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Learning Environments before Kindergarten: Developmental and Policy Considerations through an Ecological Lens

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Learning Environments before Kindergarten: Developmental and Policy Considerations through an Ecological Lens

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Education

by

Melissa S. Dahlin

Dissertation Committee:
Professor Stephanie M. Reich, Chair
Associate Professor Jade M. Jenkins, Co-Chair
Assistant Professor Andres S. Bustamante

2022

DEDICATION

To

my family, friends-like-family, and mentors

Thank you for accompanying me, guiding me, and supporting me on this most unexpected of journeys.

Not all those who wander are lost.
J.R.R. Tolkien
The Fellowship of the Ring

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ACKNOWLEDGEMENTS

First, I want to thank my advisors Dr. Stephanie Reich and Dr. Jade Jenkins. Your unwavering commitment to mentoring and coaching me were essential to my success in the program and molding me into a researcher. Thank you to my committee member Dr. Andres Bustamante and my proposal members David Purpura and Barbara Sarnecka, whose insights helped me grow as a researcher. And a thank you to all the School of Education faculty who taught me, listened to me, and provided thoughtful feedback and guidance.

It has been a very long road to this dissertation - a destination I never even imagined until a few years ago. Countless folks have intentionally, or more often unintentionally, provided opportunities and insights that led me to this PhD path. Countless more have kept me company, motivated me, and supported me in reaching this milestone.

My parents' belief in the value of education and my mom's years as a Kindergarten teacher paved the way but what really got me on the road to a PhD was Jonny Hwang's suggestion in 2005 to teach in Taiwan. I think each of us expected a lot of partying and adventures (which was certainly true!), but no one imaged that move would ultimately lead to a PhD in 2022. It was Taipei where Kristi Arnold encouraged me to take up her pre-k class when she moved. And that is how I met the kids, families, and staff at Kiddoland Montessori School who made me fall so very, very hard for early childhood education (ECE). That love for early education brought me to Teachers College, where Lynn Kagan, Jeanne Brooks-Gunn, and Rebecca Gomez exposed me to intersection of ECE research and policy. This led to me to DC where I learned from the expertise and wisdom of my Center on Enhancing Early Learning Outcomes colleagues. They inspired me to think more deeply about research and helped me see myself as someone who could conduct research. A special shout-out to Jim Squires, whose innocuous comment of, "Have you thought about UCI?" led to me back to my undergrad alma mater, UCI. To my mentors Lori Connors-Tadros, Jana Martella, and Diane Schilder – thank you, thank you, thank you!

And then there are all the folks who kept me going. My family fostered a curiosity of life, desire to understand how the world works, and a love of observation that certainly were useful in a doctoral program. However, it has been their love, support, and encouragement that has been instrumental in my perseverance through such an arduous program. Mom, Dad, Grammy, Auntie Christina, Uncle Kurt, Andrew, Hayley, Collin, Katie, Nico – time to celebrate! Grandpa, Grandma, Aunt Nancy, and Grampy – you may not have made it to the completion of this milestone in person, but the time I had with you cultivated the inner strength that guided me though the work.

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Finally, thank you to Alexandre Chen, Pugjin, and the Chen family for making sure I was fed, taken care of, and loved during the last few years. Pugjin endured a lot of cuddles and became an unofficial emotional support dog. Alex – you prioritized my well-being and did whatever you could to ensure I made it through the final steps of this journey. Thank you.

VITA

Melissa S Dahlin

EDUCATION

PhD **Expected 2022, University of California, Irvine**
Irvine, CA. Education

MA **2012, Teachers College, Columbia University**
New York, NY. International Educational Development

BA **2003, University of California, Irvine**
Irvine, CA. History, Minor in Criminology, Law, and Society

RESEARCH INTERESTS

My research interests span early childhood development and early childhood policy, as I believe engagement in both fields supports a more holistic understanding of proximal and distal influences on a child's development. My main focus is early mathematical development and how families engage in mathematics with their young children.

PEER-REVIEWED PUBLICATIONS

Dahlin, M.S. & Reich, S.M. (2022). Head Start programme participation and BMI change: Roles of family partnership and age of entry. *Health Education Journal, 81*(3), 337-351, 00178969221081805.

Reich, S.M., Tulagan, N., **Dahlin, M.,** Kerlow, M., Cabrera, N., Piroutek, M.J., & Heyming, T. (2021). Caregivers' experiences during the COVID-19 pandemic and their young children's behavior. *Journal of Family Issues, 0192513X211055511.*

Dahlin, M.S., Díaz, G., Jenkins, J.M., & Reich, S.R. (2020). Head start family services: Family characteristics as predictors of service use by Latinx families. *Children and Youth Services Review, 118,* 105376.

Martin, E., Ocampo, C., **Dahlin, M.S**., Reich, S.M., & Cabrera, N. (under review). How new mothers' and fathers' allocation of tasks relate to coparenting relationships.

Reich, S.M., Liu, Y., Tulagan, N., Martin, E., **Dahlin, M**.**S**, & Cabrera, N. (under review). Applying a family stress model to understand patterns of stress, media use, and child behavior during the COVID-19 pandemic.

Reich, S.M., Tulagan, N., **Dahlin, M.S.,** Labaff, S., Dutt, N., & Rahmani, A. (under review). Pregnant in a pandemic: Connecting perceptions of uplifts and hassles to mental health.

Whitaker, A., & **Dahlin, M.S.** (under review). Family service use in Head Start: The impact of family participation and demographic predictors of service use.

RESEARCH PRESENTATIONS

Dahlin, M.S., Reich, S.M., Kerlow, M., Cabrera, N., & Heyming, T. (2021, April 8). *Caregivers' experiences during COVID-19 and their young child's behavior.* [Virtual poster presentation]. 2021 Society for Research in Child Development Biennial Meeting.

Martin, E., Ocampo, C., **Dahlin, M.S.,** Reich, S.M., & Cabrera, N., (2021, April 9). *The relationship between how mothers and fathers divide tasks and their coparenting relationship quality*. [Virtual poster presentation]. 2021 Society for Research in Child Development Biennial Meeting.

Dahlin, M. (2020, December 2). *Head Start family services: Family characteristics as predictors of service use by Latinx families* [Virtual poster presentation]. 2021 Society for Research in Child Development Biennial Meeting.

Dahlin, M.S., Reich, S.M., & Jenkins, J.M. (2019, June 1). *Understanding uptake of services by families: Demographic contributors to service utilization in Head Start.* Poster presentation at the 2019 NAEYC PLI Institute, Long Beach, CA.

Dahlin, M.S., & Reich, S.M. (2019, June 28). *The do's and don'ts of a building a university-organizational partnership.* Poster presentation at the 2019 SCRA Biennial Conference, Chicago, IL.

RESEARCH EXPERIENCES

Baby Books 2 Project, 2018 - 2021

- Co-wrote surveys protocols and design surveys in Qualtrics to support a random control trial study exploring the impact of books with parenting tips on parenting practices and child outcomes.
- Trained and supervised 8 undergraduates on coding for math talk in video-taped parent-child interactions.

Haynes Foundation Head Start Project, 2018 - 2019

- Transformed administrative data into a research database covering five years of program data from a Head Start program (10,222 children, 9,522 families, 145 classrooms, and 389 teachers).

FELLOWSHIPS, HONORS, AND AWARDS

School of Education Pedagogical Fellow 2021, University of California, Irvine

- Participated in a yearlong pedagogical training, culminating in the instruction of 21 incoming doctoral students to prepare them for teaching in higher education during Fall quarter through the Teaching Assistant Professional Development Program.

Associated Doctoral Students in Education Service Award June 11, 2021

- Annual award to student who go above and beyond in service to the School of Education that was voted on by student body.

SERVICE

President (10/2020 – 10/2021) **| Vice-President** (10/2019 – 09/2020)
Associated Doctoral Students in Education (ADSE), University of California, Irvine

Board Member-at-Large, Members Services Chair (10/2019 – 06/2021)
Orange County Association for the Education of Young Children

Representative, School of Education (01/2018 – 02/2021)
Associated Graduate Students (AGS), University of California, Irvine

UNIVERSITY TEACHING EXPERIENCE

- Co-instructed undergraduate courses with 90- to-150-person enrollment. Courses included: Introduction to Early Childhood Education; Family, School, and Community in Early Childhood; Cognition and Learning; Multicultural Education in K-12.
- Delivered 18 guest lectures focused on early childhood mathematics, early childhood policy, Early Head Start/Head Start, and family engagement practices.

ABSTRACT OF THE DISSERTATION

Learning Environments before Kindergarten: Developmental and Policy Considerations through an Ecological Lens

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Melissa S. Dahlin

Doctor of Philosophy in Education

University of California, Irvine, 2022

Professor Stephanie M. Reich, Chair

Associate Professor Jade M. Jenkins, Co-Chair

From birth, children’s environments pose opportunities for learning experiences that can foster their school readiness at kindergarten entry (Shonkoff & Phillips, 2000). A key environment for infants and toddlers is the home, where they develop in the context of interactions with their families. Another key environment are formal learning settings such as preschool, though distal policies influence the extent to which children can access them. This dissertation takes an ecological approach to understanding these proximal and distal influences on children’s school readiness (Bronfenbrenner & Morris, 2006). A strength of the dissertation is the use of samples that include fathers and also represent the experiences of non-white, bilingual families.

Studies 1 and 2 center on the home by exploring the mathematical environments infants and toddlers engage in with their parents. Study 1 codes video-recorded parent-child interactions during play to identify the extent to which parents use gestures with talk about mathematics. Study 1 findings show that while overall frequency of math gestures is low, parents vary considerably in their gesture use. It also finds that mothers engage in math gesturing more frequently than fathers, suggesting that parental nonverbal communication patterns differ by parental gender.

Study 2 explores the extent to which English-derived coding schemes of parental spatial talk that are translated to Spanish undercount expressions of spatial concepts by excluding verbs, which in Spanish can implicitly convey spatial concepts (compared to English, which primarily uses prepositions). By creating a Spanish-derived coding scheme to compare to results with the English-derived coding scheme, Study 2 finds that nearly half of the amount of discourse is missed when using an English-informed coding procedure because verbs are not included.

Finally, Study 3 uses an event study to estimate impacts of a federal policy on enrollment of 4-year-olds in pre-k, which is important because of its focus on school readiness skills. Results indicate that awarded states increased enrollment numbers; however, there is evidence of a positive policy diffusion effects in which non-awarded states went forward with increasing enrollment as well. Collectively, these studies demonstrate that taking an ecological approach that examines both children’s in-home experiences and access to out-of-home learning provides a more nuanced understanding of children’s experiences before they enter kindergarten.

Chapter 1: INTRODUCTION

Environmental contexts, intertwined with biological factors, contribute to young children's developmental trajectories and later outcomes. These trajectories begin to diverge in the earliest years, with gaps emerging in children's cognitive, health, and social-emotional development (Doyle et al., 2009). Developmental neuroscience research demonstrates that early experiences matter greatly in the earliest of years when synaptogenesis and plasticity are highly salient (Oh et al., 2018; Pace et al., 2017; Shonkoff, 2010). Further, contexts such as socio-economic status (SES), usually measured through household income and parental education status, are linked to brain development during early childhood (Troller-Renfree et al., 2022). For instance, cortical thickness, which is important for later developmental outcomes, begins to differ between children in well-resourced and less-resourced homes at a young age (Wang et al., 2019). Children reared in low SES environments tend to have faster cortical thinning during childhood and the adolescent years, indicating an environmental role (Tooley et al., 2021; Wang et al., 2019).

Fortunately, children's earliest years are also marked by higher brain plasticity (i.e., receptiveness to change) than older children and adults (Elliott et al., 2020; Shonkoff, 2010; Tooley et al., 2021), indicating the early childhood years as a prime age range to target interventions via practices and policies. The neural circuity necessary for some skills relies on experiences, though some are experience-expectant while others are experience-dependent. Experience-expectant skills are those in which outside inputs trigger experiences that the brain "expects" to have. The timing of these experiences matter greatly for some skills (Elliott et al., 2020), as evidenced by "critical periods" in which the child <u>must</u> receive certain environmental inputs for typical development as wells as "sensitive periods" of malleability (Hensch &

Bilimoria, 2012). For instance, language acquisition has a sensitive period in the years before school entry – language proficiency declines the older a child is when exposed to a language (Hartshorne et al., 2018; Johnson & Newport, 1989). Experience-dependent plasticity is not "expected" by the brain, but happens as individuals encounter learning experiences in their environment that strengthen certain synaptic connections (Elliott et al., 2020). Early childhood is believed to a particularly important time for intervention for a variety of foundational skills, including inhibitory control, early numeracy, and the approximate number system, as well as addressing reading disabilities, all of which are both experience-expectant and experience-dependent processes (Park & Mackey, 2021). Such opportunities drive the early learning and environment focus of my dissertation studies.

Children's environments vary in terms of where, how, and with whom they spend their time. For instance, children spend time in their home with parents, with or without extended family, in child care settings that vary in type (e.g., center-based, home care), quality, and length of stay, and in their wider community (e.g., parks, community programs, places of worship). As these settings vary, so do children's experiences within them – parenting practices, teacher-child interactions, peer-peer interactions, and learning environments (e.g., materials) are just a few examples.

Early Environments and School Readiness

Understanding the heterogeneity in early experiences is important because children enter formal school (i.e., kindergarten) with vastly different skills. This is particularly concerning because early literacy and math skills predict later skills, with children moving in different academic trajectories from a very young age (Duncan et al., 2007; Morrison et al., 2019). Thus, understanding early experiences can provide insights into contributors to differences in school readiness, which could then be targeted through intervention.

The literature describes socio-economic status as a known predictor of childhood outcomes (Duncan et al., 2018; Troller-Renfree et al., 2022). Children in higher-resourced contexts often experience more optimal outcomes than their less-resourced peers. For instance, children in high SES-contexts demonstrate better language achievement, potentially due to a configuration of child characteristics, parent-child interactions, and learning resources available (Pace et al., 2017). High SES is also associated with higher executive function, memory, and emotion regulation (Hua & Wang, 2021).

Yet, it is important to consider within group variation. SES is a large bucket that masks the heterogeneity of families. Similarly, race, ethnicity, country of origin, immigration status, and language tend to be presented as a monolith in research. Yet, these demographic factors intersect with parenting beliefs, practices, child interests, work demands, and stressors in the environment in nuanced ways (Brooks-Gunn & Markman, 2005; Cabrera et al., 2006, 2007; Coba-Rodriguez et al., 2020). For instance, while maternal education has been linked to child language outcomes, this relationship may be mediated through such things as maternal reading beliefs, home learning environment quality, and reading frequency (Farver et al., 2006; Gonzalez et al., 2017; Mistry et al., 2008). The samples in my studies include a diverse set of low-to-middle income families that are predominantly non-white, speak a language other than English, and include immigrants, enabling more opportunity to study within group variation.

Early Environments and Mathematical Development

Two studies in this dissertation focus on a specific school readiness domain – mathematics – and what direct experiences in the home with parents look like. Children's development and growth in mathematics has implications for their everyday skills throughout life as well the choices of career trajectories available to them (Pew Research Center, 2016). Daily activities necessitate mathematical skills. Children and adults use mathematics when they cook, navigate spaces they move through, use maps, practice financial literacy, and engage in positive health-related behaviors (Clements et al., 2003; Jansen et al., 2016; Peters et al., 2017). Yet, children's mathematical skills, even at their initial entry into kindergarten, have much to do with distal outcomes, as early math skills are predictive of later math skills (Duncan et al., 2007; Ricciardi et al., 2021). At school entry, there is already a gap in mathematical knowledge between children from families earning low incomes and their peers from higher resourced contexts (Rouse et al., 2020).

Thus, increasingly, developmental researchers recognize children's years before kindergarten as a critical starting point for supporting a strong mathematical trajectory in the years leading up to elementary school. Research shows that children are already on different mathematical paths by the time they are age three (Starkey & Klein, 2008), suggesting a need to start young when thinking about the mathematical exposure and practices children receive. While early child care experiences play a role, the home environment of young children also contributes to later child outcomes (Tamis-LeMonda et al., 2019). For instance, interactions between parents and their young children are associated with children's school readiness across a multitude of domains, including mathematics (Turnbull et al., 2022).

Policy Impacts School Readiness Opportunities Outside the Home

In addition to exploring the home environments where children spend their time and directly receive development supports, it is also important to examine policies that influence access to pre-kindergarten (pre-k) that may influence their exposure to and quality of mathematical input when in care outside the home. Quality settings matter for young children's cognitive development and school readiness skills and, thus, it is important to understand if children are in settings associated with higher or lower quality early learning experiences (Carr et al., 2019; Soliday Hong et al., 2019). Public pre-k is associated with improved mathematical outcomes at school entry, though evidence also suggests that it is the use of math-specific curriculum that plays a critical role (Klein et al., 2019; McCormick et al., 2022; Nguyen et al., 2018).

Exploring Home and Policy Contributors to Children's Early Learning Experiences

The studies in this dissertation focus on social and cultural contributions to children's mathematical development by unpacking direct contributions of home, including non-verbal math communication (i.e., gestures) and the intersection between mathematics and parental language. First, I conducted a descriptive study to capture how parents pair non-verbal (i.e., gestures) with verbal mathematical communication during play interactions with their child. Then, I explored the extent to which an English-centric approach to coding mathematical language adequately captures the math talk (i.e., parental language that uses mathematical terminology or expresses mathematical concepts) young children receive in homes where parents speak Spanish (Anderson et al., 2005; Klibanoff et al., 2006; Susperreguy & Davis-Kean, 2016). My third study, which estimated how a federal grant competition impacted enrollment in public pre-k, has indirect implications for school readiness because of pre-k's focus on preparing children for elementary school. If enrollment increases as a result of the grant competition, then children have more access to environments specifically designed for school readiness.

These studies provide much needed insight into the types of mathematical interactions children engage in with their parents in the home, as well as the types of early learning settings they have access to in the years before they enter formal schooling. By using a biological systems theory framework, my studies address multiple layers in the child's context.

Theoretical Framing

Bioecological Systems Theory

Early experiences place children on different trajectories towards their formal schooling pathway, and this dissertation sought to explore the components of early childhood ecologies that contribute to school readiness in mathematics. Thus, I used bioecological systems theory (Bronfenbrenner & Morris, 2006) to frame my studies. This theory describes how direct and indirect forces, as well as time, interact to influence a child's development. Studies 1 and 2 focus on the microsystem where children engage directly with adults, materials, and language. For these studies, I focused on parental input of mathematical concepts through non-verbal communication (i.e., gestures) during play with toys (Study 1) and how verbal communication may differ in terms of lexical output and conceptualization of spatial mathematical language between Spanish and English (Study 2). Finally, laws and policies generated in the exosystem also influence children's direct environments, which may in turn impact their exposure to mathematical language and concepts prior to school entry. In the case of pre-k, policies influence the access to and quality of settings in which children spend time outside the home (Study 3).

Microsystem and Cultural Microsystem

In the microsystem, adults play a critical role in children's development through relationships and interactions that unfold between adults and children (Institute of Medicine and National Research Council, 2015). While a child's brain development and cognitive maturation promote increased ability to engage in mathematics, adults in the microsystem facilitate opportunities for exposure to mathematics and guide children in more advanced math development (Jordan & Levine, 2009). Adults provide math talk, gestures that model or facilitate learning, and mathematics-infused materials (e.g., puzzles, blocks, books). These inputs build more knowledge and skills than children would develop on their own (Jordan & Levine, 2009; Ramani & Eason, 2015). Additionally, children must develop procedural and conceptual mathematical knowledge to succeed in mathematics (Ramani et al., 2015; Rittle-Johnson, 2017). In the microsystem, adults can model procedural knowledge and provide children opportunities to practice it. They can also model conceptual thinking in conversations with children and encourage children to demonstrate their own conceptual knowledge. These are key areas for development to meet the Common Core State Standards in Mathematics that begin in kindergarten (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010).

A major contributor to young children's development is the home environment where they spend significant amounts of time engaging in interactions with their caregivers. Children are theorized to be born with generalized magnitude systems and implicit principles around numeracy that guide development in counting (Gallistel & Gelman, 1992; Mix et al., 2016). Children engage in mathematics in their earliest years, thus understanding the mathematical input and supports young children receive from individuals in their microsystem from infancy onward is important to map out how innate interest and environmental contributions intersect over the years before children enter kindergarten. Home mathematical environments are considered an area to target to prevent socio-economic status (SES)-related (i.e., parental education, occupational prestige, income) gaps in mathematical achievement (Galindo & Sonnenschein, 2015).

Recognizing that culture is infused in the daily practices young children engage with, I consider culture in the microsystem. The concept of cultural microsystems addresses the discrepancy between the original placement of culture as a distal influence in the macrosystem and the reality that individuals are not separate from their culture (Vélez-Agosto et al., 2017). Study 2 demonstrates that cultural processes such as language features (e.g., embedding location in verbs) may directly influence development, in this case how spatial mathematics is conceptualized. Studies 1 and 2 both contribute to understanding of cultural microsystems, as the sample and analysis approach are more sensitive to within group heterogeneity compared to studies that use categorical variables of race, ethnicity, immigration, or income to group families into broad demographic buckets. Children in the US are increasing non-white and bilingual, (Crosby et al., 2016; Johnson, 2020). The samples for Studies 1 and 2 in this dissertation include non-white children, primarily Latine children, growing up in multilingual households, which provide insights into the experiences of a growing demographic in the US.

Exosystem

In Study 3, I move from the microsystem to the exosystem, where policies crafted in distal environments ultimately influence young children's access to high quality settings within their microsystem. The quality of early learning environments is associated with children's later math performance (Dearing et al., 2009; Loeb et al., 2007; Rispoli et al., 2019). Access to no-cost early learning experiences, such as child care, Head Start, and public pre-k, has been touted as a mechanism for improving school readiness of young children, particularly for children who reside in low-income households or neighborhoods, have parents who are immigrants, or who are multilingual (Crosnoe, 2007; Morrissey & Vinopal, 2018; Padilla, 2020). For instance, participating in Oklahoma's pre-k program improved the pre-math skills of Latine children born outside the US and whose families spoke Spanish in the home; recent results demonstrate extended benefits into high school (Amadon et al., 2022; Gormley, 2008).

Chronosystem

These three dissertation studies provide insights into early learning environments in the home for infants and toddlers, which are important foundations for the development of school readiness skills (Studies 1, 2). Understanding mathematical experiences at this age is important because evidence suggests that when number knowledge skills are low at the preschool-age, this in turns supports a shallow trajectory of math development throughout the elementary school years (Garon-Carrier et al., 2018). My third study transitions to the preschool year prior to kindergarten (i.e., age 4), to understand how policy can motivate creation of public pre-k slots (i.e., availability of enrollment into pre-k) with implications for improved access to pre-k settings, which are associated with school readiness skills (Ansari & Winsler, 2016).

Funds of Knowledge Theory

Studies 1 and 2 are focused on gaining a better understanding of how mothers and fathers engage in mathematical communication with their very young children. One goal is to potentially identify naturally occurring practices that are not recognized or included in existing measures of math talk, particularly for families who identify as Latine and/or use Spanish with their children during interactions. Funds of knowledge refer to the knowledge and skills families contribute as they engage with their child, and reflect social, historical, and cultural components (Williams et al., 2020). The literature on mathematics and funds of knowledge is small, particularly for the infant and toddler age range, though growing (Leyva, 2019; Melzi et al., 2018). How Latine families engage in math socialization at home has been understudied, despite its potential to uncover strengths in these home environments (Galindo et al., 2019) and that in five states (AZ, CA, NM, NV, TX), Latine children represent over 40% of children in the state (KIDS Count Data Center, 2021). Thus, this dissertation aims to add to this literature by increasing the representation of Latine children in research of mathematical development and school readiness. Importantly, it considers the heterogeneity within low-income families and focuses on the strengths they bring.

Home, School and Policy Matter for Mathematical Development

Children develop in social environments within the cultural contexts of their home, formal outside-of-home learning settings, neighborhoods, and the larger society. While cognitive components to math (e.g., executive function, brain maturation) are important, so too is the contribution of social environments that foster exposure to and provide opportunities to engage in hands-on activities to practice mathematical skills and thinking. Mathematic-specific language inputs are necessary for math development (Purpura et al., 2017) as are activities that support math conversations. These include playing board games (Ramani & Eason, 2015; Ramani & Siegler, 2008), joint book reading (Hojnoski et al., 2014; Vandermaas-Peeler et al., 2009), food routines (Leyva et al., 2018), and block play (Ferrara et al., 2011; Ramani et al., 2014). To better understand children's school readiness in mathematics, it is important to understand children's mathematical exposure in homes as they are a place where very young children spend the majority of their time and are exposed to ongoing informal and formal learning opportunities.

Key Aspects of the Home Math Environment

Math Talk

In homes, children have opportunities to listen to and engage with their parents in mathematical talk. This includes exposing children to concepts, asking children to talk about math (e.g., asking "How many ducks?" when reading a book about ducks), using spatial language (e.g., asking children to select items “next to,” “behind”, or “above” other items), modeling or encouraging conceptual thinking (e.g., “How do you know?”), and demonstrating cognitive tools in mathematical thinking (e.g., “First, I …”). This is important for several reasons. Exposure to mathematical talk (“math talk”) is related to children’s mathematical skills in understanding the cardinal principle (Gunderson & Levine, 2011), counting and labeling (Mix et al., 2016), and advanced mathematical concepts (Ramani et al., 2015). For instance, when listening to audio recordings of naturalist interactions between mothers and young children at home, children who received more math talk from their mother had higher mathematical skills a year later than those who received less verbal mathematical input (Susperreguy, 2016).

However, it is not just the amount, but also the quality of talk that matters (Cartmill et al, 2013). Children whose parents used advance number concepts had a better understanding of these concepts (e.g., numerical magnitude understanding) than those whose parents did not use them (Ramani et al., 2015). Despite the association between math talk and child outcomes, parents engage in math talk at low levels in both observational and parent-reported data and they tend to focus more on literacy than math at home (Cannon & Ginsburg, 2008; Levine et al., 2010; Sonnenschein et al., 2012, 2016; Susperreguy, 2016). There is also variance by type of activity - parents and children used more math talk in formal learning and guided play interactions than in unguided play (Eason & Ramani, 2020).

