students according to their self-identified friends and encouraging students to use their home languages in class during small group discussions. ● Routinely share with children as they contribute ideas that their ideas are important, valued, and help the community to build knowledge.

As we organize and set-up our classrooms for another year of dynamic learning, consider the importance of a knowledge building community in supporting children to engage in robust scientific practices such as modeling and communicating explanations. As educators who care deeply about student learning and engagement in science we can reflect and consider how we organize learning opportunities to support diversity in discussions and use children's natural capabilities to create and revise models for the purpose of sense-making. Part of this work entails shifting away from an individualistic perspective on learning and adopting a more collaborative perspective on how knowledge can be built which is well supported by research (Lee et al., 2019; Scardamalia & Bereiter, 2006). We can support our students both as individuals and as productive members of a learning community as they engage in the exciting work of growing their knowledge in science.

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