Language of Parental Mathematical Input. The literature on parental math talk with young children primarily relies on samples of monolingual English speakers (e.g., Gunderson & Levine, 2011; Leech et al., 2021). This lack of information on speakers of languages other than English, as well as bilingual English and multilingual English speakers, warrants an exploration of whether there is full lexical inclusion and accurate capturing of conceptual contributions in research; in particular in the area of spatial concepts which may vary by whether the languages use propositions to convey this information (e.g., English) or verbs (e.g., Spanish). Languages vary in the way they convey mathematical concepts such as space, motion, and numerosity (Férez, 2010; Marchi Fagundes et al., 2021). This dissertation places additional focus on spatial skills, which are important predictors of spatial-specific as well as other mathematical skills (Mix, 2019; Rittle-Johnson et al., 2019). Importantly, it considers how this conceptual information might be transmitted differently in different languages. English conveys spatial talk primarily through propositions, whereas Spanish often embeds spatial concepts in verbs (Feist et al., 2007; Maguire et al., 2010). Because coding schemes that capture parental math talk are often designed and developed in English, these coding schemes tend to emphasize prepositions (e.g., in/on/under) and often do not include a robust set of verbs (Melzi et al., 2022). My sample includes a high proportion of Spanish speakers, posing an opportunity to explore the extent to which spatial math talk coding schemes translated from an English-centric framing may miss spatial math talk expressed through verbs or may not fully capture expressions of mathematics in a non-English language. Exploring math talk in a language other than English is important for researchers to understand the appropriateness and validity of the coding schemes when they are simply translated from English.

Parental Math Gestures. While there is increasingly more known about mathematics in home environments of young children, many gaps persist. For one, how parents use gestures in mathematical interactions with their children is understudied, despite evidence that use of fingers in mathematics is important for children's development of foundational mathematical concepts (Soylu et al., 2018). Adult-produced mathematical-related gestures provide additional supports in terms of demonstrating counting concepts (e.g., one-to-one correspondence), highlighting spatial features (e.g., next to, on top of), measurement features (e.g., length, width), and supporting quantification concepts (e.g., more or less). Gestures can also support procedural mathematics (e.g., using fingers to count manipulatives when practicing decomposition). While there is research on mathematical-focused interactions in formal and informal activities (Anderson et al., 2005; Eason & Ramani, 2020; Hojnoski et al., 2014), there is little on how parents use gestures in these interactions, especially with very young children. Study 1 examines gestures used by parents in home mathematical environments to provide needed illumination on the extent to which parents use gestures, the type of gestures they use, and when they use them. A benefit of Study 1 is its focus on experiences within low-to-moderate-income households. Children from low socio-economic status households tend to perform worse in mathematical assessments than their more economically advantaged peers - this may be due to experiences with math talk, parental math cognitions (attitudes, beliefs, expectations), and home practices (activities that contain mathematics) (Elliott & Bachman, 2018b). Study 1 and 2 explore mathematical practices inside the home. Study 1 captures both mothers' and fathers' use of gestures in mathematical interactions and Study 2 identifies spatial verbs used by Spanish-speaking parents. Much of the existing literature relies on observations or reports by mothers only. However, these studies fill gaps in our understanding of how fathers participate in mathematical interactions with their young children. Understanding these different facets will enable researchers to have a more comprehensive view of actors and practices that contribute to children's school readiness.

Main Issues and Gaps

Studies 1 and 2 address several limits in the literature as they relate to demographics. First, most samples in existing research on early childhood home environments capture the experiences of white and English monolingual children and families. Yet, the population of the

US is projected to be increasingly non-white (Vespa et al., 2020) and bilingual (KIDS Count Data Center, 2018), making it important to understand what learning looks like in homes of non-white children and children who are in bilingual or non-English dominant homes. Language and mathematical learning are tied together, but little is known about what home math environments look like for children raised with languages other than English (Daubert & Ramani, 2019), or the extent to which math talk procedures developed in English adequately capture mathematical concepts in Spanish. Study 2 addresses this issue, with implications for research and practice. Finally, the inclusion of fathers adds to a fuller picture of parental supports, which to date has primarily relied on samples of mothers when examining home mathematics. This is particularly relevant to Latine families as nearly three-quarters of Latine fathers live with their children and their partner (Karberg et al., 2017).

We know early math talk is important for school readiness, but how parents use math in interactions with their very young children, specifically how they use gesture to support that learning (intentionally or unintentionally) are not well understood. Study 1 provides insights into how parents use math gestures and includes a sample of fathers and bilingual English-Spanish speaking and monolingual Spanish speaking parents– populations that are noticeably absent in the current literature. This offers opportunities to explore heterogeneity within families who are typically grouped together as either "low-income" or in the same category of ethnicity, in this case Latine (McWayne et al., 2016; Vélez-Agosto et al., 2017), despite evidence that the intersection of race, immigration status, and language used by parents are associated with differing school readiness profiles (Lee et al., 2021; López & Foster, 2021).

Study 2 additionally contributes to our understanding of early math development as a school readiness skill by considering linguistic contributors to mathematics and how these may vary by language. This has several implications. First, for researchers studying parental math talk, Study 2's findings provide considerations for development of coding schemes that fully capture the lexical and conceptual contributors of a language to mathematical development. This contribution aims to address ethnic and anglophone bias in the measurement of math talk by ethnically and linguistically diverse families. In general, the design of measures on family processes or interventions, the vast majority have not included input by families who are not white or who speak languages other than English (Manz et al., 2010) and follows a more general anglophone bias in publishing (Fejes & Nylander, 2017). Secondly, findings from this study can be used to increase awareness by researchers and practitioners of the ways non-English-monolingual and bilingual families engage in and use mathematical communication. This supports increased practices that draws on families' funds of knowledge (Reyes et al., 2016; Williams et al., 2020).

Study 3 examines how a federal policy impacts enrollment in public pre-k across states. Policies play a role in fostering access to high quality learning environments because they can produce funding to increase the number of children served, create requirements around curricula and teacher training, and encourage or mandate quality measures. Both the quality and stability of childcare are associated with later academic skills (Bratsch-Hines et al., 2020; Peisner-Feinberg et al., 2001; Ruzek et al., 2014). Understanding the effectiveness of policies, which Study 3 seeks to do, provides insights into how policymakers can encourage growth in availability of pre-k learning experiences.

Conclusion

Collectively these three studies contribute to research, practice, and policy on children's school readiness, particularly in mathematics. First, they fill gaps in current research on how diverse low-to-moderate-income mothers and fathers engage in verbal and non-verbal mathematical interactions with their very young children, whether the lexical and conceptual mathematical input children receive from parents differ between use of Spanish and English, and how policies in one age group affect the types of care 4-year-old children receive (with implications for the quality of mathematical experiences they receive). Secondly, Studies 1 and 2 support identification of mathematical practices within a child's home context. Rather than clumping all lower income families together to compare against higher-resources families, these studies acknowledge that there is variability within families earning low wages that may differentially contribute to school readiness (Turnbull et al., 2022). They also provide insight into the funds of knowledge young children are exposed to at home, which may not be recognized in school readiness assessments. Finally, these studies provide insights that can inform the design of future policies that address home and early childhood classroom environments.

Chapter 2: Study 1 – Parental Gestures in Mathematical Interactions

Introduction

Research suggests that the mathematical trajectories of young children from low- and mid-to-high-income families are already on divergent paths by the time children enter formal schooling (Elliott & Bachman, 2018b; Starkey & Klein, 2008). The literature also demonstrates that young children engage in mathematics early, starting in infancy (Duffy et al., 2005; Mix, Huttenlocher, & Levine, 2002). This suggests that the home environment plays an early and important role in a young child's mathematical development.

There are several ways families can support their child's mathematical development. One pathway is through adults' use of mathematical language, referred from here on as "math talk," that exposes young children to mathematical terminology and concepts (Anderson et al., 2005; Klibanoff et al., 2006; Susperreguy & Davis-Kean, 2016). Other pathways include the activities children engage in with their parents, including board games, block play, art activities, reading books with mathematical content, using mathematics in home routines (e.g., measuring while cooking), and using math-related materials such as board games, blocks, art activities, math-related toys, and books with mathematical content (e.g., puzzles, cards) (DeFlorio & Beliakoff, 2015; Ramani et al., 2015). Yet, even within these activities, it is likely that the linguistic interactions embedded within the activity, specifically math talk, drive the learning opportunities.

For young children, learning mathematics requires the intertwining of exposure and language. The mathematical language inputs children receive from adults scaffold their mathematical knowledge, such as terminology and concepts (e.g., more or less, use of numbers to count and to map one-to-one correspondence). The mathematical language children produce and what they receive from adults in their environment (e.g., parents, teachers) are predictive of numeracy and spatial skills (Pruden et al., 2011; Purpura & Reid, 2016; Susperreguy & Davis-Kean, 2016). Additionally, emerging evidence indicates that the language(s) children speak influences onboarding of early number-word meaning (Sarnecka, 2014) and their perception of the world, with implications in particular for spatial skill development (Konishi et al., 2019). Understanding the math talk environments children experience at home is important to inform interventions to increase math talk by parents.

Mathematical language exposes children to math concepts and models mathematical thinking to young children. Yet, for very young children, it is likely that this verbal communication coupled with nonverbal communication (i.e., gestures) serve a particularly crucial role in facilitating learning of math and tools for math practices for the future. Gesture is a known component of language development, including both receptive and expressive language (Broaders et al., 2007; Iverson & Goldin-Meadow, 2005). Yet to date, the role gesture plays specific to mathematical language for very young children, and how adults use gesture with them, is largely understudied (Lee et al., 2015). Literature on preschool and elementary-age children suggests that the use of gesture by children is important in helping them learn mathematical concepts (Gunderson et al., 2015; Wakefield et al., 2019). Similarly, research with elementary-age children shows that gestures by adults can support children in learning mathematics and serve as a model for using gesture to engage in mathematics (Congdon et al., 2017). It would follow that for very young children (under age 2), the adults they interact with most also play a large role in modeling mathematical language and gesture use. This exposure likely supports children in learning concepts while also encouraging them to use gestures themselves. Largely unknown is if, how, and when parents use gestures alongside math talk.

Thus, this study focuses on the pairing of verbal and nonverbal communication by parents to convey mathematics concepts to their 9- and 18-month-old children.

Though math specific talk is a key aspect of how very young children learn mathematics, policy and classroom practice treat the development of math and language as separate domains, while guidance or inclusion of gesture being practically non-existent (Purpura & Reid, 2016). Research on the intertwined nature of mathematics and language, and in particular the nonverbal component of gesture, can inform policymakers, educators, parents, and other early childhood stakeholders in supporting optimal child mathematical development. To understand how parental math talk accompanied by gesture can support children's mathematical development, I first describe the relationship between math talk and early childhood development. Then, to understand why gestures may be a useful tool pair for math talk, I draw from the rich repository of research on gestures and general language development. Finally, I describe how gestures paired with mathematical talk is a promising, but understudied, avenue to explore.

Literature Review

The Role of Language Mathematical Development

Math talk by adults (e.g., parents) supports children's mathematical development through exposure to terms and concepts, along with adult modeling of mathematical thinking. Adults provide opportunities for children to gain more sophisticated mathematic skills as adults draw the child's attention to mathematical concepts and provide them with the vernacular needed to engage in mathematics (Eason & Ramani, 2020; Fisher et al., 2013; Skwarchuk et al., 2014). While children implicitly demonstrate awareness of some mathematical concepts (e.g., knowing what is more when offered a choice between one or two cookies), it is only through language-filled interactions that children gain more sophisticated mathematical concepts (Broaders et al., 2007; Gelman & Meck, 1983). For example, while children may be aware on an intuitive level that one set of objects is larger than another, it is the adult who provides the count number vocabulary, demonstrates one-to-one counting, supports cardinal principle understanding, and shows how to compare set sizes and identify which one has more or less.

Children's Math-Specific Language and Math Skills

Interest in mathematics language used by both adults and young children (i.e., "math talk") has fostered research into the amount and types of math talk children hear and produce, though this is often concentrated in the domain of numeracy. Previous studies have focused on general language use as a predictor of children's mathematical skills, finding that the higher a child's general language skills, the higher their mathematical skills (Purpura & Ganley, 2014). However, emerging evidence suggests that mathematic-specific language may be more important than simply having a high level of general vocabulary. For instance, a study of 136 preschool and kindergarten-age children found the association between a child's general language skills and numeracy skills lost significance when math-specific talk was included. The math-specific vocabulary, however, did have a positive association with the child's numeracy skills (Purpura & Reid, 2016).

Parental Math Talk Contributions and Children's Math Development

Levels of parental math talk, from infancy through 1st grade, have been shown to positively predict children's concurrent numeracy and spatial skills (Berkowitz et al., 2015; Pruden et al., 2011; Susperreguy & Davis-Kean, 2016) and teachers' use of math talk positively predicts preschool children's mathematical knowledge at the end of the school year (Klibanoff et al., 2006). Some evidence suggests it is not just the amount of mathematical input a child receives, but the complexity of the concepts presented to children before they enter formal school in kindergarten that informs their mathematical skills (Elliott & Bachman, 2018b). In a study of spatial training that compared modeling, gesture, and spatial language feedback by adults improved preschoolers' performance of 2D spatial knowledge (measured by the 2D TOSA), suggesting a role for adults in supporting children's spatial development (Bower et al., 2020). Thus, parental contributions via math talk are associated with children's mathematical outcomes.

Research to date on math talk has primarily focused on numeracy and spatial skills. For instance, Levine and colleagues (2010) found differences in the amount of number talk children ages 14- to 30-months heard at home, which ranged from 30 to 1800 number words in a week. They also found a positive correlation between the amount of parental number talk and children's understanding of cardinality at 46 months of age. A study of 3-year-old children's spatial skills identified SES-differences in children's performance and spatial language input from parents. Children from lower SES backgrounds received fewer spatial words from their parents and demonstrate lower spatial skills than higher SES children (Verdine et al., 2014). Less is known about the role of nonverbal communication, such as gestures that may complement terminology and concepts conveyed in math talk.

Parents are Amenable to Math Talk Interventions

Promisingly, emerging evidence suggests that parents are malleable to interventions that increase their math talk (Berkowitz et al., 2015; Eason & Ramani, 2020; Zippert et al., 2019). Parents who receive guidance on numeracy have been found to produce more mathematical language and, in turn, have children who produce more mathematical language than parents who do not receive guidance (Zippert et al., 2019). Similarly, children whose parents were prompted to provide formal instruction or guided play related to mathematics received more mathematical language input than children whose parents were in a "play as usual" condition (Eason & Ramani, 2020). While no interventions that we are aware of provide guidance to parents on use of math talk and gestures with very young children, this study can provide insight into the extent to which parents use gestures, and with which math concepts, that can be used to inform such interventions.

Gender Considerations – Parental and Child

While a substantial literature explores the role of adults in shaping children's math attitudes and achievement, less is known in the early childhood space (Gunderson et al., 2012), though evidence suggests a child's gender may elicit different mathematical input from parents. For instance, mothers have been found to provide more numeracy language to boys than girls (Chang et al., 2011). Further, parental use of spatial language with very young children (ages 2-3 years) has been found to be predictive of girls' spatial performance in first grade, but not boys' (Levine et al., 2012). In terms of parental gender, there is some evidence of gender-related differences in talk and child outcomes. In a study of use of spatial concepts with preschool-age children, the quality of spatial concepts fathers used predicted higher early mathematic scores for girls, but not boys (Thomson et al., 2020). Additionally, parent characteristics such as math anxiety and self-concept may influence whether their child takes a gendered-attitude towards math (e.g., math is for boys) (Gunderson et al., 2012). To date questions remain about the relationship of parental gender and child gender in early communication.

Child Temperament Considerations

Children's temperament influences the ways in which parents engage with their young children and the quality of that engagement (Bates & Pettit, 2007; Gagnon et al., 2014; Kiff et al., 2011; Kirchhoff et al., 2019). For instance, observational studies find high levels of parental engagement during play when children's expression of emotional intensity is low and lower levels of parental engagement in play when children's gross motor activity is high (Kirchhoff et al., 2019). Children's temperament is associated with the extent to which children engage in, or do not engage in, play (Gagnon et al., 2014). If parents or children engage in less play or differential types of play due to the child's temperament, it is possible there would be less opportunity for math communication, verbally or nonverbally, to occur during play. Thus, this study will take into account child temperament to account for contributions that these individual characteristics may make in how parents engage in play with their infants and toddlers.

The Role of Gesture

General Language and Gesture

Gestures are a form of non-verbal communication that often complement and enhance spoken language. Research on language development has found that gestures play an important role for children in communicating knowledge – both for comprehension and production (Novack et al., 2014). Studies consistently find that use of gestures by adults, including parents, supports children's understanding, models for children how to use gestures, and supports learning (Casey et al., 2018; Clark & Estigarribia, 2011; Fusaro et al., 2014; Rowe et al., 2008; Vallotton et al., 2015). There is evidence of intergenerational transmission of gesturing - parental gestures with 14-month-old children predicted children's gestures and size of their vocabulary at 20 months (Rowe et al., 2008). Efforts to support parents' use of gestures could be a pathway to facilitate children's use of gestures earlier.

Supporting children's increased use of gestures is important for a number of reasons. First, gestures can help children communicate information that may not be in their verbal repository (Goldinmeadow & Wagner, 2005; Özçalışkan & Goldin-Meadow, 2005). For instance, children can point to an object when they do not yet know the name for the object. Second, increases in adult-produced gestures could promote children using more gestures (Özçalışkan & Dimitrova, 2013). Third, in early education settings, child-initiated gestures can support student learning by communicating the child's thinking to a teacher, who then adapts instruction based on mismatches between what the child says and the knowledge a gesture indicates (Goldinmeadow & Wagner, 2005). Fourth, it can lighten the cognitive load for the child by placing some of the "thinking" into the gesture so that the child has more cognitive resources available to consider the mathematic problem (Goldinmeadow & Wagner, 2005).

For young children, research also indicates a developmental purpose for gestures. Pointing, in particular, is a key component of language development during a child's earliest years. As children move out of infancy, they start to produce and understand pointing gestures as a means to communicate and as part of a social interaction. A meta-analysis of 25 studies published between 1978 and 2009 found a relationship between pointing and language (expressive and receptive) that was both concurrent and longitudinal (Colonnesi et al., 2010). For instance, children who understood and used pointing gestures earlier had higher levels of language ability when they were older. Whether parental intervention could encourage earlier pointing or elicit more gesturing comprehension and production by young children would be a useful avenue to explore.

Gesturing by adults serves an important role in general language development for young children because it is a means for adults to communicate information, expose children to a breadth and depth of vocabulary, scaffold more sophisticated concepts, and model use of gestures to support learning. Since language and mathematics are intertwined, gestures, which accompany language, should also serve important functions to support early mathematical development. While little literature exists on mathematical language and gestures in the early learning space, there is reason to believe gestures also facilitate learning in mathematics, and that parental use of gesture can be important for young children.

Mathematical Language and Gesture

The extant research on parent-produced mathematical gestures with very young children is small. However, the literature on elementary-age children demonstrates that teachers' use of gesture for mathematical concepts benefits children's learning through two pathways: 1) additional communication on concepts and 2) calling attention to a concept (Alibali & DiRusso, 1999). Production of gestures can serve an important role in deepening mathematical learning, with a connection between child gesture and mathematical performance (Broaders et al., 2007; Novack et al., 2014). A study with third grade students found those who received verbal mathematical instruction with concurrent gestures by a teacher retained the information and were able to generalize concepts better than those who did not receive gesture input with the verbal input or who received verbal input followed by gestural input (Congdon et al., 2017). In another study, children ages seven to ten years who received mathematical instruction paired with gesture performed better immediately after instruction and improved their performance 24 hours after instruction compared to children who received only verbal input (Cook et al., 2013).

The modeling of gesture by adults could promote children to begin using gestures when talking about mathematics. While there are studies of teachers' use of gestures in formal learning environments (i.e., school settings), few studies have examined the pairing of mathematical language with gestures in the context of parents' interactions with infants and toddlers. One notable exception is McGregor and colleagues' (2009) study of toddlers' understanding of the spatial term *under* when paired with a gesture or not. The researchers found that children who received spatial language with gestures from adults displayed a stronger understanding of *under* on the post-test using novel materials not used in training. The authors argued that parental gesturing reduced children's cognition load, emphasized location and movement as they relate to *under*, and made such knowledge more generalizable (McGregor et al., 2009).

We are aware of only one other study that has explored parental use of gesture in conjunction with mathematical-related talk with very young children (Lee et al., 2015). Researchers observed 24 children between the ages of 18 and 25 months during a 30-minute play episode with a caregiver (mostly mothers) and then coded for parental gestures used simultaneously with math talk. The dyad used researcher-provided toys that had embedded mathematical content and examined the types of gestures made by type of math construct. Parental gestures were concentrated in four types: collecting/grouping/sorting (30%), counting objects (22%), tapping (18%), and holding up fingers (17%). The authors found that few parents used pointing (7%), finger displaying (4%), or sweeping by pointing a finger and moving it across an array or a set of items (2%). There was only one instance of finger counting (i.e., using a finger to count items with one-to-one correspondence) or rote finger counting (i.e., using fingers to count with no objects), and no families used a V-shape (i.e., pointing to two specific sets of items using the index and middle fingers in a V-shape). The study also found that gestures were mostly initiated by parents, and children tended to gesture in response to parent math talk. While a first step in understanding what mathematical gestures look like in families, the sample was limited to monolingual English-speakers and nearly all parents were college-educated mothers. The opportunity to understand what mathematical-related gesturing by parents looks like in low-income, multilingual families that include fathers is a critical gap to fill.

It is important to study parents’ math gestures because these actions can serve as a model for children, which in turn may lead to children themselves gesturing while engaged in mathematical thinking. Such a transfer effect would aid children’s mathematical development. A long-standing literature demonstrates that even very young children use gestures in their early mathematical inquiries. Gestures such as using a finger to count an object seem to be important for young children in acquiring one-to-one correspondence (Alibali & DiRusso, 1999). The ability to touch an object is particularly salient to young children. Young children have an easier time counting objects they can touch (Gelman & Meck, 1983; Potter & Levy, 1968) and finger counting is important for cardinal, ordinal, and number comparison concepts (Moeller et al., 2011; Noël, 2005).

To better understand potential contributors to the unevenness of school readiness, gestures are worth exploring because they may play a role in the transmission of mathematical knowledge. Proficiency in mathematics at the start of kindergarten and a supportive home learning environment are associated with decreased socio-economic status (SES)-related achievement gaps in mathematics at the end of kindergarten (Galindo & Sonnenschein, 2015). This suggests prior experiences shape children’s mathematical skills at kindergarten entry, which are then important contributors to later math development. Filling the void in research on how and when parents use gesture with math talk, and how this influences children’s own use of gestures and mathematical language, is important. This line of research could illuminate possible ways in which unequal distribution of math talk paired with gesture contribute to the gaps in mathematical knowledge between low- and high-SES children as they enter formal schooling (National Research Council, 2009).

The current study

Parent-child interactions matter in early childhood, and while research on the word gap between high- and low-income families is well established (Elliott & Bachman, 2018a; Hart & Risley, 1995; Levine et al., 2010), only recently has there been inquiry into economic gaps in early mathematical language. This nascent focus on mathematical language between parents and their young children has centered on verbal interactions despite reasons to believe nonverbal communication, alone and in conjunction with mathematical language, is necessary. Research suggests that gestures may be important when produced by children (Graham, 1999; Gunderson et al., 2015) as well as parents (Rowe & Goldin-Meadow, 2009); yet there is scant research on mathematical gestures in economically diverse families, in particular on interactions between infants/toddlers and parents from low-income families, despite being a sizeable proportion of the US population. Addressing this paucity is important given that family inputs might be associated with increasing disparities in school readiness, especially for mathematics.

Additionally, there is little research on the home mathematical environments for children who are dual language learners (Kung et al., 2020). This study sample includes parents who are Spanish-speaking, English-speaking, and bilingual Spanish and English speakers, providing insight into these understudied populations. I hypothesized that bilingual families would use more gestures because gesture can serve as a scaffolding tool for parents who switch between two languages. Further, the vast majority of studies of mathematical interactions use samples of mothers, with fathers largely left out, and parenting dyads' practices unexplored. Based on literature exploring communication patterns for mothers and fathers (Tomasello et al., 1990; Wu & Gros-Louis, 2015), I hypothesized that mothers would use more math related gestures because mothers, in general, engage in more nonverbal communication with infants than fathers do (Briton & Hall, 1995). I also explored whether there is a "spillover" effect from one parent to another between waves. Parenting research finds that, over times, parents influence each other's parenting, particular from mothers to fathers (Baker et al., 2018; Shears & Robinson, 2005). I hypothesized that a spillover association would be found from mothers to fathers but not fathers to mothers. This study provides much-needed insights into how diverse low-income mothers and fathers use mathematical-related gestures during play with toys. My research questions were:

Research Question 1: How do parents pair gestures with verbal communication to convey mathematical-related concepts with their children at 9 and 18 months (i.e., infancy and toddlerhood)? If and how do these change from 9 to 18 months? Are there difference when parents use one language (English or Spanish) or two languages[1] during the observation?

a. How frequently are math gestures used by parents?
b. How frequently do parents use gestures for specific mathematical constructs (counting, cardinality, spatial, numeral recognition, sorting/grouping)?
b. Is there "spillover" from one parent to another from when the child is 9 months to when the child is 18 months?

Research Question 2: How does mathematical gesture use differ by parent and child characteristics?

a. How does frequency of gesture differ by parental characteristics (gender, language)?
b. To what extent does the frequency of gesture use by parents differ by child factors (gender, child temperament)?

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[1] Some parents identified as multilingual, however the observations in more than one language were limited to two, so I use the term bilingual in this study.

c. To what extent do parent and child characteristics predict frequency of math gestures?

Method

Dataset

Study 1 utilizes a subset of the observational data of parent-child interactions from the Baby Books 2 (BB2) project. BB2 is a longitudinal randomized control study funded by the National Institute of Child Health and Development (NICHD) and conducted jointly through the University of California, Irvine (UCI) and the University of Maryland (UMD). One of BB2's intervention aims is to increase infants' and toddlers' linguistic, cognitive, social, and physical outcomes through paternal and maternal mechanisms. The intervention design is hypothesized to increase positive parenting practices, improve coparenting relationships, and reduce parenting stress and depressive symptoms.

The study designers recruited low-to-moderate income, first-time parents in Orange County, CA and the Washington, DC area. In both settings, the study team used an array of approaches to reach the target population within the population's community. Recruitment activities included advertisements (e.g., flyers, posters, and information sheets) in public places (e.g., parks, community centers, food banks, bus stops, malls) as well as direct recruitment from public spaces, pediatric settings (e.g., pediatrician offices, WIC locations, children's hospital waiting rooms) and early learning settings (e.g., Early Head Start and Head Start).

To be considered eligible, each parent had to meet six criteria: 1) be cohabitating heterosexual parents, 2) be first-time parents, 3) have a child less than nine months old at recruitment, 4) be over 18 years of age, 5) be literate in English or Spanish enough to read, at a minimum, at a 1st grade competency level, and 6) have an annual family income under $70,000.

Participants were screened through a phone interview or a paper packet with a background form and literacy screener to determine eligibility.

Participants were randomized into one of four possible groups: a fathers-only intervention group, a mothers-only intervention group, a father-and-mother intervention group, and a control group. Parents received books from the research teams at several intervals in the study. Participants in the intervention conditions received an educational baby book specialized to the gender of the parent (i.e., father-only group: family received books written from a father's perspective, mother-only group received books written from a mother's perspective, father-and-mother group received both types of books). The specialized children's books were designed to include anticipatory guidance messages to build parental knowledge of child development, parenting, and coparenting practices (Hagan et al., 2017). Each book also included information about the importance of math talk and provided prompts for using math questions while reading. Control participants received a children's book "as usual" without added educational material. Books were bilingual, written in English and Spanish.

Families participated in seven waves of data collection, starting from when the child was 9 months until they were 30 months old. Four of these data collections waves were conducted in-person through a home visit (W1= 9 months; W4=18 months; W6=24 months; W7=30 months). Three waves were remote and included a phone interview and online survey (W2=12 months; W3=15 months; W5=21 months). Observations and data collection specifics are detailed in the measures section. Participants receive up to $240 per parent ($480 total), distributed across the study as parents completed waves. Once a parent enrolled, they stayed in the study unless they withdrew. Thus, even if parents stopped cohabitating, moved, or their income increased, they remained in the study.

Analytic Sample

The analytic sample for Study 1 is restricted to the 286 parents who had video recordings available for both the home visit components of Wave 1 (child at 9 months) and Wave 4 (child at 18 months). The excluded Wave 1 observations had a higher percentage of Spanish and bilingual speakers and a lower percentage of English and multilingual speakers, but otherwise there were no significant differences found.

Of the parents who had data at both waves, parents were, on average, 28 years old (sd=6; range=18 - 49). Over two-thirds of the sample identified as Latine, 13% identified as Black or African-American, 8% as white or Caucasian, 6% as Multiracial, and 5% as Asian or Asian-American. Over half (54.20%) reported being bilingual English-Spanish speakers. Just over half immigrated to the US. Almost 60% were employed and 34% had at least an associate's degree. See **Table 2.1** for the descriptive data on the study sample at Wave 1 (child 9 months).

Procedures

The home visits from which data are drawn included an interview with each parent and separate observations of mothers and fathers with their children. This study uses two of the observations sections in which the parent and child played together with researcher-selected bags of: 1) grocery story/kitchen items (e.g., cash register, a basket, pizza that could be sliced, fruit and vegetables, grocery staples), and 2) various toys including a baby doll, shape sorter, car, helicopter, and a ball. While not specifically focused on mathematics, the toys contained many opportunities for math talk to occur during naturalistic play (e.g., "slice of pizza," reading numerals on a cash register, counting pieces of fruit, saying the name of and describing shapes). Each play section was timed to last five minutes, for a total of 10 minutes of observation per parent per wave for the videos analyzed.

Table 2.1. Descriptive Statistics for Study Sample

	M (SD) or %	n
Parent demographics		
Age (when child was 9 months)	28.40 (5.94)	286
Gender		
Female	52.10%	149
Male	47.90%	137
Language		
Bilingual: English/Spanish	54.20%	155
English	17.13%	49
Spanish	13.29%	38
Bilingual: English/Other	7.69%	22
Multilingual (more than 2)	7.69%	22
US born	46.50%	133
Household annual income		
$20,000 or less	22.03%	63
$20,001 to $50,000	38.81%	111
$50001 or above	30.07%	86
Missing	9.09%	26
Education Level		
Less than HS	14.69%	42
HS or equivalent	20.63%	59
Some college	30.42%	87
2 - 4-year degree/certificate/higher	34.26%	98
Child Characteristics		
Gender		
Female	52.80%	151
Male	47.20%	135
Temperament		
Shyness Average (5 possible)	2.17 (0.73)	286
Emotion Average (5 possible)	2.32 (0.73)	286
Sociability Average (5 possible)	3.67 (0.62)	286
Activity Average (5 possible)	4.23 (0.62)	286

Notes. n=286 adults. Data from W1 (child 9 months) home visit, except temperament which were collected at W2 (child 15 months).

Measures and Coding Schemes

To answer my research questions, the video observations were coded and analyzed along with parent survey data. These measures and their coding procedures are detailed below.

Math-related gestures

I designed a mathematical gesture-coding scheme to capture gestures paired with mathematical talk. The initial iteration of the scheme was adapted from Lee et al. (2015), whose coding scheme includes 10 mathematical-gestures (e.g., finger counting to count objects, using a V-shape with fingers to show two sets, etc.). An undergraduate research assistant (RA) and I piloted the scheme with 10 videos from the BB2 sample and found that the scheme was not a good fit with our videos. First, the focus of the Lee et al. (2015) scheme was on numeracy. Our video interactions included other domains (e.g., spatial) that were not captured. Additionally, many of the gestures were not seen in the pilot videos (e.g., "V-shape"), while some gestures we observed in the videos were not in the coding scheme (e.g., pointing to indicate location).

An RA and I created a list of mathematically-related gestures we observed to generate a gesture coding scheme. We went through four rounds of refining the scheme until we reached agreement using 15 videos. I then reviewed the coding scheme with a graduate student who specializes in math gestures for feedback. After this process was complete, the coding scheme was finalized with 10 constructs and the option for "other." The 10 constructs fell into five math constructs: counting, cardinality, collecting/sorting, number recognition, and spatial. Types of gesture included use of fingers or hands paired with math talk. For this study, gestures were restricted to the parents' fingers or hands being in view of the child. Thus, if a parent was using a motion with a child (e.g., picking child up and saying "up and down"), this was not coded as a gesture. See **Table 2.2** for further details on the constructs and type of gesture, along with examples.

Table 2.2. Mathematical Gesture Coding Scheme

Code	**Description**	**Example**
Counting: Point finger to object	Pointing, touching, tapping an object with 1-1 correspondence while counting	Parent counts 10 bears in a book using finger to count each bear.
Counting: Rote fingers	Abstract counting with fingers	Parent uses fingers to count without pointing to an object.
Counting: Hold or pick up object	Pick up or hold objects and move them while counting	Parent picks up a grape and gives to child and says, "1," then picks up another grape and hands to child and says, "2."
Cardinality: Fingers	Shows the amount of fingers that matches the cardinal number they say or uses fingers to indicate cardinality	Parent says there are 4 bears and shows 4 fingers while saying it. Uses two fingers in V shape to point to two objects (e.g., "The baby has two eyes.")
Cardinality: Sweeping with fingers/hands	Point or use hand while moving across an array or a set of items (Lee et al., 2015)	Parents says "Five puppies" while using fingers or hands to move across the five puppies in a book.
Collecting/grouping/ sorting: Fingers/hands	Transfer of item(s) from one location to another to either be a part of an array or a set or not (Lee et al., 2015)	Here's one toy dog to add to the other toy dogs.
Numeral Recognition: Fingers/Hands	Point or use a gesture directed at a number while saying the number	Points to the 2 on the cash register and says, "Two" or "That's a two."
Location and Direction: Pointing or indicating with hands	Point or use hands to indicate spatial orientation Location and direction are words that describe spatial locations (e.g., "top", "under", "between", "right", "left.") (Levine et al., 2012)	Point to top of box while saying "put on top (of the box)." Use hands to show up Saying "in the bag" while putting an object or pointing in the bag "Put your shoes under the bed"
Spatial Features: Pointing or indicating with hands	Dimensions, features, and shapes of objects are words that describe the size, geometric features, and shape names of two- and three-dimensional objects. (Levine et al., 2012)	Examples of such words are "long", "short", "corner", "straight", "square", and "triangle."
Orientation and transformations: Use fingers or hands	Spatial visualization Rotation (turning) Reflection (flipping) Translation (sliding) (Kısa et al., 2019)	"The piece is upside down" "Let's turn it sideways"
Other	Any gesture not captured in the above constructs. Describe gesture & math talk in the "Other – Notes" column.	

The research team (myself and RAs) micro-coded in 30 second intervals. For each item, the gesture was coded as “1” if observed in the video, otherwise it was coded as “0.” Thus, multiple constructs could be coded in the interval (10 possible per 30 seconds). It is possible that parents could use more than one gesture for the same construct during a 30 second segment; however, during the pilot session we seldomly viewed observations where this was an issue. If a parent did use pointing to count or a spatial gesture multiple times, if was typically part of contained interaction (e.g., counting “1” “2” “3’ while pointing was part of the same counting chain) or involved repeating the word “in” while pointing in the bag of basket. While these instances may indicate repeated exposure to a concept, they were rare.

Bilingual Spanish-English RAs piloted the coding procedure with Spanish videos to identify whether adaptations needed to be made. After reviewing 10 videos, RAs agreed it was appropriate to use this gestures scheme with the observations that were in Spanish or a combination of Spanish and English.

Coder Training and Reliability

I coded 10 videos to create a master coding list for reliability training. Six undergraduate RAs reviewed the *Math Gesture Coding Scheme* description sheet and met with me to discuss any questions and review how to code using the gestures scheme sheet (an Excel document where an RA coded 1 if they saw an instance of the gesture, or left as 0 if there was no gesture). Each RA coded a subset of 10 videos as part of training to a minimum of 90% agreement against the master code frequencies for gesture concepts. To protect against coder drift, each week the RA coders independently coded a subset of the same observations, resulting in double (or triple) coding of 20% of videos in W1 and 20% of videos in W4. If there was a discrepancy between coders, the footage was reviewed to make a decision on the segment in question (K=0.87, p<.001).

Parent Characteristics

Parent Gender. Parent gender was documented during the Wave 1 interview. Parent gender was coded as 0 for female or 1 for male.

Language. For this study, language refers to the language(s) the parent used in the observation, which may have differed from the parent's reported language spoken. Three dummy variables were created to capture language: English monolingual; Spanish monolingual; and bilingual (English plus one other language).

Education. During the Wave 1 interview, parents were asked how many years of school they had completed. Parents could select from a specific year in the 1 to 12 years (but no diploma) range, high school diploma/equivalent, some college, a 2-year degree or certificate, a 4-year degree of certification, or more than college (e.g., graduate school). For this study, the data were coded into four values: 1) less than high school, 2) high school diploma or equivalent, 3) some college, and 4) a college degree or higher.

Nativity. During the Wave 1 (child 9 months) interview, parents were asked if they were born in the United States. If not, parents were asked for the name of the country they were born in and how many years they had lived in the United States. Responses were coded as 0 for born outside the US and 1 for born in the US.

Household income. Parents provided income data at Wave 1. These continuous data were recoded into categorical data with 1 for income that was less than \$20,000 a year (to align with the federal poverty level of \$20,420 for a family of 3 in 2017), 2 for \$20,001 to \$50,000 and 3 for incomes above \$50,001 (U.S. Department of Health and Human Services, 2017). Some parents did not have income data, either because they did not know or preferred not to share. These parents were in the category “missing” as they likely had characteristics that differentiated themselves from families who did supply income data, and were used as a comparison group in regression analyses.

Parental Mathematical Knowledge. In each wave, participants responded to a series of statements assessing their knowledge of early childhood development and parenting practices, including mathematic development. Each wave included a series of prompts related to early mathematical development that were either true (“Words such as "on" or "under" are math words.”) or false (e.g., “The words "smallest" and "biggest" teach children about size, not math.”). Parent could agree, disagree, or state no opinion. Correct answers were scored as 1. Incorrect and no opinion responses were scored as 0. The statements, in Spanish and English, are listed in **Appendix A**. I summed the number of correct answers to create a composite continuous variable (*mathematical development knowledge)* for responses when the child was 9 months.

Descriptives of parents’ responses are available in **Appendix A.** Out of the nine items, the mean for correct responses was 5.24 (SD=2.06). The statements most parents provided correct answers for were “Talking about time is math talk” (73.78%) and “Comparing things is teaching children about math” (72.03%). About two-thirds of parents reported that no baby was too young to teach math, indicating a large proportion of the sample believed mathematical learning started from children’s earliest years. However, less than half the sample felt that comparisons of size taught children about math and less than half were aware that the spatial words “on” and “under” were math words.

Child Characteristics

Child gender. At child 9 months, parents were asked to identify their child’s gender.

Child Temperament. Parents may gesture in response to aspects of their child's temperament. Thus, child temperament was measured through parent report at 12 months using the EAS Temperament Model (Buss & Plomin, 1984) and used as a control variable. One concern is that the temperament data were collected after baseline and are endogenous to treatment. However, temperament is considered a stable trait and, thus, should not change at any point in the intervention (Durbin et al., 2007; Goldsmith et al., 1987). Each of the child's parents rated the child on a 5-point scale for each of the four dimensions of EAS: (1) emotionality, 2) activity, 3) sociability, and 4) shyness. Item responses were summed for each dimension. A 1 indicated it was not characteristic or typic of the child and a 5 indicated it was very characteristic of the child. Shyness items included "Child tends to be shy" and "Child takes a long time to warm up to strangers." Emotionality included statements such as "Child cries easily" or "Child reacts intensely when upset." Sociability included "Child likes to be with people" and "When alone, child feels isolated" (reverse scored). Activity included items such as "Child is always on the go" or "Child is very energetic." For analyses, the average score for each dimension was used separately.

Intervention Condition

I included a covariate for whether the family was in an intervention or control condition. The intervention books include language around the importance of mathematics; thus, it is likely that the parents who read this information would use more math talk and gesture. Parents were placed into one of four conditions – either control or intervention condition (father-only group, mother-only group, father-and-mother group). For this analysis, families were coded as 1 if in any of the intervention conditions, and a 0 if in the control condition (i.e., received a book "as usual" and not an intervention book). The majority of the sample (71.68%) were in one of the three intervention conditions.

Parent x Child Gender Match

A dummy variable was created as coded as 1 if the parent's gender matched the child's gender, otherwise it was coded as 0.

Analytic Plan

I used STATA 15.1 to run analyses. Below I describe my analyses by research question.

Research Question 1: How do parents pair gestures with verbal communication to convey mathematical-related concepts with their children at 9 and 18 months (i.e., infancy and toddlerhood)? How does that change from 9 to 18 months?

For my first research question, I ran frequencies for the gestures used alongside math talk. First, I explored how much of the sample used gestures or not (i.e., how prevalent were observations with at least one gesture across the observations) and then ran linear probability models to understand if those who used gestures or not were significantly different by the demographics (parent gender, language, education, or nativity; household income; child gender, temperament) used in the analysis. I then calculated the average number of gestures produced within the observations that had at least one gesture.

Second, I reviewed coding sheets to identify of the types of gestures used (e.g., use of fingers to point, fingers to sweep, the hand to hold items) within math constructs. I also reviewed coding sheets to identify the types of toys that elicited math talk with gesture. Third, I ran proportions to identify the distribution of constructs within the observations (e.g., did parents tend to use more cardinality than spatial constructs within an interaction?).

Then I then ran frequencies to identify the mean and range for the total frequency of gestures and the frequency by math construct (e.g., counting, cardinality) for when the child was 9 months and 18 months, as well as for change in frequency of gestures between these ages. I ran these for the full sample and then ran separate analyses by language used during the interaction (English, Spanish, or Bilingual). I used an ANOVA test to identify if differences between language groups was significant.

To understand change over time, I ran cross-lagged path models in which I use the 9-month mathematical gesturing data to predict use of mathematic gestures during the 18-month visit. I ran OLS regressions to understand the extent to which parental knowledge predicted the amount of math gestures a parent used at each time point (child 9 months, child 18 months) with one full group analysis and also by language of observation, controlling for parental early math knowledge, parental education, household income, parental nativity, treatment condition, child gender, and child temperament.

Research Question 2: How does mathematical gesture use differ by parent and child characteristics?

To answer Research Question 2, I first ran descriptive statistics (mean, ranges) separately for mothers and fathers both for the total number of gestures and for each construct. I ran t-tests to determine if differences in means were significant by parent gender. These were conducted for when the child was 9 months and 18 months old. These tests were conducted between mothers and fathers within the full sample and within each language grouping (i.e., mothers compared to fathers in English observations).

I ran OLS regressions separately for mothers and fathers to understand the extent to which parental knowledge predicted the amount of math gestures used at each time point (child 9 months, child 18 months). I then ran a cross-lag model to understand how parents of the same child influenced each other (i.e., a “spillover” effect). I used 9-month data to predict if mothers’ use of math gestures predicted fathers’ use at 18 months and whether fathers’ use of math gestures at 9 months predicted mothers’ use of math gestures at 18 months. For these analyses, I controlled for parental early math knowledge, parental education, household income, parental nativity, treatment condition, child gender, and child temperament.

For child characteristics, I ran frequencies (means, ranges) to look at differences in gestures received by sons and daughters. I ran t-tests to determine if means between boys and girls were significantly different. I ran these for the full sample and within language grouping for when the child was 9 months old and 18 months old. To explore whether parents used gestures differently with children who were same gender as them (e.g., moms with daughters), I ran analyses separately for same gender parent/child dyads and different gender dyads to compare means and ranges. I conducted t-tests to determine if differences were statistically significant.

Finally, I ran an OLS regression to predict the *total frequency of gestures* separately for mothers and fathers, then within each language grouping by mothers and fathers. I used several covariates: parental education level, parental US nativity, parental math knowledge, household income, child gender, and child temperament. Capitalizing on the random assignment nature of the data, the experimental condition was included as an independent variable to assess treatment effects on math-related gestures. This also takes into consideration the nonindependence of family clustering.

Results

Prevalence of Gesture in Observations

A total of 572 observations were coded (n=286 at child 9 months (infants); n=286 at child 18 months (toddlers)). In each wave, over 75 percent of parents used at least one gesture in an interaction and a higher percentage of mothers than fathers used gestures. The only significant differences between parents who did and did not gestures were in parental gender and child gender. Father were less likely than mothers to use gestures with their infant (-11.13 percentage points; $p<0.05$) and toddler (-13.33 percentage points; $p<0.05$). Female toddlers were 11.58 percentage points less likely to receive gestures than males ($p<0.05$). Of parents who used a gesture, they used on average, 3.92 (sd=3.04) when their child was an infant and 5.00 (sd=3.61) when the child was a toddler. **Appendix B** contains more detailed information.

Types of Gestures and Materials

During play segments, the shape-sorter, cash register, and pizza pan with slices elicited much of the gesture with math talk. For instance, as children attempted to put the shape in the sorter, parents used fingers to point in the middle of the shape-sorter while saying “in the middle.” Similarly, parents pointed to a shape outline while encouraging their child to put the shape object in (“Put the triangle in here” while pointing with fingers to the triangle outline). Parents also used fingers or their hands to indicate “on” the shape-sorter box when telling children to “put on the lid” that the child held. Connecting a number word (e.g., “two”) to its Arabic number (“2”) was exclusively seen in interactions using the cash register, which was not surprising given it was the only play item with Arabic numbers. Few parents used gestures to indicate spatial features (e.g., curved, edge, straight). Coding of gestures within the spatial features item usually related to using hands to hold up a shape or fingers to point to a shape while saying the shape’s name. Examples of math words and gestures are available in **Table 2.3.**

Table 2.3. Examples of Math Talk and Gesture, by Category and Type of Math Concept

Construct	Type	Example
Counting	Fingers - Pointing	Pointed to pizza slices while counting
	Rote Fingers	Holds up fingers while saying count words
	Hands - Holding	Pick up pizza slices while counting to show child
Cardinality	Fingers	Saying “six” while showing six fingers.
	Sweeping	“We have five slices” while sweeping hand over the 5 slices of pizza
Group/Sort		“Put all the fruits in one pile, and the vegetables in another pile” while using hands to indicate separation between groups.
Number Recognition		"5" pressed 5 on register “Uno”(one) while pressing 1 on cash register.
Spatial	Location/ Direction	"Take the pizza **out**" took pizza out of dish (show with hands) "Put it **on** that" pointed on top of block "**In** here" pointed to circle hole "**On** the pizza" pointed on pizza “**Arriba**” (up) while pointing to ball going up **“En** este” (in this) while pointing to a hole in the shapesorter
	Spatial Features	"Circle" pointed to circle on lid "Triangle" pointed to triangle on lid “Cuadrado" (square) while holding up a square block
	Orient/ Transform	"Turn it" twist pineapple piece "Sideways, straight" while turning the lid “Vuelta” (turn) while indicating with hand as to how to put a shape in the hole

Distribution of Constructs

Due to the low frequency of items within constructs (e.g., direction, shape, and motion in spatial construct), I report frequency by constructs (e.g., spatial). Spatial concepts represented the highest proportion of gestures that infants and toddlers received. For observations that were in English or two languages, spatial concepts had, on average, the highest proportion of gestures at both waves. However, for observation in Spanish, the highest proportion of gestures infants received was for number recognition concepts; however, by toddlerhood, spatial-related gestures were the most frequent. Spanish and bilingual observations, in general, had a lower proportion of spatial gestures than observations in English. This may be related to the coding procedure being developed in English and subsequently relying largely on prepositions, as discussed in the limitations section. More detailed information is available in **Appendix B.**

Frequency of Math Gestures in Full Sample and By Language

Full Sample

Parents, on average, increased their use of gestures from infancy (2.98, sd=3.14) to toddlerhood (3.98, sd=3.80). There was a wide range in gesture use, from no gestures to 15 (infancy) and 18 (18 toddlerhood). On average, parents increased their use of gestures by 1.01 gestures (sd=4.27) from the child's infancy to toddlerhood. A large standard deviation indicated a large range of change in gesture use, with some parents decreasing (up to 12 fewer) or increasing (up to 12 more) gestures between waves.

Spatial gestures were most common at both waves (infancy: m=1.60, sd=2.18; toddlerhood: m=2.59, sd=2.98), followed by number recognition, counting, and cardinality at child 9 months. When a child was 18 months, spatial was followed by counting, number recognition, and, rarely, cardinality. At each wave, gestures related to cardinality or sorting/grouping were rarely used. For instance, when the child was an infant, only 6.29% of interactions used a gesture paired with a cardinality math word (e.g., holding up 2 fingers and saying, "They baby has two eyes.") and only two parents used sorting/groups concepts (e.g., "Let's put the banana with the fruits.").

Full Sample, By Language

Although I hypothesized bilingual observations would have more gestures than the monolingual observations (English or Spanish), the opposite was found. Bilingual observation had the lowest frequency of gestures when the child was an infant. By toddlerhood, bilingual observations had more gestures, on average, than Spanish monolingual observations, but fewer than English monolingual observations. ANOVA tests showed non-significance between means of the three language groupings when the child was 9 months old, 18 months old, and the change in gestures between these ages. See **Appendix B** for a detailed description of means for the total number of gestures and by math construct.

Parental Gesture Use at Infancy as a Predictor of Later Spatial Use

The total frequency of gestures used in when the child was 9 months old positively predicted gestures when the child was 18 months old for English videos (β=0.39, $p<0.001$) and Spanish videos (β=0.26, $p<0.05$), but not for bilingual videos. No other parent and child characteristics were predictive.

RQ2: Differences by Parental Characteristics and Child Characteristics

Parental Gender – Full Sample

As seen in **Table 2.4,** mothers, on average, used more total gestures than fathers when the child was an infant and a toddler. When looking within constructs, mothers gestured more than fathers, though this was only significant for counting. Between both waves, both mothers (m=1.36, sd=4.49) and fathers (m=0.62, sd=3.99) subtly increased their gesturing between waves, but none of the changes were significant overall or by construct. See **Appendix B** for details.

Table 2.4. Gestures Produced, Separate Analyses for Mothers and Fathers

	Moms (n=149)		**Dads (n=137)**		
	m(sd)	Range	m(sd)	Range	t-test
Child 9 mo					
Total #	3.38 (3.33)	[0,15]	2.53 (2.86)	[0, 15]	t(284)=2.31*
Counting	0.61 (1.41)	[0, 10]	0.33 (0.81)	[0, 5]	t(284)=2.05*
Child 18 mo					
Total #	4.75 (3.81)	[0, 16]	3.15 (3.63)	[0, 18]	t(284)=3.61***
Counting	0.96 (1.50)	[0, 6]	0.50 (1.14)	[0, 7]	t(284)=2.88**
Spatial	3.09 (2.97)	[0, 14]	2.04 (3.00)	[0, 19]	t(284)=3.00**

Note. Only statistically significant findings included. Language refers to language used in interaction. * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Parent Gender - Within Language

On average, mothers used more gestures with infants and with toddlers than fathers in each language grouping. When the child was a toddler, these differences were significant between mothers and fathers in the English monolingual (t(145)=2.63, p<0.01) and Spanish monolingual (t(95)=2.21, p<0.05) observations. For construct-level items, the only significant differences between mothers and fathers were when the child was a toddler. These difference were in counting for English monolingual observations (mothers: m=1.00, sd=1.53; fathers: m=0.47, sd=1.25; t(145)=2.31, p<0.05) and spatial for Spanish monolingual observations (mothers: m=2.24, sd=2.30); m=1.31, sd=1.82; t(94)=2.17, p<0.05). See **Appendix B** for more details.

None of the changes in means between waves were statistically significant. However, parents who gestured to their infants tended to continue gesturing when the child was a toddler. For English monolingual observations with mothers, gesture use with a 9-month-old was predictive of gesture use when the child was 18 months old (β=0.52, p<.001). For fathers, gesture use at child 9 months predicted gesture use at child 18 months (β=0.33, p<.05).

In testing spillover effects from one parent to another, OLS regressions showed no significant relationships between a parent's total frequency of gestures when the child was an infant and their partner's total frequency of gestures when the child was a toddler for the full sample or when looking separately by language of observation.

Child Gender – Overall

Across both waves, there were no significant differences between daughters and sons, with two exceptions. For infants, differences in counting gestures were driven by girls receiving more counting gestures than boys (girls m=0.63, sd=1.44; boys m=0.30, sd=0.75, t(284)=2.36, p<0.05). When looking at changes from infancy to toddlerhood, the positive change in gesture use was higher for boys than girls (girls m=0.05, sd=1.60; boys m=0.50, sd=1.57, t(284)=2.40, p<0.05).

Child Gender - Within Language

When looking withing language groupings, there were only two significant findings. Girls received more cardinality gestures than boys during infancy (girls: m=0.13, sd=0.55; boys: m=0.00; sd(0.00); t(149)=2.04, $p<0.05$) and toddlerhood (girls: m=0.18, sd=0.59; boys: m=0.04, sd=0.20; t(145)=2.02, $p<0.05$) in English observations. Only two constructs showed significant differences between means during infancy and toddlerhood. In the Spanish observations, boys received more counting gestures in when they were toddlers (m=0.43, sd=1.40) while girls received fewer (m=-0.35, sd=1.83) (t(95)=2.28. $p<0.05$). In bilingual observations, girls received more spatial gestures as toddlers, while boys received fewer (girls m=0.32, sd=1.16; boys m=-0.42, sd=1.02, t(36)=2.08, $p<0.05$). See **Appendix B** for item level means and ranges.

Gender Match Between Parent and Child

Parents did not differ significantly in gesture use with a child that was the same gender as the parent, with one exception. Mothers used more cardinality gestures with daughters than sons in the English interactions (daughters m=0.32, sd=0.74, sons m=0.03, sd=0.16, t(74)=2.02, $p<.05$). I explored whether the interaction of child gender and parent gender predicted frequency of math gestures, but OLS regressions showed no significance for when the child was an infant or a toddler.

Predicting Math Gesture – Full Sample with Parent/Child Characteristics

Some parent characteristics were predictive of gesture use. For both infants and toddlers, their fathers' knowledge of early mathematics positively and significantly predicted the frequency of gestures used with math talk (9 months: $\beta=0.28$, $p<0.05$; 18 months: $\beta=0.38$, $p<0.05$)**.**

For infants, there were several significant predictors that emerged within language grouping. In English monolingual observations, fewer gestures were used by mothers who lived in households with incomes between \$20,001 to \$50,000 ($\beta=-3.31$, $p<0.05$) or over \$50,0001 ($\beta=-3.47$, $p<0.05$), while mothers in the treatment conditions, on average, used more gestures ($\beta=2.05$, $p<0.05$). In the Spanish monolingual observations, mothers used fewer gestures if their child was a boy ($\beta=-2.35$, $p<0.05$) or if the household income was between \$20,001 to \$50,000 ($\beta=-4.27$, $p<0.05$). However, the higher a mother rated their child's activity temperament, the fewer gestures they used ($\beta=-1.96$, $p<0.05$). For mothers in the bilingual sample, there were no significant findings. For toddlers**,** the only significant finding within language grouping was for mothers who used English - the higher they rated their child's temperament as emotional, the less they used math gestures ($\beta=-1.82$, $p<0.05$). See **Appendix B** for regression tables.

Discussion

Parental use of gestures with children in earlier childhood is an important communication tool that can capture attention, share information, and introduce objects and concepts (Clark & Estigarribia, 2011; Deák et al., 2014, 2018; Zukow-Goldring & Arbib, 2007). Findings from this study show that parents do use gestures to communicate and convey mathematical concepts to their infants and toddlers, though these forms of nonverbal communication differ between mothers and fathers.

Parents Vary in their Frequency of Gesture Use

Parental gestures were infrequent, with an average of four math gestures within a 10-minute observation. However, there was wide variability, with a chunk of parents not gesturing at all (20% in Wave 4), the majority gesturing between one to nine times, and about 10% gesturing 10 or more times over a 10-minute play interaction. The variability in gestures paired with math concepts mimics the large variability found in math language by parents to young children (Gunderson & Levine, 2011; Pruden et al., 2011) and variability in parental communication with infants (Kuchirko & Tamis-LeMonda, 2019). These findings are also consistent with studies on maternal math-related gesture that also found high variability between parents (Cartmill et al., 2010; Kısa et al., 2019). Given that parents talk about numeracy more than spatial talk (Zippert et al., 2020), it was unexpected that the proportion of counting gestures was very low, while the highest proportion of gestures was related to spatial constructs. The affordances of the toys available to parents may have influenced the opportunities for numeracy compared to spatial talk, which is discussed further in the future directions section.

The finding that the average amount of gestures in bilingual observations at both waves was less than the mean for either of the monolingual observations (English or Spanish) was surprising. Evidence suggests that toddler- and preschool-age bilingual children follow pointing more than labeling, though this is a weaker association for the language the child uses more (Verhagen et al., 2017). It may be that parents in the bilingual interactions engaged with children more often in the language the child used more, thus, needed fewer gestures.

Mothers and Fathers Differ in Frequency of Gestures

A consistent pattern across analyses was mothers’ more frequent use of gestures than fathers. This is not surprising - females are perceived to engaged in more nonverbal communication than men (Briton & Hall, 1995) and, in the US, are socialized to decode nonverbal cues more than men (Halberstadt et al., 2013).

Parenting and gender research indicates different communication patterns between fathers and mothers when engaging with infants, both verbally and nonverbally. In general, fathers talk less and use less parentese (language geared towards infants that uses simplified language and a slower tempo) than mothers during a child's first two years of life, though they appear to increase as the child ages and become more active (Shapiro et al., 2021). Further, parents may differ qualitatively in communication with their infants, with research finding that mothers emphasize speech related to attention and fathers use more cognitively challenging language (Kokkinaki et al., 2020; Rondal, 1980).

These differences in gesture use by fathers and mothers may also reflect the play context of the observation. Parents were provided toys and asked to play with their child as they usually would. Research finds that mothers and fathers tend to engage in different patterns of play, with fathers engaging more in physical play (e.g., rough and tumble play) than mothers; overall studies find that fathers engage less frequently in play during a child's infancy, though frequency of play increases as the child ages (Amodia-Bidakowska et al., 2020; Cabrera et al., 2017). When playing cognitive games, fathers have been found to demonstrate lower quality of play than mothers (Teufl & Ahnert, 2022). Thus, it may be that parents engaged differently during play in ways that facilitated or discouraged math gesture opportunities. For instance, if mothers engaged in more play with the items, there would be more opportunities to gesture while counting, indicating direction or location, or identifying shapes; conversely, if fathers engaged more in physical play and used the materials less, there would be less opportunity for math gestures. An important next step would be coding for the type of play interactions parents engaged in and when math gestures were used.

These differences in how mothers and fathers interact with their children are important because they relate to children's language trajectories. Father cognitive stimulation in the early years is associated to children's later skills (Cook et al., 2011; Fagan et al., 2022) and fathers' participation in play, as well as mothers', is linked with children's vocabulary skill (Cabrera et al., 2017). While less is known about gesture, there is evidence that parental gestures that facilitate joint attention are related to child language at 12 months and the concurrence of pointing gestures by parents and children predict infant language outcomes (Choi et al., 2022; Salo et al., 2019). While much of these studies use English-speaking samples, findings of maternal gesturing and infant vocabulary skills have also been found in Spanish-speaking families (Minto-García et al., 2020).

Child Factors and Parental Gestures

As Children Grow, so do the Frequency of Gestures they Receive

As their children aged, parents used more math gestures, though there were a few exceptions. This aligns with another study findings that parents use more gestures during puzzle play with preschool age children than toddlers (Vallotton et al., 2015). However, another study using puzzle play with children ages 16-to-21 months found that child age did not predict parents' use of gesture, though it did predict spatial talk (Kısa et al., 2019). Literature on more general communication finds that mothers use more advanced vocabulary with their gestures as children age out of infancy, while fathers exponentially increase their verbal inputs (Poulain & Brauer, 2018; Shapiro et al., 2021) but their gesture use during play decreases as children move out of infancy (Palacios et al., 2018). Because parents tend to use more math talk as children grow, there may simply be more math talk to pair gestures with at older ages. Parents report more home numeracy activities with 4-year-olds than 3-year-olds, suggesting that parents increase math talk in response to the child's age (Thompson et al., 2017). Longitudinal studies of home math environments should include gesture in order to understand how parents' use of math-related gesture relates to child age.

Both Girls and Boys Receive Gestures from their Parents

Some evidence suggests parental behaviors and actions differ based on their child's gender, reflecting gender stereotypes. For instance, parents may have higher demands for sons than daughters, ask girls more questions, and talk more to girls in general (Cherry & Lewis, 1976; Grebelsky-Lichtman, 2014). Further, parents engage in different mathematical discourse based on the parent-child gender match (Tzuriel & Mandel, 2020). However, this study found no evidence of differences in gestures based on child gender with the exception of mothers in Spanish when children were infants (they used more gestures with daughters), though by toddlerhood this no longer was significant. The lack of gender differences overall echoes other studies that have found no difference in gesture between daughters and sons in language (Özçalışkan & Goldin-Meadow, 2005; Pınar et al., 2021) or math activities (Baenninger & Newcombe, 1995; Kısa et al., 2019b; Lee et al., 2015).

It may be that the focus on quantity in prior research masked differences in quality of the gestures, which may be where child gender differences emerge. A systemic review of the literature on gendered parenting found that parents tend to play differently with a child based on the child's gender (i.e., sex-stereotyped play) and spend more time talking about social topics with girls compared to learning-related topics with boys (Morawska, 2020). The quality of spatial talk between fathers and daughters has been identified as different from fathers and sons, though interestingly the quality of talk only mattered for girls' outcomes in spatial skills (Thomson et al., 2020). In a study of the complexity of discourse preschool-age children engaged in with parents while reading books, boys received a higher amount of complex numeracy questions from a parent than girls did (Uscianowski et al., 2020). While these studies did not include gestures, they did indicate that parents engage in varying levels of quality during mathematical-related discourse. Additionally, though puzzle play is a predictor of child spatial transformation tasks and quality of play has been found to be higher between parents and sons, the quality of play only relates to spatial transformation performance for daughters (Levine et al., 2012). Thus, future work should explore whether the quality of gestures relates to children's mathematical outcomes in general and differentially by gender. Gestures can support a wide array of activities, such as drawing attention to an object, labeling an object, demonstrating information about the object, among other purposes. Whether parents differ in the purpose of the gesture as it relates to math has not been studied, nor how it may differentially impact math skills for sons and daughters.

Mothers' Frequency of Gestures Differ in Response to Child's Emotional Temperament

Temperament infrequently predicted gesturing. During infancy, the child's perceived activity level predicted fewer gestures in Spanish-speaking observations. Evidence suggests parenting practices differ based on children's activity level (Larkin & Otis, 2019; Laukkanen et al., 2014). Activity temperament ratings were informed by items such as "child is always on the go" and "child is very energetic." Children whose temperamental activity level was high may have been "on the go" and, thus, had less opportunity to engage more deeply in play where parents could use more math talk with gestures.

In toddlerhood, only child emotionality predicted frequency of gestures, and only for mothers in English-speaking observations. The higher a parent rated the child's temperament as emotional (which involved negative affect and strong emotional reactions), the lower the frequency of gestures. This was not unexpected, as mothers adjust their parenting practices in response to a child's negative emotionality (Laukkanen et al., 2014; Paulussen-Hoogeboom et al., 2008). Items on this sub-scale included the child crying easily, getting upset easily, being fussy and crying, being emotional, and reacting intensely when upset. Parents with children who they rated high on this measure may spend more time avoiding potentially triggering situations with their children, which might include reducing nonverbal communication.

Interestingly, fathers and mothers did not appear to influence each other's gesturing frequency over time, despite prior evidence that parenting practices "spillover" from one parent to another (Baker et al., 2018). It may be that parents had fewer opportunities to view each other's gestures due to busy schedules or preferences for engaging in talk and play not related to mathematics when jointly playing with their child. However, more likely is that the lack of finding relates to the overall low use of gestures by both mothers and fathers.

Future Directions

More work is needed in going beyond quantity and looking at quality of interactions that contain math talk and gesture (Kısa et al., 2019). This section highlights suggested future pathways for researchers.

Child Gestures and Responsiveness to Parental Gestures

This study focused on how frequently parents gestured to their young children in tandem with math talk. An important future direction would be exploring how and when children gesture back to parents, and how that relates to child outcomes. Very young children do engage in nonverbal conversations with mothers by gesturing in response to parents' gestures (Kuchirko et al., 2018). Child-produced gestures, and the type of gesture they use (e.g., showing and give versus pointing), are associated with children's language development (Choi et al., 2021). Gestures produced by preschool children have been linked to their knowledge of cardinality (Gordon et al., 2021) and are an avenue to nonverbally express math knowledge (Gordon & Ramani, 2021). Child gesturing may be more important for older children, such as preschoolers, given that 9- and 18-month-old children are in the beginning stages of fine motor development and, thus, may not use gesture as frequently due to less ability to control their fingers and hands. Child gestures in the observations for this study were rare and outside of the purview of this study. When feasible, studies should concurrently looking at parent and child gestures to provide a more comprehensive understanding of intertwined mechanisms that support children's mathematical development.

Purpose and Quality of Interaction

Parents use gestures for a number of reasons – to get a child on task, to share information (e.g., labeling an object), to indicate properties, to encourage a child to complete a task, and/or to promote joint attention (Bakeman & Adamson, 1986; Gelman et al., 1998; Matatyaho & Gogate, 2008). An informal review of the interactions within the sample observations suggests that much of the gesturing was related to encouraging a child to complete an action, for instance putting a toy in a basket or bag, inserting a shape in the shape-sorter, or placing a pizza slice in the pan. While the concept of "in" is an important spatial term, the focus was more on the completion of the task (compliance) than teaching the child the concept. Such requests were common and, anecdotally, it appears that much of the spatial talk may be repeated through directions emphasizing "in" or "on." Future research should also document the type and reasons for math talk by parents when paired with gesture to better understand whether children receive a diverse array of math concepts in verbal and nonverbal form, or whether they tend to receive the same concept frequently.

Similarly, coding for the intent of the interaction (e.g., informational, compliance, etc.) would provide additional contextual information to understand how parents use gestures. This could also inform whether parents are using math-paired gestures that seek to support conceptual knowledge, procedural knowledge, of procedural flexibility (Rittle-Johnson, 2017). For instance, pointing to a square and saying “square” to a child would support conceptual knowledge of a square; whereas, using fingers to map one-to-one correspondence while counting objects may support procedural knowledge (i.e., indicating to the child that using a finger to help map count word to object is a strategy). Further, play is not the same experience – materials, types of play, and other factors may promote more gesture use of different types and for different purposes. For instance, symbolic play seems to promote higher joint attention and gesture use compared to functional play (Quinn & Kidd, 2019). Little is known about the types of gestures that specifically support mathematical skills (Cook, 2018). Finding out which gestures work best for what math construct, when, and for whom could inform intervention with parents, which in the language literature have shown promising results (Vallotton, 2012).

Affordances of Toys

Parents and children in our sample spent their time interacting with each other as well as objects. Better understanding of the affordances of these objects and how they influence parent and child communication is an important avenue to further explore. There is evidence that as early as three months of age, the dynamics of interactions are shaped by the combination of the parent, the child, and the materials or object of interaction (Gliga & Csibra, 2009; Rossmanith et al., 2014). For instance, Tamis-LeMonda et al. (2012) found that Mexican mothers living in the US differed in their gesture use depending on the activity (e.g., book-reading or stringing beads). Items such as puzzle and blocks may elicit more orientation and transformation talk (Levine et al., 2012; Zippert et al., 2020), while cards might elicit number talk, and activities involving stringing beads might support pattern talk (Zippert et al., 2020).

In this dissertation study, the objects provided to parents involved the potential to engage in play around a number of math concepts (e.g., cash register for numeral recognition, shape-sorter requiring items to be place in relation to holes, a helicopter that the parent or child could lift up, etc.). It may be that the gesture frequency would differ if other items were included, particularly blocks, puzzles, and multiple items of the same product. While there were many different types of fruit items, there was little counting of them. This may have been different if there were multiple toys that were the same fruit. For instance, if there had been multiple play apples in the store/kitchen play set, parents may have had more opportunity to count apples using their fingers to gestures one-to-one counting and then conclude with the cardinal number (e.g., pointing while saying "1-2-3 apples" and then using their hand indicate the full set while saying "We have 3 apples.").

Anecdotal evidence from the larger project demonstrates how influential an object can be in producing math talk and gesture. Originally, this study planned to include the book reading between parent and child captured in the larger Baby Books 2 observation videos. However, the book used during the 9-month wave focused specifically on counting, while the 18-month book did not. Preliminary analyses showed the 9-month book drove a high frequency of counting gestures, whereas the 18-month book elicited almost no counting gestures. The book sections were not ultimately included in these analyses because the frequencies were an artifact of the book and would skew results when comparing gesture use over time. The book differences do provide evidence of the importance of considering the affordances of objects in play interactions. Future research should explore how different objects relate to math gestures.

Encouraging a More Nuanced Conception of Families

Math socialization practices are not universal (Galindo et al., 2019). While this study does take a more heterogeneous approach to understanding families within the umbrella of lower socioeconomic families, more nuanced work is needed. Race, time in US, context of where one lives in the US, immigration status, and country of origin are all important to consider as they may impact the ways parents engage with their children (Kuchirko & Tamis-LeMonda, 2019). In a study of Mexican, Dominican, and African-American mothers, findings indicated different patterns of speech and gestures (Tamis-LeMonda et al., 2012). While all paired gestures with verbal communication, there were some differences. Mexican mothers used the most gestures, and in particular with behavior-related interactions (rather than information sharing), even when controlling for education (Tamis-LeMonda et al., 2012). Future work should explore rich the heterogeneity within typical groupings such as race, ethnicity, and language.

Limitations

This study provides a descriptive look at types of math gestures parents use with very young children; however, a major limitation is that it cannot report whether these gestures support children's own use of gestures and whether that impacts their math development. Because gestures are posited to scaffold a child's learning by labeling objects or communicating meaning, it will be important to study the extent to which and when gesture support specific mathematical outcomes. Second, this study proposed to include the frequency of math talk to identify the proportion of math talk that used gestures; however, these data have not yet become available for the full set of observations in this study. Another limitation is that this study only looked at the finger and hand movements parents made. It did not include facial expressions or other forms of nonverbal cues, such as head nodding, that support communication between infants and their parents (Fusaro et al., 2014). Further, the set of demographic variables I used accounted for little of the variance in gesture use, suggesting the need to explore other potential contributors that were not captured in these analyses. Finally, RAs coded for gestures used with math talk based on a coding scheme that did not include spatial verbs in Spanish. As discussed in

Study 2, Spanish-speaking parents use verbs that carry spatial meaning. Thus, the use of spatial gestures in the Spanish and bilingual videos may have been undercounted, which may explain the lower frequency of spatial gestures observed. To test for proof of concept, an RA reviewed 20 videos for gestures that used spatial verbs and found that 11 of the 20 included spatial verbs with gestures. These 11 videos would have added, on average, two gestures. While this is a small snippet of the videos, it does indicate that, among parents that did use gestures, their use of spatial gestures would likely be slightly higher for Spanish and bilingual observations if spatial verbs were included.

Conclusion

Findings from this study help illuminate how parents of young children in low-income households use gestures in combination with mathematical language. With gaps in mathematical skills emerging between children from low- and high-income families before formal school entry (Elliott & Bachman, 2018b), it is important to understand how the environments young children on the lower end of the economic spectrum relate to early mathematical experiences. While much of the early mathematics literature compares children from low socioeconomic status (SES) against peers with more privileged SES (Klibanoff et al., 2006), this paper looked at heterogeneity within the large umbrella of low-to-moderate SES. Importantly, the exploration of paternal math language and gesture as well as coparents' use is important given that prior research has primarily been conducted with only mothers and rarely considers input from more than one parent. Thus, this study also fills a gap in the parenting research on better understanding gender differences in parental communication practices (Shapiro et al., 2021; Yaffe, 2020) and how couples might influence each other's use over time (or not). Furthermore, research has mostly focused on math gestures in the numeracy domain. This study contributes to an expanded look at the types of mathematical concepts parents use gesture for, especially for spatial relations (Zippert et al., 2020). Future research should expand more to look to at gesturing around patterns and measurement, which did not occur in our observations with these very young children. Findings from this study should also prompt further research to understand whether parental mathematical gestures are associated longitudinally with children's use of gesture and their mathematical performance. This study provides evidence that nonverbal communication paired with math talk, though low in prevalence, does occur between parents and their infant and toddlers and that the amount of gesturing is not uniform among families, highlighting the need to better understand how, when, and why parents pair gesture with math talk.

Chapter 3: Study 2 - Capturing Spatial Talk in Spanish: Lessons from Infusing a Verb-Framed Approach to a Spatial Talk Coding Scheme

Introduction

Math communication that flows between parents and their children through verbal and non-verbal interactions serves as an important conduit for early mathematical development. Findings that exposure to mathematical talk ("math talk") positively relates to children's mathematical skills (Gunderson & Levine, 2011; Ramani et al., 2015) have led to an increase in studies that examine the frequency, complexity, and contexts in which young children hear and engage in math talk with their families (Elliott & Bachman, 2018a; Gunderson & Levine, 2011; Susperreguy & Davis-Kean, 2016). These studies, along with parallel studies in early learning settings such as child care and pre-kindergarten (pre-k), serve important roles in illuminating the types of math environments young children experience. These studies commonly use approaches that examine the frequency and type of math words, typically nouns, prepositions, adverbs, and adjectives, in parent-child play interactions. Despite 23% of children in the US speaking a non-English language as their primary home language (U.S. Census Bureau, 2019), the majority of research centers on children who are monolingual English speakers, though fortunately this is beginning to change (Hornburg et al., 2021; Leyva et al., 2017, 2019; Melzi et al., 2022).

While mathematics may be often thought of as "language-neutral" in popular culture and, thus, requiring a simple one-to-one translation of concepts (e.g., more, down, under), there is evidence of linguistic differences in how mathematical ideas are expressed across languages and that these differences have implications for children's mental models and perceptions of the world. While conceptually interesting, it also holds "real world" ramifications. For instance, it is important to understand the extent to which translated versions of math word coding schemes attain linguistic equivalence. By using an English-centric framing of math talk, researchers may inaccurately report the levels and types of math talk by parents who speak languages other than English, potentially missing out on ways that non-English speaking parents provide math support. Further, this also has implications for equity in terms of curriculum and assessment design within an educational system that typically designs in English first and then translates to non-English languages. Additionally, there is evidence that language plays a role in shaping the development of some mathematical concepts, in particular spatial relationships (e.g., direction of mental number lines, orientation) (Casasola & Ahn, 2018; Chow & Ekholm, 2019; LeFevre et al., 2010). Based on these reasons and the importance of spatial relationships in early math development (Bower et al., 2020; Casey et al., 2008; Mix, 2019), this study explores the intersection between spatial concepts and how they are conveyed in Spanish, a language that often expresses implied spatial concepts in verbs.

Literature Review

Math is not language neutral. Emerging evidence suggests that some mathematical concepts onboard at different times due to grammatical differences between languages. For instance, children raised speaking a language without plural markers (e.g., Japanese) demonstrate knowledge of “one” versus “two” later than children reared in a language with plural markers that embed “one” and “two or more” in its grammar structure (e.g., English) (Sarnecka, 2004; Sarnecka, 2014; Sarnecka et al., 2007). Grammatical features also may expose children to more cues to indicate singular versus plural features. For example, Spanish adjectives become plural along with nouns, while in English, the adjective is the same for singular or plural nouns. Thus, a child receives more reinforcers for plurality in Spanish than English. While such numeracy examples are important, a less explored area in early childhood mathematical development is spatial language, which encompasses shapes, spatial dimensions, locations and directions, orientation, and transformation.

While evidence continues to build that early spatial skills and parental spatial talk are important for later math skills (Bower et al., 2020; Casey et al., 2014; Rittle-Johnson et al., 2019), there is a lack of literature on how parents who use a language other than English engage in spatial talk with their children and how that language is conceptualized, with only one study I could identify that focused on bilingual English-Spanish children (Melzi et al., 2022). These gaps motivated this study's focus on spatial language among Spanish-speaking families with very young children.

The Importance of Spatial Development and Parental Spatial Talk

The importance of early spatial skills are evidenced by early learning expectations such as California's Preschool Learning Foundations (California Department of Education, 2008) and the Head Start Early Learning Outcomes Framework (U.S. Department of Health and Human Services, 2015) which clearly state desired outcomes and skills related to shapes and locations of objects and people in space. Further, knowledge of spatial concepts is required of children once they enter elementary school (e.g., California Common Core Standards). Thus, spatial skills are an important component of school readiness, and a skill that is associated with general math achievement. Early spatial knowledge not only predicts later spatial knowledge, but also concurrent and future mathematical knowledge (Frick, 2019; Mix, 2019; Young et al., 2018) – making it a critical school readiness skill to foster.

While the out-of-home mathematical experiences children receive are valuable in their mathematical development, so too are the mathematical interactions young children engage in with their family. Math talk by parents is an important pathway to increasing children's exposure to and practice with mathematical vocabulary and concepts (Cartmill et al., 2010; Casey et al., 2014; Kısa et al., 2019; Thomson et al., 2020). For instance, maternal use of spatial language and gestures with their 3-year-olds during block play positively related to their child's mathematical skills at age 4 and a half, while support via planning during block play showed positive associations with both reading and mathematics (Lombardi et al., 2017).

Parental Spatial Talk, Parental Language, and Children's Perception of the World

How a language (and by extension, culture) conveys spatial concepts may influence how children organize and express the spatial world around them - how they conceive of and engage in the world through verbal expressions and mental models. Space serves as a way to organize the world, yet little is known about the youngest years of life and how innate and cultural factors contribute to spatial development (McCrink & de Hevia, 2018). For instance, how we spatially organize information has links to culture and language. The ability of very young Japanese children to distinguish between bounded and unbounded space (e.g., a street versus a field) is believed to stem from use of different verbs in Japanese to express crossing these specific types of spaces. Yet, English-speaking children, who use the same verb to indicate crossing either of these spaces, do not make this distinction – implying that language is linked to differing perceptions of the world (Konishi et al., 2019). A study including New Zealand English and Brazilian Portuguese speaking adults found differences in use of spatial relations, with New Zealand English speakers using more directional terms and a wider range of terms. Based on their findings, the authors stressed the importance of context when translating spatial relation terms (Marchi Fagundes et al., 2021).

The suggested roles of language and culture also appear in studies on spatial-numerical associations. Studies find that parents demonstrate spatial biases in creating pictorial narratives (i.e., ordering of pictures from right to left or left to right) for their toddlers based on whether their language engaged in reading or writing from left to right (e.g., English) or right to left (e.g., Hebrew) (McCrink et al., 2018). Similarly, when children observe an adult reading a storybook, they engage in count direction that follows the storybook's language (e.g., in English from left to right and in Arabic from right to left) (Göbel et al., 2018). This suggests a cultural transmission of how space is conceptualized, though other findings related to spatial-numerical association in mental arithmetic point to a role of innate contributions (Masson et al., 2020).

For this study, I focused specifically on the intersection between language and the spatial component of motion, which captures location and direction (e.g., "put it in the basket", "we're going into the store"). How language structures the expression of location and direction concepts vary, to the extent that it may lead to different perceptions of events (Konishi et al., 2019). Languages differ in the extent to which the direction is implied in a verb (i.e., verb-framed) or directly stated in a preposition (i.e., satellite-framed) (Slobin, 2003; Stringer, 2012; Talmy, 1991). For instance, "going up*"* in English could be conveyed in Spanish as "va subiendo," in which the verb subiendo (conjugated from *subir*) conveys the direction ("up") rather than the preposition ("up") used in English.

Such linguistic features may influence how parents socialize children in their language to conceptualize space. For instance, the Korean language includes a verb ending that signifies a tight fit (e.g., a Lego block fitting into another Lego block), which English does not. It is hypothesized that this linguistic clue may support spatial conceptualization. While children seem to be born with an ability to distinguish the tight fit concept, English-speaking infants begin to lose this spatial concept by 18 months, whereas infants exposed to Korean still understand and are able to generalize the tight fit concept at 18 months (Casasola & Ahn, 2018). These links between differentiations in language and different perceptions of the world are interesting in their own right, but take on added importance due to the role of spatial language and spatial skills in young children's mathematical development both in their early childhood and longitudinally (Ribeiro et al., 2020; Thomson et al., 2020).

Implications for Research and Practice

The structure and use of location and direction likely provide different math talk experiences for young children depending on the language of their caretaker. This has direct implications for research on early mathematics. One way in which developmental scientists study math talk is through coding schemes that code adult-child interactions. These coding schemes for spatial language are typically developed in English and then translated into other languages such as Spanish. Some location and direction concepts translate when presented in preposition format (e.g., dentro/inside, debajo de/under), but not including Spanish verbs with encoded path direction may leave such translations severely underdeveloped and will likely underrepresent spatial concepts. For instance, it would leave out spatial language from verbs that inherently provide such relations such as: away from (apartar(se) and distanciar(se)); up/onto (elevar(se), encaramar(se), encumbrar, escalar, levanter(se), and subir); into (encerrar(se) and profundizar); down from/to (bajar, caerse, derrumbar(se), and descender); and out of (salir) (Férez, 2010). Despite the potential for missing out on a significant amount of language using location and direction, little is known in the literature about linguistic differences in spatial talk between adults and young children, though one existing study indicates using ground-up approaches to code for spatial talk is imperative to understand the full context of mathematical dialogues between parents and children (Melzi et al., 2022).

The Current Study

This study asked, “What happens when a parental spatial talk coding scheme is derived directly from the parents’ language (e.g., Spanish), rather than the standard method of translating an English-derived scheme into another language?” Specifically, this study created a verb and preposition specific coding scheme in Spanish and compared it to the “as-usual” translated-English-to-Spanish preposition-focused version when applied to mother-child and father-child play interactions. This allowed for an approach that might be better positioned to reflect the true extent of spatial concepts used in Spanish and how they are conveyed (e.g., in verbs) rather than expecting a similar conceptualization in English. In addition to its contribution to the research literature on how language and spatial concepts intersect, it also may potentially lead to rethinking how we assess early math in children who are multi-linguals, approach coding for “math talk” in adult-child interactions, and design assessment to be linguistically appropriate.

The bulk of research on math talk in early childhood has relied on English-based tools and little research has explored the appropriateness of translations of these coding schemes with non-English speaking dyads, with the exceptions only recently emerging (Melzi et al., 2022). Evidence highlights grammatical and linguistic contributions to math development (Almoammer et al., 2013; Sarnecka, 2014), but these have mainly focused on numeracy rather than spatial concepts. Though math talk encompasses many aspects of mathematics (e.g., addition, counting, cardinality), spatial concepts may be particularly vulnerable to being missed when using a framework translated from English to Spanish. English’s satellite-framing structure places location, direction, and other spatial indicators into prepositional phrases, which might omit spatial concepts embedded in verbs frequently utilized in verb-framed languages such as Spanish. Thus, I explored:

Research Question 1a. To what extent do parents use Spanish spatial verbs during parent-child play interactions with toys?

I hypothesized that the majority of parents will use at least one verb with a spatial concept during the observation. The average number of verbs used would likely be low, given the literature's documentation of low averages of mathematical talk by parents of young children (Ramani et al., 2015). I expected that spatial verbs would occur in equal amount as the prepositions.

Research Question 2. When compared to Spanish spatial word coding scheme using an English-centric framework (i.e., without verbs), how much spatial math talk is excluded by not including verbs?

I expected that including spatial verbs would increase the total amount of spatial talk in an observation.

Method

Dataset

This study used data from the Baby Books 2 (BB2) project, which was also used in Study 1. Descriptions of the recruitment process and participation criteria are available in the methods section of the previous chapter. For this study, I used data from the first (child at 9 months old) wave of data collection in which members of the BB2 team conducted a home visit that included a recorded observation of parents and their child during play with researcher-provided toys.

Analytic Sample

The analytic sample for this study was restricted to only include parents who used Spanish or a combination of English and Spanish in the parent-child observation at Wave 1 and whose child completed the Preschool Language Scale (PLS) (Zimmerman et al., 2002) at Wave 4 (child age 18 months). Because I was using transcriptions to identify spatial words in Spanish, the sample was limited to Wave 1 observations utilizing Spanish with a transcript. Only children with PLS data at 18 months of age had transcriptions available, leaving a sample of 144 parent-child interactions for this study. Of the 144 observations, 124 were run with a coding script successfully. The remaining 20 were manually coded, for a total of 144 observations. While the majority of the observations were in Spanish (61.61%), the majority of parents reported being bilingual in English and Spanish (62.89%) or multilingual (6.94%). Parents were, on average, 28 years old (sd=6 years), though there was considerably large range, from 18 to 52 years. See **Table 3.1** for more details on other parent demographics.

Table 3.1. Descriptive Statistics for Study Sample at Wave 1

	m (sd) or %	n
Parent demographics		
Age	28.76 (6.24)	144
Parent Gender		
Female	51.39%	74
Male	48.61%	70
Child Gender		
Girl	45.83%	66
Boy	54.17%	78
Race/Ethnicity		
Hispanic or Latine	95.14%	137
Multiracial	2.08%	3
Asian/Asian-American	0.69%	1
Black/African-American	0.69%	1
White/Caucasian	0.69%	1
Other	0.69%	1
Parent-Reported Languages Spoken		
Spanish-only	29.17%	42
Bilingual: English/Spanish	63.89%	92
Multilingual	6.94%	10
Language Used in Observation		
Spanish-only	61.61%	88
Bilingual: English/Spanish	38.89%	56
Born in US	16.67%	24
Education Level		
Less than HS	27.78%	40
HS or equivalent	23.61%	34
Some college	22.22%	32
2 - 4-year degree/certificate	11.11%	16

4-year degree/certificate or higher	15.28%	22
Employment Status		
Working for pay	55.56%	80
Attending school	4.17%	6
Unemployed	4.86.%	7
Stay at home parent	25.69%	37
Multiple (2+ of above)	9.72%	14
Early Math Knowledge	5.04 (2.00)	144

Notes. n=144 adults. Parents self-reported data at Wave 1 (child 9 mo.).

Procedures

To answer the research questions, video-recorded play interactions from home visits at Wave 1 (child 9 months of age) were coded. The play interactions utilized two sets of researcher-selected toy sets. One set featured grocery store and kitchen items such as a cash register, basket, sliceable pizza in a pan, plastic fruits and vegetables, utensils and other grocery staples. The second set included a baby doll, shape sorter, car, helicopter, and ball. Though these toys were not selected primarily for their "mathiness," they did contain multiple opportunities for use of spatial language (e.g., putting pizza slice in or out of pan, noting location of the helicopter or ball, etc.). The researcher provided the family with five minutes to play with each set of toys, for a total of 10 minutes of play interaction.

Measures and Coding Scheme

To answer my research questions, I used two lists of spatial words – an existing list for prepositions and a list I developed to capture verbs. The preposition list captured math talk "as usual" (i.e., English-centric) that focused on a satellite-framed view of language. The other captured Spanish verbs with spatial language embedded in the verb. I describe the coding schemes in further detail below.

Spatial Math Talk (English-centric)

Drawing from extent research on math talk between adults and children, members of the BB2 team who were engaged in a separate math grant with partners at University of Pittsburgh and New York University created a coding procedure that contained math concepts in numeracy, spatial, and measurement subdomains informed by approaches taken in the early math literature. This coding procedure was an adapted version of spatial talk coding schemes used in several other projects and modified to be used on a math grant (Levine et al., 2012; Verdine et al., 2019). This list was created to use in a script in Datavyu (Datavyu Team, 2014) for all transcripts to create output that identified the math word and the full utterance that used the math word (discussed in more detail in the Analytic Plan section of this paper). The team met several times to discuss the coding scheme and refine based on group consensus. Spanish-speaking team members translated the coding scheme into a Spanish version.

For this study, I focused on one of the math constructs – spatial talk - and limited the math word list to only include spatial-related concepts, giving a total of 344 math words (e.g., a lado de, en, entre). This list (see **Appendix C**) was used to create a list of math words that did not include spatial verbs. While there were two verbs included on the original list (voltear (turn over), girar (rotate)), these were the extent to which the list included verbs as math talk – no other location or orientation verbs were included and, thus, would not be picked up in the output from the script.

Spatial Math Talk Expressed in Verbs

As part of this study, a supplemental Spanish math word list containing verbs with spatial concepts was created through an iterative process of reviewing BB2 observation videos, informal focus groups of English-Spanish bilingual speakers, and the use of a language translation app in order to create as exhaustive a list of possible verbs. To test proof of concept and begin generation of a verb list, four bilingual English-Spanish members of the BB2 research team reviewed five BB2 videos to identify potential verbs with embedded spatial concepts. These verbs were matched against the concepts listed in the English math talk scheme to ensure they captured similar concepts; if not, they were removed. A similar process was used with the language translation app, WordReference. The draft math verb list was reviewed by a graduate student in the Spanish and Portuguese Department at UCI, a bilingual English-Spanish professor, and a graduate student lab member in the UCI School of Education. Undergraduate research assistants (RAs) who were fully fluent in English and Spanish piloted the list. If they identified any spatial verbs in the video that were not on the list, they then added the verbs to the list. After coding 31 videos, the final 10 videos of these videos produced no new words, and the spatial verb list was finalized.

After initial analyses were completed, a publication on spatial math by Spanish-speaking Latine parents was published that provided four additional words not on our list but potentially within the parameters of the coding scheme: arrimar (put against or put next to), derramar (spill), salir (leave/go out), and tirar (let fall) (Melzi et al., 2022). These were then added to the list and analyses rerun to account for these verbs. Including the new verbs, a total of 35 verbs were identified (See **Appendix D**).

Covariates

I included a set of parent and child covariates in some analyses. Parents who spoke more to their child during the interaction have more opportunities to say spatial words, thus I included a continuous variable for total number of utterances a parent made during the interaction. An utterance included any words stated that was preceded or followed by a pause. Parent gender (0=mother, 1=father) was self-reported during the first wave of data collection. Similarly, child gender was reported by the parents at wave one (child 9 months old) and coded as 0=female and 1=male.

Parents who were born outside the US may have received more formal education in a language other than English, which could possibly influence the types of spatial words they use. For instance, a parent who attended school in a Spanish-speaking country may use a more sophisticated or complex set of spatial words due to formal exposure to such concepts than someone born in the US. Thus, I used a dichotomous variable for nativity of parent (0=born outside US, 1=born in US).

Other parent characteristics included parental employment status, which were mutually exclusive and, for OLS regression analyses, were dummy coded (0=no, 1=yes) for 1) working for pay, 2) unemployed, 3) training or school, 4) stay-at-home parent, and 5) multiple if two of more of the categories were selection (e.g., a stay-at-home parent in training/school). For parent education, I created dummy variables (0=no, 1=yes) for: 1) less than a high school degree, 2) a high school diploma or equivalent, 3) a degree from a 2- to 4-year certificate or degree program, and 4) graduate degree or certification (e.g., Master of Arts degree).

Finally, I include a parent knowledge of early math development variable measured during Wave 1. It is possible that parents with more knowledge of early math development may use different or use more math talk than parents with less knowledge. In this scale, parents were asked to agree, disagree or have not opinion with nine statements (e.g., "Words such as "on" or "under" are math words."/"Palabras como "encima" o "bajo" son palabras de matemáticas."). If parents were more aware of words that contained spatial concepts, they may be more likely to use them as they engage with their children. All statements are available in **Appendix E**. I created a continuous variable that summed the number of correct responses out of the nine. On average, parents reported correct answers for 5.04 (sd=2.00) of the nine items, ranging from none correct to all nine correct.

Data Analysis Plan

The spatial words developed through each method – the English-framed coding (e.g., satellite words) and Spanish-informed coding (i.e., verbs and prepositions) – were entered into separate Excel workbooks. Datavyu (Datavyu Team, 2014) was used to analyze the frequency of spatial satellite words and of spatial verbs in order to determine how many words would be captured through the English-informed coding scheme compared to a Spanish-informed coding scheme. I created a script in the Ruby programming language to tag and identify utterances that included any of the verbs included in the preposition or verb lists (see **Appendix F** for the scripts). Because the program only identified exact words, I inserted the infinitive and conjugations (yo, tú, él/ella/usted, nosotros/nosotras, vosotros/vosotras, ellos/ellas/ustedes), moods of the verb (indicativo (indicative) – presente (present), imperfecto (imperfect), pretérito (past), futuro (future), condicional (conditional); participio (participles); subjunctive (subjective) – presente (present), imperfecto (imperfect), futuro (future), imperative afirmativo (positive commands), negativos (negative commands)), as well as combinations of verbs (infinitive and affirmative commands) plus direct object pronouns (me, te , lo, la, nos, os, los, las), indirect objects pronouns (me, te, le, nos, os, les), reflexive pronouns (me, te, se), and indirect plus direct object pronoun combinations. Ultimately the list of verbs reached 6,905 words when including all the forms, moods, and pronouns combinations, while the preposition list contained 344 words (2 verbs contained 138 of these words).

Output containing the tagged word and corresponding utterance were exported to Excel sheets. RAs who were fully fluent in English and Spanish reviewed the output to determine if the verb as used in the utterance conveyed a spatial concept (e.g., “ponga el otro” (put another one) was considered not specific enough to include as it would not be captured in the “as usual” coding scheme). Rarely did an utterance contain more than one verb but if it did, each was counted as a separate word.

I decided to review Spanish and bilingual Spanish-English videos separately because families in bilingual observations had a larger "set" of spatial words to choose from (i.e., English and Spanish) and may differ in use of spatial verbs than families who only used Spanish in the interaction. Further, because the focus was on exploring extent of Spanish verbs, I only ran scripts for Spanish prepositions and verbs. English spatial talk was not included in the spatial talk analyses for the English-Spanish videos. A scan of 10 transcripts of bilingual observations indicated that Spanish was used in an utterance, on average, 68% of the time and another 5% of utterances used a combination of English and Spanish. While not the full sample of bilingual observations, it does indicate that a large chunk of time was spent using English in these observations. This limitation necessitates the separation of findings to two groups: Spanish-only videos and bilingual Spanish-English videos. Parents had less "time" in Spanish if they used English as well, and, thus, English-Spanish videos are not directly comparable to the Spanish-only observations as they only contain a partial snapshot of the full spatial talk.

I then used STATA 15.1 to run descriptive analyses to answer my research questions as described below.

To answer research question one, I first ran descriptive statistics to identify the percentage of parents who used at least one spatial verb in the observation for the full sample and then within groups by: language (monolingual Spanish, bilingual English/Spanish), parent gender, and child gender. Because parents who talked more may have more opportunity to use verbs, I also looked at means of how many utterances a parent used. To understand if parents who used a spatial verb differed from parents who did not, I ran a logistic regression to identify if any parental characteristics or child characteristics (parent gender, child gender, education level, employment, nativity, household income, math knowledge, parental use of a spatial preposition in the “as is” coding) were associated with a higher likelihood of using any spatial verbs.

I then ran frequencies of total number of spatial verbs per parent during the 10-minute observation. I looked at the total sample together and then ran means to look at within difference by the following groups: parent gender, child gender, and language of observation. Because of evidence that use of spatial talk may vary by parent and by child gender, I wanted to look at mothers and fathers separately as well as sons and daughters (Thomson et al., 2020). I separated by language of observation because bilingual observations had fewer minutes of Spanish talk available to code (due to part of the observation being in English) than the Spanish-only observations. I also ran an OLS regressions to understand whether parental characteristics predicted the amount of spatial verbs a parent used, using the full set of covariates. Finally, I ran frequencies for individual verbs to identify the most frequently used ones, which I grouped into different types of spatial concepts (e.g., up, down, in).

To answer research question 2, I combined the non-verb spatial (prepositions) and verb spatial words into one dataset. First, I calculated the percent of observations with at least one spatial word. Then I ran logistic regressions to identify if parents who used spatial talked differed from those who did not in terms of a set of parent and child characteristics (parent gender, child gender, education level, employment, nativity, household income, math knowledge). I calculated the mean for the total number of spatial words used by parents who used at least one spatial word.

I then ran descriptive statistics (i.e., mean, range) to understand the extent to which the English-based coding scheme “missed” spatial content by not including verbs across the full sample. To do this, I compared the means of the English-based coding scheme (i.e., no verbs) and the coding scheme that included verbs. I ran t-tests to identify whether differences were statistically significant. I then calculated the proportion of spatial verbs in the total spatial talk. I ran correlations for the number of segments with spatial verbs and the number of segments with spatial non-verbs. Finally, I ran an OLS regression to understand how total parental utterance and family characteristics (parent gender, child gender, parental nativity, parental employment status, parental education, and parental early math knowledge) predicted the total number of spatial verbs and prepositions a parent verbalized.

Results

A total of 144 observations were analyzed for spatial concepts in Spanish expressed directly through prepositions and indirectly through implied direction/location in the verb.

Research Question 1a. To what extent do parents use Spanish spatial verbs during parent-child play interactions with toys?

Prevalence of Observations with Any Spatial Verbs

The majority of videos (60%, n=86) contained at least one instance of spatial verb use. Three-quarters of interactions using Spanish-only had one or more spatial verbs, whereas 36% of bilingual interactions did, though the English-Spanish videos had fewer opportunities for Spanish spatial verbs given that part of the observation included English that was not coded. For mothers, 63% used at least one spatial verb, whereas fathers had slightly lower percentage (56%).

About 60% of children, regardless of gender, received at least one spatial verb. Parents who used spatial verbs also tended to talk more, expressing 213.60 (sd=83.83) utterances during the 10-minutes observation, with a range of 42 to 429 utterances compared to the utterances of parents not using any spatial verbs (m=163.67, sd =83.42). Across videos with spatial verbs, an average of 3.58 spatial verbs (sd=3.97) were used. Descriptive analyses showed a normal distribution of utterances, with no obvious outliers.

Parents who used spatial prepositions were also more likely to use spatial verbs. Parents born outside the US were more likely to use at least one spatial verb (OR=5.08, 95% CI [1.63, 15.80]) than parents born in the US. This is not surprising given that of parents born in the US, only 33% used at least one spatial verb compared to 65% of parents born outside the US. When looking within bilingual interactions, parents who were born in the US and outside the US had similar percentages of using at least one spatial word (roughly 40%). When looking within Spanish-only observations, 75% of parents born outside the US used at least one gesture verb compared to 67% of those born in the US. Unsurprisingly, parents who used spatial prepositions were also more likely to use spatial verbs as well (OR=1.18, CI [1.04, 1.36]). Other parental characteristics were not significant in predicting spatial verbs.

Descriptive Analysis of Spatial Verbs Used in Interactions

Across the full sample of 144 observations, parents used an average of 2.14 (sd=3.54) spatial verbs during the 10-minute play with toys observation, with parents using 0 to 21 spatial verbs. A higher frequency of mothers used at least one spatial verb compared to fathers and mothers, on average, also used more spatial verbs, though these differences were not significant While girls and boys were equally likely to receive at least one spatial verb, girls received a higher frequency of spatial verbs. Despite the 10-minute length of observations, in reality parents in the bilingual observations had less time available for Spanish spatial verbs to be observed than their peers in the Spanish-only observations because parents also used English in the videos.

From a sub-sample of bilingual videos, about 30% of the interaction was not in Spanish. Thus, it is not surprising that in looking at the total number of spatial verbs used, Spanish observations had a higher mean than the bilingual (English/Spanish) videos. T-tests and OLS regressions showed none of these differences to be statistically significant. See **Table 3.2** for further information on spatial verb words.

Table 3.2. Total Number of Spatial Verb Words

	m (sd)	Range
All	2.14 (3.53)	[0, 21]
Parent Gender		
Father (m=70)	2.09 (3.87)	[0, 21]
Mother (n=74)	2.19 (3.21)	[0, 15]
Child Gender		
Boy (n=78)	1.99 (3.12)	[0, 15]
Girl (n=66)	2.32 (3.99)	[0, 21]
Language of Observation		
Spanish only (n=88)	2.56 (3.38)	[0, 15]
Bilingual (n=56)	1.48 (3.70)	[0, 12]

Notes. Full Sample n=144 parents.

Results from an OLS regression showed that, on average, the more talkative the parent was during the observation, the more spatial verbs they produced ($\beta=0.01$, $p<0.01$). This pattern of a positive and significant relationship between parents' talkativeness and their production of spatial verbs held for fathers ($\beta=0.01$, $p<0.05$), sons ($\beta=0.01$, $p<0.01$), and use of only Spanish in the interaction ($\beta=0.01$, $p<0.01$). No other characteristics significantly predicted the total number of spatial verbs a parent used. See **Table 3.3** below for more information.

Table 3.3. Characteristics Predicting Total # Spatial Verbs

		Parent Gender		Child Gender		Language	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	All	Mothers	Fathers	Girls	Boys	S	E/S
Total Parent Talk	0.01**	0.01	0.01*	0.01	0.01*	0.01**	0.01
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)
Parent Male	0.24			-0.69	1.06	-0.42	0.55
	(0.77)			(1.18)	(1.19)	(1.16)	(1.20)
Child Boy	-0.35	0.05	-0.75			0.71	-1.44
	(0.60)	(0.85)	(0.98)			(0.77)	(1.17)

Parent born in the US	-0.87	-0.36	-1.59	-1.67	-0.32	0.59	-0.79
	(0.86)	(1.07)	(1.72)	(1.14)	(1.47)	(2.08)	(1.28)
Employment Status							
Working Full Time	0.69	0.68	1.18	-0.91	3.04	0.64	0.36
	(1.04)	(1.78)	(1.45)	(1.45)	(1.76)	(1.37)	(1.85)
School/Training	-1.27	-0.93	-2.75	0.00	1.38	-0.47	-1.71
	(1.81)	(2.29)	(4.60)	(.)	(2.52)	(3.72)	(2.68)
Unemployed	1.11	1.24	2.52	-1.83	4.37	0.74	0.80
	(1.68)	(2.09)	(4.31)	(2.27)	(2.74)	(2.22)	(2.94)
Stay at Home Parent	1.06	1.21	1.79	-1.58	3.47	0.30	0.13
	(1.23)	(1.71)	(4.09)	(1.61)	(2.12)	(1.51)	(2.75)
Education							
Less than HS	-0.34	-0.65	-0.24	-0.85	0.43	-0.09	-0.44
	(0.85)	(1.35)	(1.20)	(1.06)	(1.42)	(0.98)	(1.87)
Some College	0.07	0.47	-0.76	-0.99	0.92	1.51	-1.41
	(0.87)	(1.20)	(1.40)	(1.13)	(1.44)	(1.13)	(1.73)
2-4 Yr Degree/Cert	-0.57	-0.61	-0.47	-0.36	-0.27	-0.39	-1.41
	(1.09)	(1.37)	(2.22)	(1.38)	(1.94)	(1.53)	(1.73)
4 Yr Degree/Cert +	0.02	-0.24	1.58	0.58	-0.72	1.43	-2.17
	(0.98)	(1.18)	(2.13)	(1.20)	(1.72)	(1.26)	(1.97)
Early Math Knowledge	0.10	-0.06	0.31	0.13	0.21	0.09	0.39
	(0.15)	(0.21)	(0.24)	(0.18)	(0.28)	(0.21)	(0.28)
Adjusted R^2	0.04	-0.07	0.04	0.00	0.02	0.01	-0.02
Observations	144	74	70	78	66	88	56

Notes. Standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001. Language is language of observation. Reference group for employment is Multiple (2 or more of employment categories). Reference group for parent education is high school diploma or equivalent.

Over the 35 verbs hypothesized to be used for spatial concepts, ten were identified in transcripts. The most frequently used spatial verb was *sacar* (to take out), with 60% of parents who used spatial verbs using some form of *sacar*. Across the full sample, the mean use of *sacar* was 1.12 (sd=2.29). *Meter* (to put) was the next most common spatial verb (m=0.33, sd=1.17). Of parents who used spatial verbs, 29% used a form of *meter*. The third most commonly used spatial verb was *poner* (to place), with 22% of spatial verb-using parents using it (m=0.21, sd=0.61). The fourth most common spatial verb was *sentar* (to sit), used by 15% (m=0.14, sd=0.51) of parents. See **Table 3.4** for a list of verbs used, the forms taken in the observations, and examples.

Table 3.4. Spatial Verbs in Observations

Verb	Forms	Examples
Sacar	saca, sácalo, sacado, sácala, sácalas, sácale, sácalos, sácame, sacamos, sacando, sacar, sacarlas, sacarlo, sacarlos, sacas, sacaste, sácate, sacó, saqué, sáquelo, saquemos, saques	Sácalas todas. (*take them all out*)
Meter	metió, metiendo, mételos, mételo, mételas, mete, metas	Mételo. (*put it in*)
Poner	ponte, ponlo, ponle, póngalo, pones, ponerlo, ponerle, poner, ponen, ponemos, pone	Ponle a tu pizza cheese. *(put it on your cheese pizza*)
Echar	eches, echarle, echar, échalo, échale, échala, echa, echarlo	Échale chile a la pizza. (*put spice on the pizza*)
Sentar	siéntate, sentarnos, sentar	Siéntate. (*sit down*)
Subir	subir, sube, subiendo	El cohete va subiendo. (*the rocket is going up*)
Levantar	levantar, levántese, levántelo	Levántelo. (*lift up*)
Recoger	recojas, recógelo	Asi es mas facil recógelo. (*so it's much easier to pick up*)
Quitar	quito, quitármela	Quitármela. (*take it off*)
Salir	salen, salió, salir	Mira, salió. (look, it came out)

Note. This list includes the verbs identified in the transcripts.

Research Question 2. How much spatial math talk is excluded by not including verbs?

Prevalence of Observations with Spatial Prepositions and Verbs

When combining the direct (prepositions) and implied spatial words (verbs), 81% of videos contained at least one instance of spatial talk. There were no statistically significant differences between those who did and did not use any spatial talk for any of the key characteristics (e.g., parent gender, child gender, employment status). Of the 115 parents who used at least one spatial preposition or spatial verb, the mean was 5.80 (sd=5.77). [For descriptives for the "as usual" coding, see **Appendix G**].

Total Spatial Talk without and with Verbs for the Full Sample

When including spatial verbs, the total amount of spatial talk increased from a mean of 2.57 (sd=3.43) to 4.71 (sd=5.67). This difference was statistically significant (t(142=-5.99, p<0.001). For each observation, including spatial verbs increased the spatial talk total by an average of 2.14 words (sd=3.53). **Table 3.5** displays means by parent gender, child gender, and language of interaction, though none of these differences were significant. See **Appendix H** for further information on ranges.

Table 3.5 Comparison of Total Spatial Talk with and without Verbs

	Parent Gender		Child Gender		Language	
	Mothers (n=74) m (sd)	Fathers (n=70) m (sd)	Girls (n=66) m (sd)	Boys (n=78) m (sd)	Spanish (n=88) m (sd)	Eng/Sp (n=56) m (sd)
Prep-only	2.96 (3.80)	2.16 (2.96)	2.09 (3.06)	2.97 (3.68)	3.15 (3.62)	1.66 (2.90)
Verbs + Prep	5.15 (5.60)	4.24 (5.74)	4.41 (5.60)	4.96 (5.75)	5.71 (5.82)	3.14 (5.09)
Diff	2.19 (3.21)	2.09 (3.87)	2.32 (3.99)	1.99 (3.12)	2.56 (3.38)	1.48 (3.70)

*Note*s. Diff is the difference between a parent's total with and without spatial verbs included. Language is language of observation.

Spatial verbs accounted for nearly half of the total spatial language. On average, the proportion of spatial languages expressed through a verb was 0.40 (sd=0.37). The amount of spatial verbs a parent said was positively and strongly correlated with the amount of spatial prepositions they used (r=0.81, p<0.001).

Participant Characteristics and Frequency of Spatial Talk Using Propositions and Verbs

In considering total spatial language, both spatial verbs and prepositions were counted. OLS regressions for the full sample showed that parents who talked more, whether about math or not, also used spatial verbs more (See **Table 3.6**). The positive association between talkativeness and a higher total use of spatial prepositions and verbs was found for mothers, fathers, daughters, sons, and interactions in Spanish and in English. When separating analyses by child gender, boys whose parent worked full time received more total spatial talk (β=4.69, p<0.05) than boys whose parents had two or more employment types (e.g., working full time and going to school). No other predictors were significant.

Table 3.6. Characteristics Predicting Total # Spatial Talk (Prepositions + Verbs)

		Parent Gender		Child Gender		Language	
	(1) All	(2) Mothers	(3) Fathers	(4) Girls	(5) Boys	(6) S	(7) E/S
Total Parent Talk	0.03***	0.02**	0.03***	0.03**	0.03***	0.04***	0.02*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Parent Male	-0.72			-1.18	0.58	-1.68	-0.82
	(1.16)			(2.03)	(1.55)	(1.83)	(1.57)
Child Boy	-0.73	-1.08	-0.39			-2.22	0.59
	(0.91)	(1.37)	(1.37)			(1.21)	(1.53)
Parent born in the US	-2.04	-1.66	-1.91	-2.87	-0.53	3.74	-2.59
	(1.29)	(1.71)	(2.39)	(1.96)	(1.91)	(3.29)	(1.68)
Employment Status							
Working Full Time	1.53	2.59	1.60	-1.38	4.69*	2.30	-0.58
	(1.56)	(2.89)	(2.01)	(2.51)	(2.28)	(2.17)	(2.40)
School/Training	-1.80	-1.12	-2.92	0.00	1.23	-2.31	-3.64
	(2.72)	(3.71)	(6.37)	(.)	(3.27)	(5.89)	(3.49)
Unemployed	1.83	2.78	4.98	-2.38	5.99	0.99	0.16
	(2.53)	(3.39)	(5.97)	(3.92)	(3.55)	(3.52)	(3.83)
Stay at Home Parent	1.31	2.18	1.16	-1.91	4.63	0.21	-1.14
	(1.84)	(2.77)	(5.67)	(2.78)	(2.75)	(2.39)	(3.58)
Education							
Less than HS	-0.21	-2.20	0.94	-1.89	2.03	0.19	-1.24
	(1.27)	(2.20)	(1.67)	(1.83)	(1.84)	(1.55)	(2.44)
Some College	-0.50	-0.52	-1.28	-2.94	1.86	1.44	-3.25
	(1.31)	(1.95)	(1.94)	(1.96)	(1.86)	(1.80)	(2.25)
2-4 Yr Degree/Cert	-0.23	-0.98	-0.52	-0.76	0.36	0.32	-1.82
	(1.64)	(2.23)	(3.08)	(2.39)	(2.51)	(2.43)	(2.26)
4 Yr Degree/Cert +	-0.49	-1.58	2.01	-1.88	1.11	1.48	-3.18
	(1.47)	(1.92)	(2.95)	(2.08)	(2.22)	(2.00)	(2.57)
Early Math Knowledge	0.14	-0.19	0.54	0.11	0.37	0.23	0.53
	(0.23)	(0.34)	(0.33)	(0.31)	(0.36)	(0.33)	(0.37)
Adjusted R^2	0.16	0.08	0.17	0.13	0.17	0.16	0.09
Observations	144	74	70	78	66	88	56

Notes. Standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001. Language is language of observation. Reference group for employment is Multiple (2 or more of employment categories). Reference group for parent education is high school diploma or equivalent.

Discussion

Concerningly, results from this study indicate that the amount of spatial talk expressed by Spanish-speaking families was vastly undercounted when using a coding scheme derived from a language that is satellite-framed (i.e., English). Findings provide additional confirmation to the only study to my knowledge of parental spatial talk with young children to explore Spanish and English expression of spatial concepts, which found a high proportion of spatial talk in verb-form for Spanish-speaking families (Melzi et al., 2022).

Prevalence of Spatial Talk in Context

Of note is that even with the inclusion of spatial verbs, math talk totals were low and there was variability in how much spatial talk a parent expressed. A considerable chunk of parents used no spatial verbs or spatial prepositions, yet one parent used 32 spatial prepositions and verbs in ten minutes. The variability in use of spatial language is also reflected in the large standard deviations (i.e., larger than the means) for both the preposition-based and preposition plus verb-based coding schemes. This pattern persisted when breaking apart results by parent gender, child gender, and language of the observation, which mirrors other findings of large variance in math talk produced by parents in ethnically diverse samples (Levine et al., 2010; Pruden et al., 2011).

Another factor in the low prevalence of spatial talk was likely the very young age of the children in the sample (child 9 months old). As children age, mothers tend to increase the amount of language directed towards their children (Rowe et al., 2005). It may be that the amount of total spatial talk would be higher if children were preschool or elementary age. Additionally, the set of toys the dyads engaged with did not include items such as puzzles and blocks that typically elicit a lot of rich spatial talk (Ferrara et al., 2011; Levine et al., 2012; Pruden et al., 2011). Perhaps if they had, the frequency of spatial words by parents would be higher.

In general, observations solely in Spanish had more spatial talk than observations in which parents used a mix of English and Spanish. However, this is likely because the focus of this study was on Spanish spatial verbs and scripts were run for Spanish only. Thus, the amount of time in Spanish-language interactions was lower than the bilingual observations. Whether parents used more spatial talk in English and if there were specific types of concepts expressed more in one language than the other is important to consider and discussed further in the conceptual section of this discussion.

Interestingly, means for spatial verb use were higher for parents born outside the US than those born in the US. Foreign-born parents had, on average, lived in the US for 9.70 years (sd=6.79) and were, on average, 29.70 years old (sd=6.29), indicating much of their formal education was likely not in the US. It may be that these parents developed a more robust exposure to academic Spanish, which may be related to using implicit forms of direction embedded in verbs. In work with elementary and middle school children whose parents immigrated to the US, parents' education in their home country was the strongest predictor of a child's academic achievement (Pong & Landale, 2012). Other research has found that parental immigration status, neighborhood context, and education play a role in language development but not math (Landale et al., 2016). Such findings highlight the heterogeneity of families and the importance of looking at nuances that incorporate the complex contexts of families to better understand the mechanisms through which education and migration influence children's math learning (Elliott & Bachman, 2018b; Lefevre et al., 2002).

Predictors of Spatial Verbs and Total Spatial Talk in Spanish

Overall parental talk was a consistent predictor of the amount of spatial verbs expressed as well as the total spatial talk that included prepositions and verbs. This association is not surprising. If parents speak more, there are more opportunities for spatial talk to emerge as they engaged in activities with their children. However, this is counter to findings in numeracy that overall talk does not account for total math number talk (Eason et al., 2021; Elliott et al., 2017; Gunderson & Levine, 2011).

The only demographic characteristic that predicted spatial talk (and only for preposition plus verbs) was parents' full time employment status, though this was only found for interactions with sons. Parents who worked full time used more spatial verbs with their sons. It is possible that parents' work experiences expose or attune them to mathematical concepts that they then bring into the home, though more research is needed to disentangle these findings (Elliott et al., 2020). That males received more spatial talk aligns with some previous findings that boys hear and receive more spatial language from parents than girls, though the literature in general is mixed on child gender and spatial talk (Fink et al., 2020; Pruden & Levine, 2017; Wu et al., 2021).

Parental education did not predict spatial talk, for verbs specifically or for the proposition plus verb coding. Maternal education has been identified as a predictor of young children's math skills (Susperreguy & Davis-Kean, 2016), though practices in the home learning environment have been found to mediate this association (Zadeh et al., 2010). Knowledge of early math development did not predict use of spatial verbs or total spatial language (prepositions plus verbs). This construct contained items capturing parents' awareness of early mathematics that included a variety of math concepts including numeracy (stating the total number of items in a set), spatial (e.g., "in" and "on" are math concepts), and when or how children learn mathematical concepts (e.g., babies are not too young to learn math), thus it may have been too general to predict spatial-specific language.

Conceptual Implications

This exploratory study provides evidence that families who use Spanish express spatial concepts implicitly through verbs as well as explicitly through prepositions. While capturing this is important for accuracy in research, it also leads to bigger-picture questions about what this means for children's spatial vocabulary, spatial concept development, and perceptions of the spatial world. In other words, when spatial concepts are expressed in verbs, what does that mean for children's development of spatial skills?

Children in Spanish-speaking interactions were exposed to both prepositions and verbs that convey spatial concepts. This suggests children in Spanish-language interactions receive a more diverse set of spatial words and, consequently, have a richer pool of vocabulary to describe the spatial space around them than children who speak English. Future research should expand on this exploratory work to identify the spatial vocabulary children themselves begin to use and whether they too use verbs to indicate space. For this work, researchers should use toys that support a wider range of spatial concepts than the ones in this study. I found that spatial verbs were clustered in just a few verbs - sacar (to take out), meter (to place), poner (to put), and sentar. Over half of parents who used a spatial verb used a form of sacar at least once. However, from an informal review of videos, much of these terms came about as parents were taking items in and out of the toy bag or putting shapes in or out of the shape-sorter and placing them somewhere else, which may explain the high frequency of these verbs. The play pizza also elicited a lot of spatial verbs because there were opportunities to take the pizza slices out of the pan they came in (e.g., "Sácalas todas."/"*Take them (the pizza slices) all out*.") or to put items "on" the pizza (e.g., "Ponle a tu pizza cheese."/"*Put cheese on your pizza.";* "Échale chile" a la pizza"/"*Put spice on the pizza.")*. The types of spatial verbs used in this study likely reflect demand characteristics of the toys that facilitated *in/out* concepts because the shape-sorter required children to put shapes *in* or take them *out*, the toy grocery cart and pizza slices also required *in/out* locations and actions.

There was likely an interaction with the toys and the child's age as well. At nine months of age, children often put things in their mouth. Thus, unsurprisingly, parents told children to not put toys in their mouth or described the child putting things in his/her mouth either through prepositions (i.e, "en boca, no!"/ *Don't put it in your mouth*) or verb plus a combination (i.e., "tú todo lo quieres meter a la boca."/ *You want to put everything in your mouth*.). The toys parents had available offered few opportunities for concepts such as on/under, top/bottom, through, and other spatial configurations. When researchers have used blocks or puzzles to document a broader array of spatial concepts (Levine et al., 2012; Verdine et al., 2014), they find a greater variety of spatial concepts than this study. Future research should consider the diversity and extent of spatial concepts they hope to capture and then identify toys that are more likely to provide opportunities for such spatial talk.

Another important implication is that children in Spanish-speaking interactions could receive spatial concepts that contained more specificity in their meaning than a preposition, which may influence spatial development. In research on numeracy development, specific types of talk have been linked to development in specific skills. For instance, parents' use of large numbers is associated with children's cardinality skills (Gunderson & Levine, 2011) and maternal labeling of set size is linked to children's math skills (Casey et al., 2018). Because spatial verbs may denote a specific context (e.g., montar, scalar, subir all denote "up" concepts in specific ways), such concepts may be diffused across several different words, whereas in English they may be more consolidated in a few prepositions. Whether or not spreading out a concept or consolidating supports children in learning that spatial concept is not known, but important to understand. There were instance of parents using a spatial verb with a spatial preposition, though these instances were only coded for the preposition that would be picked up in the "as is" coding scheme. That children possibly receive multiple spatial cues in a parental utterance that could help them to more quickly solidify these concepts. Future research should explore and unpack the extent to which and how the spatial concept and the breath versus specificity of the verb or preposition used influence children's spatial skill trajectories.

Findings from this study lead to a question of whether it matters for children's spatial perceptions if direction or location are implicit versus directly stated. Existing evidence indicates links between how people perceive the world and language (Konishi et al., 2019; Slobin, 2003; Talmy, 1991). Further, there is emerging evidence that as individuals learn a new language, they begin to adapt both their linguistic coding and their conceptualization of motion events to the language of study (Wang & Wei, 2021). In other words, not only do they learn the vocabulary of the language, they also change their cognitive concepts about motion events in response to the new language. Research in numeracy also indicates that the language a child is reared in and their cardinality development are linked (Sarnecka, 2014). Children may have to become more attuned to spatial considerations when location or direction are embedded in verbs. Future research should take a more nuanced examination of when and how parents use spatial verbs compared to prepositions (e.g., does this differ by object referenced, purpose of motions, etc.) and how use of verbs shapes young children's conceptions of space.

Finally, another important conceptual implication lies in the language used during bilingual interactions. Some spatial concepts may be more commonly referred to in one language than another and it would be useful to identify any patterns of spatial language use that varied by concept. There is some evidence of bilingual parents predominantly using one language over another for certain math concepts. For instance, bilingual English and Mandarin Chinese parents tend to verbally express cardinality concepts in Mandarin rather than English, which the researchers suggest is due to structural differences between English and Mandarin (Chang & Sandhofer, 2019). Other work has found a link between the language structures of English and Mandarin and the extent to which math is embedded in language (Kung et al., 2019). Such studies looking at when and how parents use math concepts in bilingual families are rare. The languages children receive math talk in and what that configuration looks like has been understudied (Hornburg et al., 2021), though findings from the present study suggest children in bilingual English-Spanish compared to Spanish-only interactions receive spatial concepts in different amounts or in different ways. Future work should explore whether differences in how concepts are expressed in different languages, and how bilingual parents choose to verbally share them by language choice, alter perceptions of the world.

Implications for Research and Practice

Preposition-focused coding schemes clearly underrepresent spatial talk in Spanish. Based on findings from this study, if the preposition framing was not translated in ways that included implicit spatial concepts expressed in verbs, almost half the spatial words a parent used would be missed. While the prevalence of spatial talk is not high, missing verbs matters because most research on math communication between parents and young children typically rely on coding schemes derived from an English lens (Hornburg et al., 2021; Melzi et al., 2022). This highlights the critical need for researchers to not simply translate coding schemes to other languages, but to also consider how the construct of interest may be expressed differently in language. If researchers do not take this into account, they greatly risk reporting inaccurate and invalid results. Even more concerning is the potential to create false assumptions. When using an English-centric coding scheme, Spanish-speaking families would appear to use fewer spatial words with their children than they actually do, which could contribute to deficit-based perceptions of Spanish-speaking families (Adair et al., 2017). Further, as a research community, we risk missing rich and complex findings that would come about from studying the expression of math concepts in the context of the linguistic structures and affordances of different languages that parents use.

Findings suggest that researchers should employ careful consideration of linguistic and cultural affordances when using measures or adapting a coding scheme for use with a different language than it was developed in. An example of a measure developed in response to a multilingual environment is the Mother Tongue Adapted Coding Scheme. This measure assesses teacher-child quality in early learning settings with multilingual children and was created to adapt to sociolinguistic aspects and affordances of specific languages teachers used rather than using a strict translation approach (O'Brien et al., 2020). The measure was developed in Singapore, where not only are different language used (e.g., English, Tamil, Chinese) but different varieties of these language exist as well (e.g., "mainland" Mandarin and Taiwanese Mandarin). Because the variety of the language used had implications on instruction and interactions, the coding scheme was developed to be context specific. Another promising strategy is taking a more culturally relevant approach to creating or translating measures, such as engaging in focus group with families to identify vocabulary and concepts they use or using inductive coding of families to inform a measure (Burnette et al., 2020; Covarrubias et al., 2020; Melzi et al., 2022).

Similarly, these findings indicate that curriculum and assessment designers should be intentional in their design process to reflect ways in which spatial talk may be received or expressed in languages other than English. While reviewing the literature and talking to linguistic experts are useful, this should be coupled with approaches that partner with families to capture how they actually express these concepts in their everyday life and to inform a strengths-based approach informed by families' socialization of mathematics (Galindo et al., 2019; Melzi et al., 2022).

Future Directions

Exploring the extent to which parents use spatial talk is a first step to more critical questions of how spatial talk relates to children's own use spatial talk and, most importantly, children's spatial math skills. Extant literature identifies a link between spatial talk and children's spatial development outcomes, but much less is known about what features of spatial talk parents use and the activities that matter most in spatial development: Do some types of activity and materials matter more than others? Does the way in which a parent encourages spatial talk matters? Does spatial talk prompted by technology elicit more or a different quality of spatial talk? (Chan et al., 2020; Hall et al., 2022; Ho et al., 2018; Uscianowski et al., 2020).

Based on this study's findings, another promising direction is looking at is verbs in English that carry implicit spatial information. While the focus in this study was on verbs in Spanish that carried implicit spatial concepts because the verb-framed approach of Spanish makes it much more likely to have spatial verbs, there are also some verbs in English that too carry implicit spatial direction or location without the need for a preposition. For example, *enter* implies "in" and *exit* implies "out." It would be worthwhile to explore the extent to which such verbs exist in English, how frequently and in what ways parents use them, whether they are utilized differently by speakers of English and another verb-framed language, and whether they are associated with certain aspects of early spatial development.

Limitations

First, while this study was greatly enhanced by the input, support, and insights of fluent native Spanish speakers, I, as the author, am only at an advanced beginner level of Spanish. This is a major limitation which I sought to address with as much advice and review as possible by native Spanish speakers, but it is still a major limitation. Concerns by research assistants coding in Spanish led to this examination of whether exclusion of spatial verbs was masking the true extent of spatial talk in Spanish. This study provides proof of concept for this concern, but additional analyses and work should be conducted by a fluent English-Spanish researcher. Similarly, I am not trained as a linguist. The impetus for this paper was rooted in a question around measurement to inform child development research, but the topic is deeply interconnected with linguistics. Ideally, future work would involve collaboration between developmental psychologists and linguists. Another limitation is that for both the preposition-informed and verb-informed words, research assistants (RAs) reviewed transcripts to determine if a spatial concept was implied by the word. Findings may have differed if the RAs coded from the recorded observations with the statements in context of an activity or interaction. Finally, this paper examined the amount of spatial talk used but it did not examine when and how parents use math talk, for instance, the type of support provided, prompts given, and directiveness, or the quality of the spatial talk, which would support a more nuanced analysis (Eason et al., 2021; Leyva et al., 2017; Melzi et al., 2022).

Conclusion

Lack of research that represents the math discourse of bilingual or non-English-speaking children in families earning low-to-moderate incomes limits our understanding of children’s early math experiences and prohibits our ability to design scalable, culturally sensitive, and feasible interventions and supports for early math learning. This study provides evidence of the importance of understanding and designing research to capture the full complexity and richness of spatial talk in families that are not monolingual English speakers. Spatial verbs are used by parents who speak Spanish and this spatial talk is not captured by English-informed spatial coding scheme that rely on spatial concepts expressed through prepositions. Consequently, these schemes likely undercount the amount of spatial talk parents express. Findings from this study should encourage researchers to take a more nuanced view of how spatial concepts are expressed when conducting research in multilingual contexts. This study contributes to conversations in the field on how to capture and measure the contextual nuances of early home mathematical environment, particularly related to cultural and family contexts (Hornburg et al., 2021).

Chapter 4: Study 3 - Effects of a Federal Pre-k Grant on State Pre-k Enrollment

Introduction

Availability and access to early childhood education is critical to ensuring that parents of young children can productively engage in the workforce (Kimmel, 2006; Schochet, 2019). Further, the quality of the early experiences young children receive is essential to a child's optimal development (Bratsch-Hines et al., 2020; Dearing et al., 2009; NICHD Early Child Care Research Network, 2003; Vandell et al., 2010). For these reasons, many countries consider early childhood care to be a public good and either directly provide, or heavily subsidize, the cost of early care (Gould et al., 2017; Howard, 2018). For example, France provides affordable day care for very young children and offers universal free preschool at age three (Lundberg, 2012).

The landscape in the US, however, is quite different (Waldfogel, 2001). Policymakers have historically ignored or hesitated to offer public early education (Lombardi, 2019). For young children, US federal policy provides subsidies for child care to low-income families (i.e., the Child Care Development Fund (CCDF) program), offsets through tax credits, and slots in the federal Early Head Start/Head Start program for families with incomes below the federal poverty threshold (Michelmore & Pilkauskas, 2019). These policies thus reflect the long-standing view that early care is a household responsibility to be determined within the family, with very little government involvement, and that market forces should dictate the structure of early child care supply in the US (Karch, 2014; Rose, 2010).

When attempts at universal child care at the federal level failed in the 1970s with the veto of the Comprehensive Child Development Act, early childhood advocates turned their focus from the federal to state government as a vehicle for the delivery of early education (Karch, 2014). Four-year-olds became the focus rather than the broader birth-five continuum. Targeting this age was more feasible politically because it addressed school readiness concerns and was framed as a way to reduce inequities children experienced before kindergarten (Karch, 2014). Following this shift, state policymakers have dramatically expanded the supply of care for 4-year-olds through state pre-kindergarten (pre-k) funding over the past 30 years, moving from a few states to nearly all states providing some type of public pre-k program (Friedman-Krauss et al., 2020; Kahn & Barron, 2015; Weiland, 2018). From 2002 to 2019, 4-year-olds served in state-funded pre-k programs grew from 14 to 34% (Friedman-Krauss et al., 2020).

While pre-k expanded in states over the past decades, the federal government made a few unsuccessful attempts at widening federal involvement in child care (e.g., the proposed Child and Family Services Act of 1975, The Child Care Act of 1979, Prekindergarten Dropout Act of 1988) while continuing to fund Head Start, CCDF subsidies, and early tax credits (Karch, 2014). Additionally, since its creation in 1965, school districts could opt to use their Federal Title I funds from the Elementary and Secondary Education Act (ESEA) for 4-year-old pre-k provision. The No Child Left Behind Act revision of ESEA by Congress during George W. Bush's administration included some preschool-aged programming (e.g., reading programs for pre-k age children, professional development for some ECE educators). However, ESEA did not directly fund pre-k slots.

The Obama administration engaged in much more active and direct work related to pre-k policy than preceding administrations, particularly through limited grants to states via a competitive process. First, the administration incentivized state "systems-building" activities to support implementation of pre-k (i.e., Race to the Top – Early Learning Challenge) through awards granted in 2011, 2012, and 2013. Following the RTT-ELC, the administration offered to provide direct federal funding for pre-k slots to states through a new competitive Preschool Development Grant - Expansion (PDG-E)[2] program in 2014.

A key question about these activities is whether they actually achieved their aims. There was no overall evaluation of the effectiveness of PDG-E as a federal grant (Farran, 2016). Existing data are limited to state-level information through annual progress reports that provided raw numbers of seats funded and state-specific internal evaluations (see Goodson et al., 2018). States pre-k enrollment, on average, was growing in the immediate years prior to PDG-E (Barnett et al., 2016). Thus, a key question is whether states that received PDG-E funding boosted enrollment at a faster rate than would have occurred in the absence of this funding, to understand whether a unique competitive approach to public funding was successful. Thus, a key aim of my study is to examine whether PDG-E achieved its primary aim of increasing new pre-k slots, which has not been, and is not planned to be, assessed by the federal government.

With any new large policy expansion, it is also important to explore the potential for unintended consequences. For instance, did the limited nature of these federal pre-k expansion funds reduce growth in states who applied and did not receive funding? Did this lower interest or generate pushback to expanded enrollment in such states because of the failure of the application? Or did it generate a positive policy diffusion? Research on policy diffusion finds that states often mimic policies of other states and the competition process itself may have spurred non-awarded PDG-E states to also increase enrollment by other means (Karch, 2007; Shipan & Volden, 2012). This would suggest that states who did not win may have been just incentivized through the application process to proceed with pre-k expansion as the winning

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[2] To prevent confusion with federally-funded Preschool Development Grant Birth – 5 (PDG B-5), a more recent and separate grant, we use the term PDG to denote states that responded to the Preschool Development Expansion Grants of 2014, which were implemented in winning states in the 2015-16 program year.

states did. However, little is known about whether the states that received funding had an increase in slots compared to those that did not.

My study provides a multi-state evaluation of the effects of this federal expansion of funding for pre-k to evaluate whether the policy had an impact on child pre-k enrollment using event study and difference-in-difference methodologies. Specifically, I estimate the effect of PDG-E on the percentage of 4-year-olds enrolled in pre-k in the states who received PDG-E funding before and after PDG-E was implemented, compared with the states who applied for, but did not receive PDG-E grants.[3] The nature of the competition allowed me to create a control group of states to serve as a counterfactual to what would happen to PDG-E states in the absence of PDG-E. This study contributes to knowledge on effectiveness of federal incentives to promote pre-k growth in the states that can inform federal policy approaches to engage with early childhood education.

Literature Review/Background

Federal Role in State Early Care and Education Systems Prior to PDG

The US early care and education (ECE) sector relies on funding from federal, state, local, and private dollars, operating within a heavily market-based system (Karch, 2014; Rose, 2010). These varying sources of funding also come with differing standards and requirements. The ECE system therefore operates as a fragmented non-system of early childhood programs and services that include a variety of actors such as state pre-k, Head Start, private or community-based child care programs, and early intervention (Gallagher et al., 2004). These actors operate in siloes,

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[3] While 18 states were awarded Preschool Development Grants in 2014, 5 of these states were “Development” states whose focus in the initial part of the grant was on developing the pre-k system. Some states did not offer slots until 2018. Thus, the development states are not considered in the analyses because they did not explicitly fund 4-year-old pre-k slots in most of the study years. I use the term PDG-E to refer to states that received the expansion funding.

typically tied to their funding mechanism, despite serving the same pool of young children aged birth through eight years (Kagan & Kauerz, 2012).

The federal government has sought to address this fragmentation in recent years by encouraging states to engage in systems-building activities through the Race to the Top – Early Learning Challenge grants (RTT-ELC), which awarded grants through a competitive process to 20 states over three years (2011 to 2013).[4] Administered jointly by the U.S. Departments of Education (ED) and Health and Human Services (HHS), the grant sought to bring together early childhood actors within states to coordinate to grow and support the supply of high-quality early learning programs. The mechanism RTT-ELC used to increase quality was requiring the development or improvement of tiered quality rating and improvement systems (TQRIS) for child care providers statewide, and increasing the number of top-tier-rated providers. The design of RTT-ELC prompted states to engage with and coordinate different stakeholders in the ECE system including child care, Head Start, early intervention, and state pre-k (e.g., standards alignment) (Mathias, 2015). Although the grant intended to increase the number of children in high-quality programs, it did not directly provide funds for enrollment. It was not until the Preschool Development Grants of 2014 that the federal government provided funding that was specific to funding of state pre-k slots (compared to other funding like Title I that could be used for pre-k but was not mandated).

Preschool Development Grant (2014)

In 2014, ED and HHS announced the Preschool Development Grant (PDG) that would provide direct funding for new and enhanced quality pre-k slots over a four-year-time frame. For "new" pre-k slots, grantees could not use the federal funding to supplant a state source, and states

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[4] 1st phase (2011): CA, DE, MD, MA, MN, NC, OH, RI, WA; 2nd phase (2012): CO, IL, NM, OR, WI); 3rd phase (2013): GA, KY, MI, NJ, PA, VT (Administration for Children and Families, 2019a)

had to propose how many slots would be created using the PDG-E funding. However, states could spend money on enhancing existing slots to improve their quality. Participating programs were required to offer several quality elements including high-quality professional development, child-teacher ratios capped at 10:1, class sizes capped at 20 students, a full-day of care equivalent to elementary school (minimum 5 hours a day), inclusion of children with disabilities, and a lead teacher with at least a bachelor's degree.

States were designated as either "Development" or "Expansion" states based on the reach of their pre-k programs. States that served less than 10% of their 4-year-olds in public preschool and had not received an RTT-ELC grant could apply for a *Development* grant that focused on infrastructure and implementation of high-quality preschool programs. States that serviced more than 10% of 4-year-olds or had received an RTT-ELC grant were eligible to apply for an *Expansion* grant to enhance quality in their state preschool program and increase reach to additional eligible 4-year-old children. States who received RTT-ELC grants were scored separately from states that had not. Because RTT-ELC recipients had previous funding to enhance their systems and delivery, the separate categories ensure that states that did not have the systems-building advantage were not competing against those that did (Klein, 2014).

Thirty-five states and Puerto Rico applied to PDG. Eighteen states received grant funding – five for Development (AL, AZ, HI, MT, NV) and 13 for Expansion (AR, CT, IL, LA, MA, MD, ME, NJ, NY, RI, TN, VA, VT). As seen in **Figure 4.1**, PDG-E winners were located in the eastern half of the United States, mostly concentrated in the northeast, whereas states that applied for Expansion grants but did not receive them were more evenly spread across the country. Twelve of the states who did not receive Expansion grants after applying had previously received RTT-ELC funding (CA, CO, DE, GA, KY, MN, NM, NC, OH, OR, PA, WA) compared to only two applicants who did not receive RTT-ELC funding or PDG-E (SC, TX). Ultimately, the U.S. Department of Education reported that PDG distributed nearly one billion dollars of funding, with 167,725 children served (U.S. Department of Education, 2019). Of these, 75,701 of these children were in newly created pre-k slots (i.e., a slot that would not have existed without federal funds).

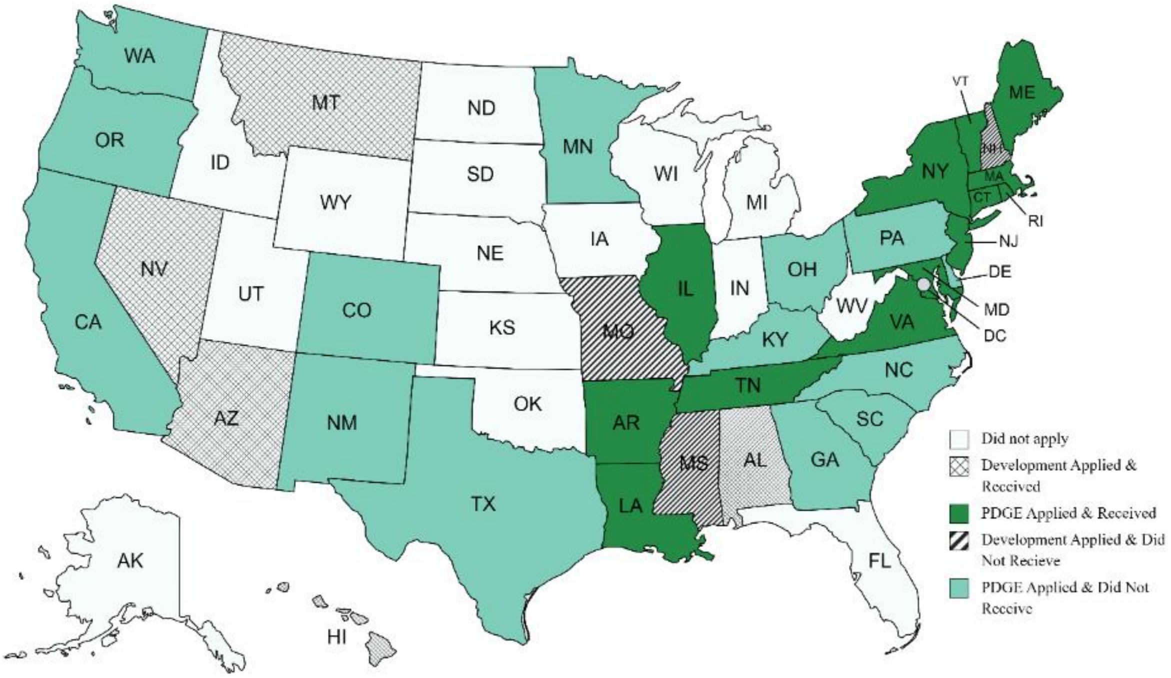

Figure 4.1. PDG Application and Receipt of Funding by State

The focus of this study are the 13 Expansion states (PDG-E). Implementation of Expansion slots began in the 2015-2016 school year, with additional unduplicated slots funded for the 2016-2017 and 2017-2018 school years; the bulk of new pre-k slots were to be created during the initial implementation year. Participation in the state pre-k programs was free for families. Each of the state’s programs capped family income eligibility at 200% of the Federal Poverty Level. Although most states were increasing pre-k enrollment for 4-year-olds during this time, the number of slots added through PDG was substantial. In 2015-2016, pre-k enrollment increases in these 18 states accounted for about 50% of the national increase in pre-k enrollment (Barnett et al., 2017), suggesting that this infusion of federal funding had an immediate impact.

PDG and the Potential for Policy Diffusion

It is important to not only understand PDG's impacts on pre-k enrollment - PDG-E also presents an opportunity to understand the effects of a fairly recent federal approach to incentivize educational improvement. PDG was funded by Congress, but its design and implementation reflected the policy approach taken by the Obama administration and then-Secretary of Education, Arnie Duncan, which aimed to build states' administrative capacity to implement educational reform or programming (e.g., aligned state data systems, aligned standards and assessments) and to support innovation in education. This approach was a major contrast to the US Department of Education's previous focus on monitoring for compliance (McGuinn, 2012). Indeed, a key change in the approach is reflected by the disbursement of funding to a few states through competitive grants, rather than a standard formula in which all states receive some funding allocation adjusted for things such as state population or poverty. This approach incentivized states to articulate clear, actionable plans for use of the funds and, if awarded, the funding to enact their proposed policy changes (McGuinn, 2010).

The competitive nature of PDG-E and the interest demonstrated by the large pool of state applicants created the possibility for policy diffusion. Although states create and implement policies, these decisions are often interrelated with other policies at the federal and local levels, as well as others states' policies. Policy diffusion is defined "as one government's policy choices being influenced by the choices of other governments" (Shipan & Volden, 2012, p. 788). Large federal incentive competitions, such as PDG-E, can spur diffusions by signaling to states the priorities and preferences of the federal government, in this case for pre-k expansion, and raise states’ awareness of each other’s pre-k policies through the grant-writing process (Karch, 2007). If PDG-E did spur policy diffusion, it would provide evidence of a value-add of the competitive approach, with benefits accruing beyond the scope of the initial grant recipients.

The extensive policy diffusion literature identifies four ways in which policies diffuse across governments: competition, learning, imitation, and coercion (Gilardi, 2016; Karch, 2007; Shipan & Volden, 2012). Competition is typically more regional, and is often seen in policies such as welfare, whereby states mirror policies of a neighboring state to disincentivize movement into a state with higher welfare benefits. Learning happens when states observe policies and their effects in another state, determine it a useful policy, and then enact it in their own state. Imitation occurs when a state, in essence, copies another state’s policy regardless of whether the policy was effective. Coercion happens when states are pressured to pursue, or are penalized for not pursuing, a policy. For instance, the federal government can withhold types of funding to states who do not adopt a policy (e.g., loss of highway funding if states did not lower speed limits) (Shipan & Volden, 2008). States who adopt pre-k may be imitating or emulating other state’s pre-k approaches, particularly because pre-k often has bipartisan support and is popular with voters (Lieberman, 2014).

When it occurs, diffusion is also influenced by factors such as the complexity of the policy, whether the original policy was viewed as having a positive effect, and the capacity, wealth, and population of a state (Mooney, 2001; Shipan & Volden, 2008, 2012). For instance, states “learn” when policies are less complex and imitate quickly after implementation. States who are wealthier, bigger, and have more capacity tend to adopt policies earlier than other states. However, as state policy is complex, so are factors that influence whether a policy diffuses to a state because decisions are made within their electoral, ideological, and political contexts (Allen et al., 2004; Gilardi, 2016; Gilardi & Wasserfallen, 2019; Karch, 2007). This includes the influence of multiple actors in the policy arena and the strength of professional associations, lobbyists, and advocates who can dictate whether a state picks up a policy from another state (Karch, 2007; Shipan & Volden, 2012). For instance, the strength of teachers' unions and of Democratic control of legislature in a state are associated with decreased likelihood of teacher performance pay measures (Finger, 2018). Further, some policies take less work to emulate because they have wide support, relevance, or popularity– pre-k is a policy issue that has bipartisan and public support (Gilardi, 2016; Rigby, 2007).

Another possibility is that through the grant application process itself, states who applied but did not win would be positioned to increase enrollment. This would be an effect of the grant application serving as a time-sensitive reason to organize and create policies and plans to expand. PDG-E offered a means to fund pre-k that did not require state legislature approval or allocation of limited state funds. This would be a major motivation for states to apply for PDG-E. The grant application required detailed planning of where the seats would be placed, evidence of agreements with subgrantees, and how the state would provide and sustain the seats after the four years of federal funding. Applications had to demonstrate readiness to implement PDG-E funding quickly, positioning states to be capable of implementing expansion. Thus, because everything was ready-to-go for implementation, states could possibly have pursued increased enrollment through other funds. Estimates of impacts of the grant, with a consideration of possible diffusion effects in response to the competitive process, would both provide a holistic view of PDG-E's effect on pre-k enrollment, and contribute to the literature on approaches to stimulating the growth of pre-k. Given that the federal government continues to pursue incentives to drive changes in education, it is valuable to study PDG-E to better inform this approach.

Current Study

My study's primary aim is to examine the extent to which a federal competitive grant met its stated goal of increasing enrollment of 4-year-olds in pre-k. There has been no evaluation of PDG's impact at a national level, thus this study fills a major gap in understanding the larger impact of the program and value added of federal intervention in direct pre-k funding. This approach could also illuminate possible diffusion effects due to the grant's signaling of federal priorities for 4-year-old education.

> ***Research Question:*** How does a large policy expansion of pre-k slots for 4-year-olds through PDG-E impact enrollment of 4-year-olds in a state preschool program across multiple states?

I hypothesize that the Expansion funding enabled awarded states to increase the proportion of the 4-year-old population enrolled in pre-k compared with states who applied for, but did not receive the funding. However, the extent of that increase is unclear, as are the potential for diffusion effects across non-PDG-E states.

Methods

Event Study Approach

This study takes a study event approach using state-year panel data to exploit the exogenous policy expansion as a result of PDG-E across all PDG-E applicant states, comparing pre-and post-period change between awardees and non-awardees. To understand impacts of PDG-E, I would want to know what would have happened in PDG-E states had they not received the funding (i.e., the counterfactual). Causal studies address this issue of lack of true counterfactual by using random assignment into a treatment or control condition. The competitive grant structure of the PDG-E funding removes random assignment as a possibility - states selected into applying and then a committee of grant scorers rated these applications to determine winners. States selected into applying for PDG-E, and winners were then selected by a committee, and both introduce bias to the study, threatening causal inference. States who chose to apply and won likely differed fundamentally from states that did not apply or states that applied and did not win, making them incomparable.

Fortunately, the event study can serve as an analytic tool that allows the researcher to exploit natural experiments, such as PDG-E, in which some states adopt a policy (i.e., receive treatment) and others do not, to address the random assignment concern (Clarke & Tapia-Schythe, 2021). This approach builds off of difference-and-difference methods (DID)[5] that have been frequently used to evaluate the impact of policies between states that adopt a policy (i.e., treated) and non-adopters (i.e., comparison) (Angrist & Pischke, 2009; Lechner, 2010). DID methods compare the outcome of interest between the treatment group and a carefully selected comparison group in one pretreatment period and one posttreatment period - before and after the policy change (Marcus & Sant'Anna, 2021). Event studies use multiple pre- and post-treatment periods that allow for graphical representations of the variable of interest before and after policy implementation that help visualize any change.

Selection bias is reduced first by identifying the best comparison based on a thoughtful consideration of which states differ the least from the PDG-E grant award. State early childhood policies vary considerably (Jenkins, 2014), thus it is important that the comparison states have

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[5] Recent work has raised concerns about bias when using difference-in-difference models with staggard timing of roll-out (i.e., policies turn on/off at different times in different groups) (Cunningham, 2021; Goodman-Bacon, 2018). This issue is not relevant for PDG-E because all states implemented the same year (2015-16).

similar ECE policy dimensions in order to estimate causal impacts. The comparison group must also meet the parallel trends assumption, that the treatment and control groups show similar "parallel" trends lines to test for common pre-trends (Abadie, 2005; Abadie et al., 2010). If both groups show similar trends before PDG-E implementation, the analysis can use the trajectory of the control group post-implementation to estimate a counterfactual for treatment states (i.e., what would have happened if states did not receive PDG-E funding). If states were on similar tracks before PDG-E, the researcher can assume that in the counterfactual, the treatment group would continue follow a similar track as the control group.

Identifying a Comparison Group

A major hurdle in identifying a strong comparison group is that states vary enormously their early childhood policies. States differ in governance of ECE programs as well as how they structure program components such as cost-per-child, length of pre-k day, whether pre-k is offered in public schools or a mixed delivery setting (i.e., private providers and/or public school), and types of comprehensive services offered (Gormley, 2007; Jenkins, 2014; Jenkins & Henry, 2016; Meyers et al., 2001). Further, the tools states use to implement ECE policies (e.g., coerciveness, stringency) can vary by political context (e.g., conservative or liberal legislatures, wealth of the state, etc.) (Gormley, 2011; Rigby, 2007). These nuances in state policy can make finding appropriate comparison groups difficult. Thus, I explored several different comparison groups.

First, I considered a comparison group of states that did not receive a PDG-D/E grant. I decided including the states who were eligible for a Development grant but did not apply would not be appropriate because these state either did not have a robust pre-k program, or a program at all. As defined in the RFP, Development states served less than 10% of the state's 4-year-olds, and the goal for these states were to develop their pre-k programs (U.S. Department of Education, 2017), whereas Expansion states had robust pre-k systems and were focused on expansion. Thus, these were fundamentally different states in terms of robustness of their pre-k programs. This left the Expansion eligible states, but including states who chose to not apply also posed a problem. Political support and strong leadership by the early learning leaders in a state are considered important for sustained high-quality pre-k (Minervino, 2014). It is likely that states who did not apply lacked political will or capacity, or simply were not interested in expanding pre-k – making it a poor comparison group.

I then considered restricting my analyses to states that had received Race to the Top – Early Learning (RTT-ELC) challenge funding and comparing those who applied and received against those who applied and did not receive. States who previously won RTT-ELC had prior federal funding to engage in cross-sector collaboration and quality enhancement work in their states. As prior winner of a federal competitive grant, they also had experience in successful grant applications and meeting federal requirements for how these were implemented. These similarities indicated this would be the best comparison group; however, this grouping failed the parallel trends assumption that the treatment and non-treatment groups were on similar trajectories. While I kept this as a robustness check, it was not appropriate for my main event study.

The closest approximation of similar states would be those who applied for PDG-E and within that group comparing those who received the funds against those who did not – these 27 states became my analysis sample. All these states were interested in expanding their state pre-k 4-year-old enrollment and had the capacity to plan for expansion, as demonstrated by the willingness to engaged in the intense response to funding proposal (RFP) process. Political support was indicated by the state governor signing the state PDG application (a requirement). Finally, in writing the application, states had to have a concrete vision and plan for increasing enrollment of its 4-year-old population and meeting quality requirements. This grouping also passed the parallel assumptions test.

A possible selection bias concern remained around how these states were selected. One concern is political bias; however, the states selected represented included states led by Republicans and Democrats. They also ranged in size from very geographically small with small populations (e.g., Rhode Island) to larger states with large populations (e.g., New York). I also conducted a review of each application's scores to determine the extent to which states who did and did not receive PDG-E were comparable. Scores on the applications ranged from 72.8% (SC) to 95.9% (MD), with an average score of 86.6%. The states with lower scores often lost points across multiple items, but were not completely deficient in one particular area. There were many sections of the application (e.g., B-3 alignment, budget and sustainability, monitoring, etc.) but all applicants, with the exception of Texas, received full points for the category most aligned to my research questions (Competitive Priority 3: Creating New High-Quality State Preschool Program Slots). Many of the states who applied but did not receive the funding operated well-regarded pre-k programs and early childhood systems at the time (e.g., NC, WA). See **Table 4.1** on the following page for a list of states in the comparison groups, which are grouped by RTT-ELC recipients and non-RTT-ELC recipients.

Measures

I use a state-by-year panel data, whereby each row contains values for the outcome, predictors, and covariates for each state in a single year from the 2010-11 program year ("2011") to the 2019-2020 program year ("2020").

Table 4.1. Treatment and Comparison groups, by RTT-ELC Status

Treatment Group: PDG-E Applied & Received (n=13)	**Control Group: PDG-E Applied & Didn't Receive (n=14)**
RTT-ELC Recipients (n=6)	RTT-ELC Recipients (n=12)
Illinois	California
Maryland	Colorado
Massachusetts	Delaware
New Jersey	Georgia
Rhode Island	Kentucky
Vermont	Minnesota
	New Mexico
	North Carolina
	Ohio
	Oregon
	Pennsylvania
	Washington
Non RTT-ELC Recipients (n=7)	Non RTT-ELC Recipients (n=2)
Arkansas	South Carolina
Connecticut	Texas
Louisiana	
Maine	
New York	
Tennessee	
Virginia	

Event of Interest and Window – Enrollment of 4-year-olds in Public Pre-k

This study sought to estimate PDG-E's effect on enrollment of 4-year-olds in pre-k. However, using the raw number of 4-year-olds enrolled in pre-k was problematic because states vary in population (i.e., a large enrollment increase could simply reflect a small increase in a very populous state). Thus, I use the percent of 4-year-olds enrolled in state pre-k to account for differences in state populations. This metric is useful to understand the extent to which the state serves 4-year-olds. My dataset covers ten program years from 2010-11 to 2019-20 – 5 years before the policy was implemented, the implementation year, and 4 years post-implementation.

Although national trends showed an increase in enrollment (Barnett et al., 2016), trends in the time period before and after PDG show both treatment and control groups at a similarly stable level of enrollment before implementation in the 2015-16 program year (see **Figure 4.2**). PDG-E states enrolled on average, 30.9% of their 4-year-olds in the year before implementation (2014-15), and the comparison group enrolled, on average, 22.5%. Looking more closely at states who received PDG-E, the majority increased the percentage of 4-year-olds in the state served in pre-k (CT, MA, ME, NY RI, TN) from the prior program year. However, three states did not change (LA, MD, VA) and three states actually served a smaller percent of their 4-year-olds (AR, IL, VT) from the prior year (see **Appendix I** for details).

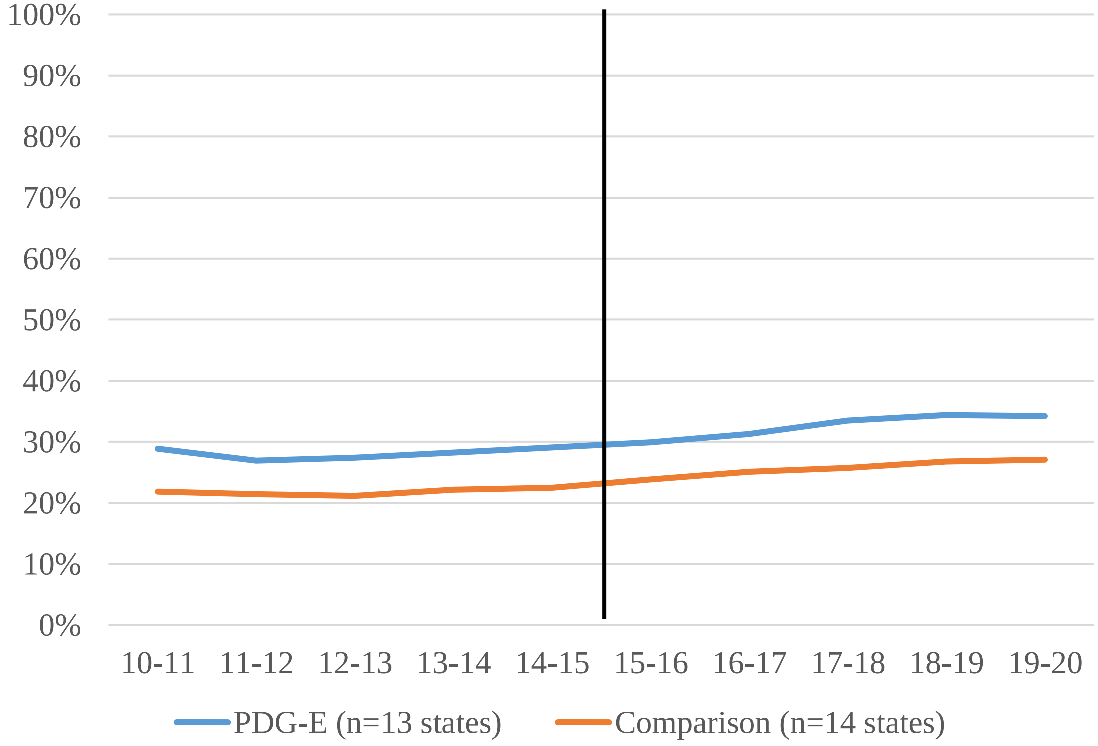

Figure 4.2. *Trends in Percentage of 4-year-olds in State Pre-k*

PDG-E Status

The implementation of PDG-E was my key policy variable, coded as 1 for PDG-E states and 0 for states that did not receive PDG-E funding. PDG-E states include the following 13 states: Arkansas, Connecticut, Illinois, Louisiana, Maine, Maryland, Massachusetts, New Jersey, New York, Rhode Island, Tennessee, Vermont, and Virginia.

Covariates

I included several state-level covariates to account for the diversity of states in my sample in order to avoid extraneous factors influencing my estimates.

State Population. I used state population to control for differences in size. I used data from the National Welfare Dataset maintained by the University of Kentucky (University of Kentucky Center for Poverty Research, 2020).

State Economic Indicators. I included indicators of the economic characteristics of state unemployment rate, poverty rate, and Gross State Product (Bassok et al., 2016). I accessed these data from a dataset maintained by the University of Kentucky (University of Kentucky Center for Poverty Research, 2020).

State Demographic Characteristics. I included racial/ethnic make-up (Kaiser Family Foundation, 2020) as well as state median household income (SMI) and percent of the population accessing Supplemental Nutrition Assistance Program (SNAP) from University of Kentucky Center for Poverty Research (2020).

Child Care Reimbursement Rates. I also controlled for Child Care Development Fund (CCDF) reimbursement rates. This was an indicator of how generous the subsidy system was in the state, which could be an indication of larger differences in early childhood policies. Data on initial reimbursement rates for infants, toddlers, and preschoolers comes from the CCDF Policy Database (Stevens et al., 2016).

Descriptives by each state for the implementation year (2015-16) are available in **Table 4.2** below. The PDG-E and non-PDGE-E states had significant differences on most variables. PDG-E states served a higher percentage of their state 4-year-olds in the implementation year, though non-PDG-E states, on average, had a larger number of 4-year-olds in the state as well as larger populations. The poverty rate was lower in PDG-E states and state median income was higher. PDG-E states, on average, had lower Gross State Product. In terms of racial and ethnic demographics, PDG-E states has a smaller percentage of white residents and higher percentages of Hispanic and Multi-race residents than in non-PDG-E states. CCDF reimbursements rates for toddlers and preschoolers were lower in PDG-E states. State-level descriptives for all years in the study (2010-11 through 2019-20) are available in **Appendix I.**

Table 4.2. Descriptives for Treatment and Comparison Groups by State, 2015-16 (Implementation Year)

	Received PDG-E (n=13 states)	**Applied & Didn't Receive PDG-E (n=14 states)**	**T-test**
4 yo Pre-k[a]	24,148 (27853)	39,809 (58510)	t(268)=2.77**
Pre-k % State 4yo[a]	31.0%	23.8%	t(268)= -3.49***
Total # 4 yo state[b]	77,096 (61351)	134,661 (137627)	t(268)= 4.38***
Population[c]	6,415,597 (5114381)	10,488,446 (10604227)	t(268)=4.04***
Unemployment Rate[c]	5.8%	6.1%	t(268)=0.93
Poverty Rate[c]	12.2%	13.4%	t(268)=2.89**
State Median Income [c]	$62,323 ($12327)	$57,451 ($9,175)	t(268)= -3.70***
GSP (USD millions) [c]	$411,930 ($393828)	$607,691 ($377,991)	t(268)= 2.87***
% Pop SNAP[c]	13.7%	14.3%	t(268)=1.44
Race/Ethnicity[d]			
White	68.7%	64.4%	t(268)= -2.47*
Black	13.5%	11.6%	t(268)= -1.62
Hispanic	10.8%	16.1%	t(268)=3.84***
Asian	4.4%	4.2%	t(268)=-0.74
American Indian/ Alaska Native	1.5%	2.0%	t(268)=1.64
Native Hawaiian/ Pacific Islander	0.5%	0.8%	t(268)=1.61
Multi	2.5%	2.5%	t(268)= 2.05*
CCDF Reimbursement Rates[e]			
Infant	$691 ($200)	$645 ($202)	t(268)= -1.91
Toddler	$630 ($189)	$582 ($167)	t(268)= -2.25*
Preschool	$596 ($174)	$549 ($158)	t(268)=-2.32*

Notes. Sources: NIEER State of Preschool Yearbooks; a) Table 2, b) Appendix C; c) University of Kentucky Child Welfare Database; d) Kaiser Family Foundation; e) ACF CCDF Administrative Data Tables: Table 7; + p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Analytic Plan

My analysis compared changes in PDG-E (treatment) states with states who applied to PDG-E but did not receive funding (control) in the time period before PDG implementation (2010-2015 fiscal years) and after (2016-2020 fiscal years) to isolate a treatment effect (Murnane & Willett, 2011). As noted earlier, the parallel trends assumption inherent in DID studies must be met (Marcus & Sant'Anna, 2021). As seen in **Table 4.2**, while PDG-E states served a higher percentage of 4-year-olds than comparison group states and showed a steeper uptick from 2013 to 2014, these differences were not statistically significantly different in any of the years prior to implementation, indicating the parallel trends assumption was met.

First, I ran a simple OLS regression to identify whether PDG-E status predicted an increase in the percentage of 4-year-olds in pre-k in a state. For treatment states, the PDG-E indicator was set to 0 for the years prior to implementation, and was to set to 1 for the PDG implementation year and thereafter. For control states, PDG-E was set to 0 for all years. I included the full set of controls and clustered for standard errors at the state level.

For the event study, I used the eventdd command in Stata 15.1, estimating the following equation:

$$Perc4yo_{st} = \alpha + \sum \beta_j \text{ (Lag j)}_{st} + \sum \gamma_k \text{(Lead k)}_{st} + \mu_s + \lambda_t + X'_{st}\Gamma + \varepsilon_{st}$$

in which $Perc4yo_{st}$ was the outcome variable (percentage of 4-year-olds enrolled in state pre-k), s indexed state and t indexed time. The variables μ_s and λ_t are the state and time fixed effects, X_{st} indicate my set of time-varying covariates, and ε_{st} is an unobserved error term.

Event study approaches include leads and lags in the model that signal when the policy was "on" or "off" – enabling a longer time horizon to study trends for the key coefficient of 4-year-olds enrolled in state pre-k. This aids in understanding whether the treatment and control group were on parallel trends in the years prior to implementation, any differences between treatment and control groups, and whether differences post-implementation increased or decreased over time (Clarke & Tapia-Schythe, 2021). To indicate time periods before PDG-E implementation, I created dummy variables for "lead" years before implementation, coded as 0 for each state in the comparison group and 1 for each state in the treatment group for the relevant year (e.g., for PDG-E states, lead2 was coded as 1 in 2013-14 to indicate 2 years before implementation, lead1 was coded as 1 in 2014-2015 to indicate 1 year before implementation). I also crated dummy variables for "lag" years to indicate the number of periods away from PDG-E implementation and. For instance, "lag0" was the year of implementation (i.e., 2015-16), and each lag variable following indicated years since implementation (e.g., lag1 was 2016-17, lag2 was 2017-18). These lag variables were coded as 1 for states who received PDG-E and 0 for those who did not. The baseline period that served as a reference period was 2014-15, the year prior to implementation.

I also included a set of state level covariates to control for potential confounds, these include population, state median income, poverty rate, unemployment rate, percent of state population accessing the Supplemental Nutrition Assistance Program (which provides benefits to low-income families to support food security), state racial/ethnic demographics, a state and year interaction term, and reimbursement rates for child care (infant, toddler, preschooler). State and time fixed effects were included to control for potential effects constant within states and time to account for unobserved variables bias. I clustered standard errors at the state level.

This approach provided me a coefficient that estimated PDG-E's impact on the percentage of 4-year-olds in pre-k as a result of the policy by looking at differences between my treatment and control groups. The lead and lag dummy variables provided information on whether differences in changes in the percentage of 4-year-olds served in a year were significant or not. All years prior to implementation should not be significant (i.e., states were, on the whole, similar), while post-implementation years should be significant if there was an impact.

Another benefit of the event study design is that it includes a graphic that plots the leads and lags for clearer interpretation of the data. This visualizes differences between PDG-E and non-PDG-E states in the percentage 4-year-olds enrolled in pre-k, along with confidence intervals, for multiple years prior to and after PDG-E implementation.

Results

Increased Rate of 4-Year-Olds Served in State Pre-K

Both PDG-E and comparison states, on average, increased the percentage of 4-year-olds served in state pre-k from 2014-15 (year before PDG-E implementation) to 2015-16 (year of implementation), as seen in **Table 4.3**.

Table 4.3. Percent of 4-Year-Olds Served in State Pre-K.

	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
PDG-E	28.9%	26.9%	27.0%	28.3%	29.1%	29.9%	31.3%	33.5%	34.4%	34%
Comparison	21.8%	21.4%	21.0%	22.2%	22.5%	23.9%	25.1%	25.7%	26.8%	27.0%

Notes. PDG-E states n=13; Comparison states n=14.

First Stage – OLS Regression

Receiving a PDG-E grant predicted a rate of increase that was lower than in the comparison group (β=-0.02), though this was not statistically significant (see **Table 4.4**).

Table 4.4. OLS: Receipt of PDG-E Funds on Percentage of State 4-year-olds Enrolled in Pre-k

	(1) All Applied
PDG Implemented	-0.02
	(0.02)
Observations	270

Notes. Standard errors in parentheses; Covariates are omitted from table for brevity; + p<0.10, * p<0.05.

Thus, while the PDG-E and comparison states all increased the number of slots available, comparison states increased at a faster rate than PDG-E states.

Second Stage – Event Study

Consistent with the negative coefficients in the OLS model, the event study results indicated that while both PDG-E and comparison states increased the percent of 4-year-olds enrolled in state pre-k after PDG-E was implemented, the rate of increase was higher for the comparison group. **Figure 4.3** displays point estimates and their 95% confidence intervals for each year, with the baseline period one year before implementation of PDG-E. In the years prior to PDG-E implementation, if states were on different pre-trends, the coefficient estimate (the red dot) would move above 0 on the y-axis. In **Figure 4.3**, this does not happen – thus providing a visualization that states had similar pre-trends.

For post-implementation years, if PDG-E had an impact on percentage of 4-year-olds enrolled in a state, we would expect to see a jump above the 0 on the y-axis in the year after implementation (time “0”). As shown in **Figure 4.3**, this does not happen and, in fact, there is a negative trend in the estimated coefficients of percentage of 4-year-olds in pre-k. This implies non-PDG-E states were increasing the percentage of their 4-year-olds served more than PDG-E states.

Although the post-PDG-E coefficients were not significant at conventional levels, the event study analysis showed marginally significant ($p < 0.10$) negative impacts of PDG-E on changes in the percentage of 4-year-old enrollment in one year post implementation (i.e., the 2016-17 program year) and for the 2018-19 and 2019-20 program year. The full set of event study regression results are available in **Appendix I**.

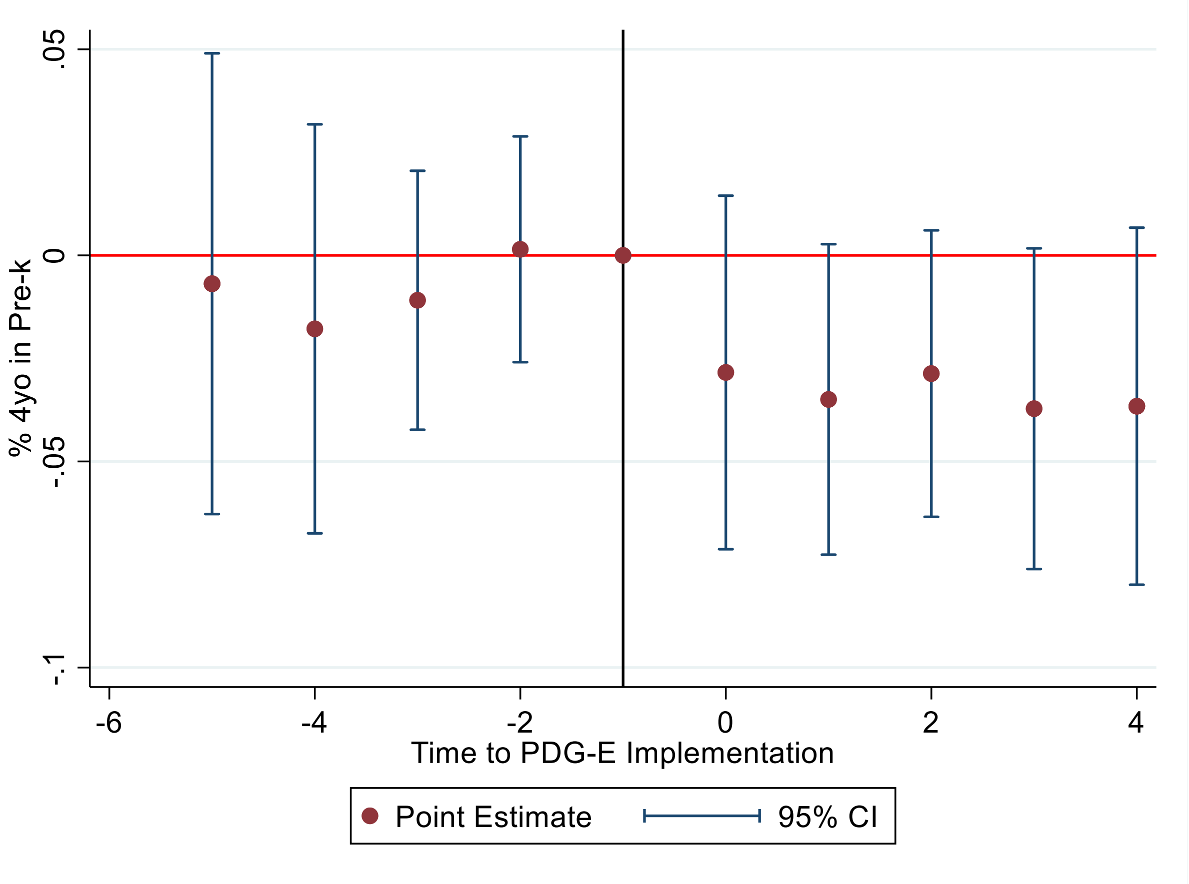

Figure 4.3. Event Study Estimates for Percentage of 4-year-olds Enrolled in State Pre-k

Robustness

Concern: Extraneous Policies

One threat to my analysis is the potential that other policies or policy contexts influenced the enrollment of 4-year-olds in a state and were enacted concurrently with the PDG-E award. In reviewing PDG-E and comparison state policies at the time of implementation or shortly before, two states stood out: California and Illinois. In 2014, California implemented its Local Control Funding Formula that gave more leeway to local education agencies on how state funds were used (e.g., providing unrestricted block grants instead of categorical programs) and provided higher levels of funding to districts that served high-need students, including low-income, English-language learners, children in the foster care system, and children experiencing houselessness (Lafortune, 2019). The definition of high needs included a population similar to the eligibility for the California State Preschool Program. A large increase in funding for pre-k in 2015-16 was attributed to local education agencies (LEAs; i.e., school districts) being able to fund state pre-k slots with these new allocations (Barnett et al., 2017). In Illinois, a budget impasse began in July 2015, shortly before PDG-E implementation, that did not end until 2017. While PDG-E funded slots were not impacted, other parts of the ECE system likely were.

To address this concern, I ran my analyses excluding California and Illinois. Findings showed a similar pattern of negative but insignificant coefficients in the OLS analysis, and the event study also showed a negative and marginally significant trend three years after implementation (2018-19 program year; **Figure 4.4)**. OLS models for the original event study that compared PDG-E applicant states that received and did not receive PDG-E funds, and robustness checks are available in **Appendix I**. The full set of event study regression results are available in **Appendix I**.

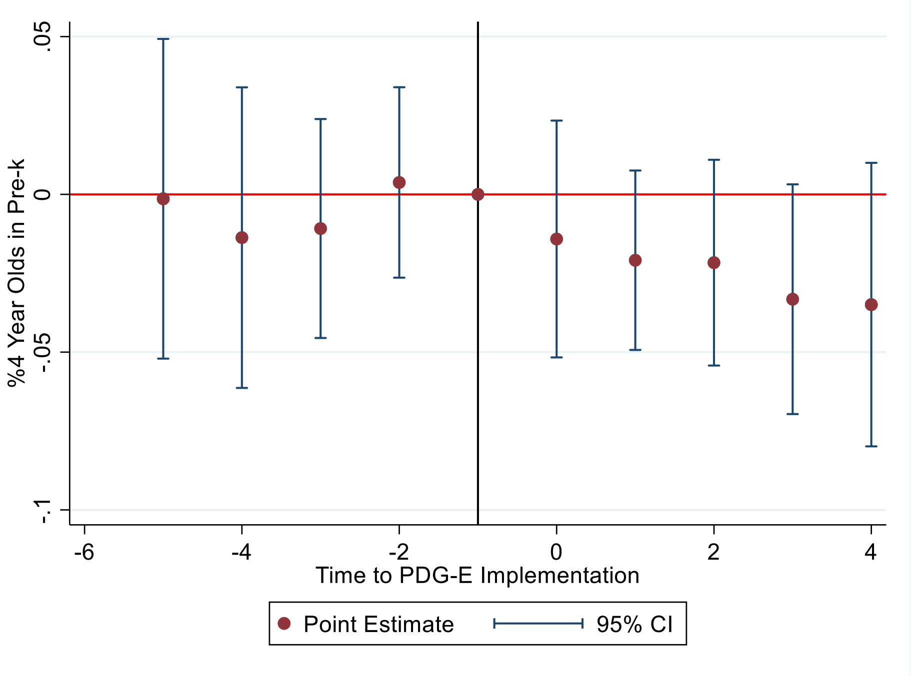

Figure 4.4. Percentage of 4-year-olds enrolled for All PDG-E Applicants, Excluding CA, IL

Concern: States' Capacity Advantages from an RTT-ELC Grant

Another possible confound is that states who received RTT-ELC funding may have had more robust systems and policies in place due to the grant's capacity building emphasis. To address this possibility, I ran another analysis restricted to states who had previously won an RTT-ELC grant (n=6 states intervention group, n=12 states comparison), and within this restricted group, comparing received PDG-E (IL, MA, MD, NJ, RI, VT) to those who did not (CA, CO, DE, GA, KY, MN, NM, NC, OH, OR, PA, WA). These states as a group had similar pre-trends for 4-year-old pre-k enrollment

The OLS results for this subgroup were similar to the original model, whereby treatment states had a negative and marginally significant decrease in the percentage of 4-year-olds enrolled in pre-k (β=-0.04, $p<0.10$). Event study analyses also showed a decrease at initial implementation (see **Figure 4.5**), though none of the findings were significant (see **Appendix I)**.

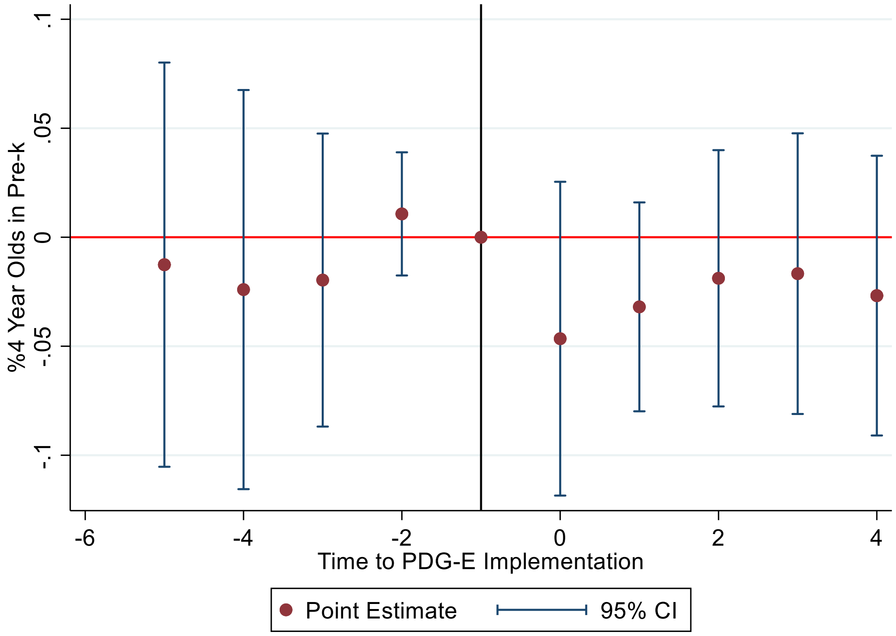

Figure 4.5. Trends in Percentage of 4-year-olds Enrolled in State Pre-k, RTT PDG-E States

In light of the concerns about California and Illinois, I estimated another model with only the RTT-ELC states that also excluded California and Illinois. When excluding California and Illinois from the analysis, the direction of the coefficient changed in the OLS (β=0.03) but was not significant (see **Appendix I**). As seen in **Figure 4.6**, the event study analysis showed a decrease at implementation in comparison to the non-PDG-E awarded states, though not significant.

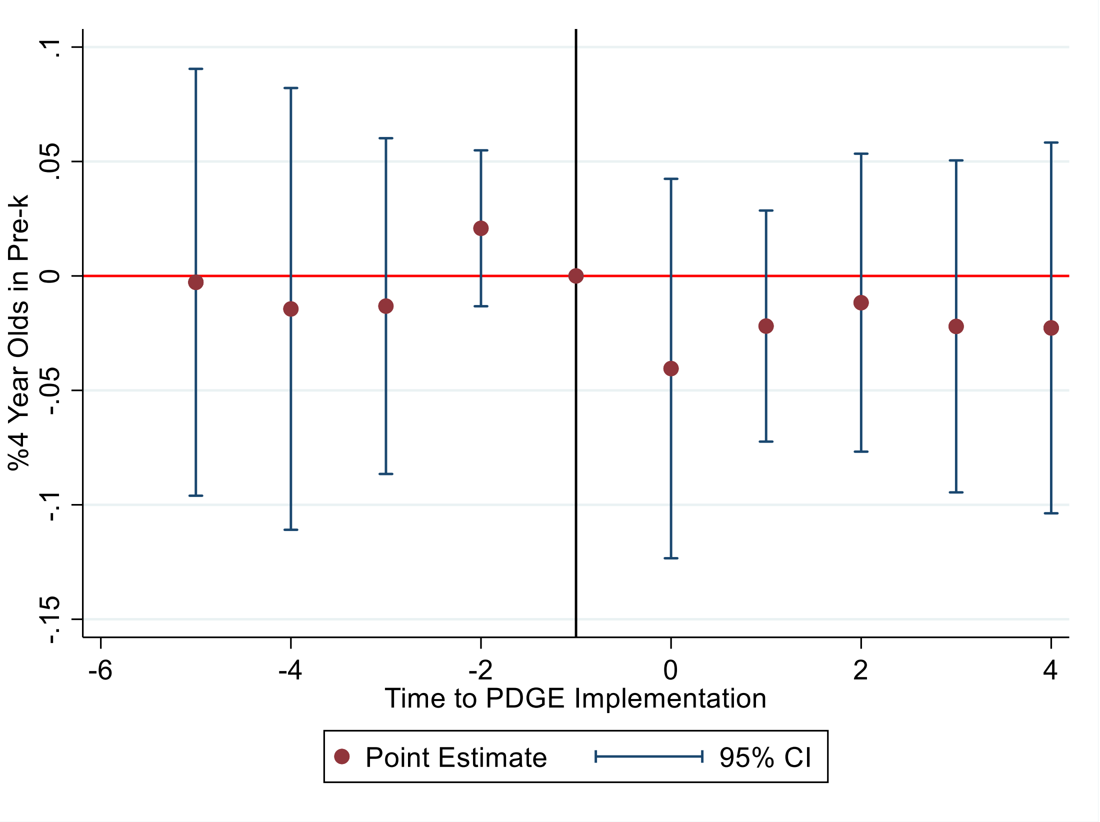

Figure 4.6. Trends in 4-year-old Enrollment in Pre-k for RTT-ELC/PDG-E States, w/o CA, IL

Discussion

This study aimed to understand the extent to which the PDG-E grant met its objective of expanding pre-k opportunities for 4-year-old children across the country. Little is known about the overall effect of the federal PDG-E program because the government did not solicit a full evaluation (Farran, 2016). This study fills this critical gap in knowledge by considering all the grantees together, and employing an event study to estimate impacts of PDG-E on pre-k enrollment of 4-year-olds. The federal government's use of this competitive grant to incentivize states was a departure from its previous approach of penalties and mandates (McGuinn, 2010), making it an exciting opportunity to also explore policy diffusion effects through the signaling of a federal priority for pre-k expansion.

Did Federal PDG-E Funding Increase Pre-k Enrollment?

States who received PDG-E successfully added new slots in state pre-k in the first year of implementation (see **Appendix J**). However, and unexpectedly, when compared against states who applied to PDG-E and did not win, it was the comparison states who showed a higher rate of increase in the percentage of their 4-year-old population served. While surprising, policy diffusion is a potential explanation for why the non-awarded PDG-E applicants, as a whole, began enrolling a higher percentage of 4-year-olds in state pre-k compared to awarded states.

Implications for Federal Incentives in Early Childhood Education

The Preschool Development Grant – Expansion (PDG-E) was part of a series of incentive-focused grants aimed at educational programs that emerged in the early 2010s. This incentive approach differed from previous federal administrations' focus on compliance for educational policies (McGuinn, 2012). The Race to the Top – Early Learning Challenge used funding to support states in building the quality of their early learning systems (Administration for Children and Families, 2019a). The Early Head Start - Child Care Partnership used a grant application process for states to apply for funding to increase child care supply for infants toddlers (Smith et al., 2019). More recently, the Preschool Development Grant - Birth to Five (PDG B-5) initiative provided a competitive grant funding opportunity to align programs, maximize parental choice, disseminate best practices, foster partnerships, and engage in continuous improvement practices for children ages birth to five (Capizzano, Dahlin et al., 2019). Thus, while important to understand if PDG-E met its specific aim, it is also important to examine PDG-E as part of a broader effort by the federal government to use incentives to drive educational policy change within states.

These findings suggest that there appeared to be a positive diffusion effect in which comparison states who did not get federal money to expand their pre-k slots also managed to increase their enrollment of 4-year-olds in pre-k. Federal incentive approaches may provoke policy action in states by signaling their federal interest and commitment (Gilardi, 2016; Shipan & Volden, 2008). In its application announcement, the U.S. Department of Education and Department of Health and Human Services described PDE's purpose as "to support State and local efforts to build, develop, and expand High-Quality Preschool Programs" and specified that only 4-year-olds could be funded with grant dollars (Applications for New Awards; Preschool Development Grants, 2014, p. 48854) – a clear indication of federal interest and financial support in expansion of pre-k for 4-year-olds. When a new iteration of grants appeared (PDG B-5) in 2018 and 2019, this time focused on birth to five-year-old systems building rather than direct funding of seats, nearly all states and territories applied (52 total). The applicant pool was substantially higher than the 36 applications to the initial 2014 PDG program, which may indicate that states view this competitive approach as the way federal government will allocate funding for early childhood, increasing their motivation to participate.

Yet these findings may reflect how the competitive grant structure provided states the opportunity and motivation to organize and plan for expansion. The application process required governor approval, collaboration among various early childhood stakeholders, and design of how the expansion would unfold. These conditions may have created buy-in within the state by policymakers and the general public that led to seeking and obtaining additional funding for the slots without the federal funding (Delaney & Neuman, 2018; Gormley, 2011). States may have viewed the funding as nice, but not necessary. For instance, the city of Cleveland planned to use PDG funds to expand pre-k slots, but already had local funding ready in case Ohio's application was unsuccessful (which it was) (O'Donnell & Dealer, 2014). There is indication that states who did not win did, in fact, see large increases in state preschool funding. California, Georgia, New Mexico, Ohio, Texas, and Washington – states in my control group that applied to PDG-E but did not receive funding – increased their funding for state pre-K in the 2015-16 year, though California and New Mexico's funding increases were due to a change in the funding formula that gave districts flexibility to use state funds for pre-k (CA) or TANF fund (NM) (Barnett et al., 2017).

Indeed, there is evidence from analyses of Race to the Top, a competitive grant supporting state-level K-12 education reform, that indicate the diffusion hypothesis. In reviewing effects of Race to the Top (K-12), Howell and Magazinnik (2017) noted that states that did not win increased the adoption of education reform policies, noting that, "For losing applicants, at least, an important part of the answer has to do with the structure of the competitions themselves. In an effort to improve their chances of winning, all participating states—winners and losers alike—had incentives to adopt new education policies. In a competition with private bids and an uncertain number of winners, many participating states had incentives to seek higher scores by first enacting some of the policies that RttT championed" (pp. 523-524). While PDG-E states may not have been in the position of needing to enact policies before applying necessarily, they would have had to concretely map out what the expansion would look like and, in the process, create buy-in along with a roadmap for expanding regardless of the application's success.

It is important to acknowledge that state context matters. States vary tremendously in their ECE policies, both in terms of governance structures (e.g., whether ECE programs are housed in one office or diffused across different agencies) and how they structure their pre-k program (Connors & Morris, 2015; Jenkins, 2014; Jenkins & Henry, 2016; Karch, 2007; Rose, 2010). For instance, states differ in their per pupil costs for pre-k, how quality is defined and measured, where pre-k is offered (e.g., private programs and/or public school), hours in a "full day" program, teacher qualifications, professional development, and a multitude of other program components. The policy diffusion literature also points to differences in state political contexts. For instance, the diffusion of policy ideas from the national level to the state level often occur in the context of strong policy advocates and professionalized legislators within a state (McCann et al., 2015). For states who did not win a PDG-E grant, the capacity and strength of the pre-k advocates within these states may have played a role. Another consideration is the financial health of a state. For example, evidence suggests it was the better financially resourced states for which Race to the Top spurred policy adoptions, regardless if the states applied or not or whether they won or not (Howell & Magazinnik, 2020). Interviews with key state decision-makers at the time of PDG-E implementation could illuminate such factors within the state that impacted decisions on enrollment and better contextualize the findings of this study within the political actors, processes, and decisions that informed state actions (Apollonio & Bero, 2017). This could provide information such as whether non-awardee states had infrastructure for costs in place that could support expansion even without federal funding.

Finally, although the study findings may indicate a diffusion effect, there is a concern about equity if only some states receive funding (i.e., grant process). If the federal government wanted to pursue additional grants for direct funding of more 4-, or 3-year-old, seats in public pre-k in only some states, is that fair for other states that do win, even if they were able to find state or local money to increase seats? Does this promote a “rich-get-richer” mentality that rewards better-positioned states at the expense of other states? Does it unfairly burden non-winner states to provide the funding from already tight budgets, whereas winner states do not need to make a comparable investment? The Preschool Development Grant B-5 of 2018 and 2019 took a competitive approach but awarded nearly all states who applied with funding (Administration for Children and Families, n.d.), offering another approach that uses incentives that does not reward a select few.

Future Directions

Evaluations of Federal Grants. PDG-E was one of many federal incentive grants. Future work should explore the collective impact of such grants on their purported aim and, as indicated from this study, possible diffusion effects. Evaluations of RTT-ELC looked at comparison across states in some areas (e.g., quality ratings) but did not estimate impacts using a control group. For instance, an evaluation of the nine Round 1 RTT-ELC winners used descriptive data to document availability of high-quality programs (i.e., rated as top-tier in quality rating systems), but this did not include states in later rounds or a comparison to states that did not receive funding (Institute of Education Sciences, 2019). Similarly, the PDG B-5 grants that began in 2018 require states to engage in evaluation (Administration for Children and Families, 2019b), but do not include plans for an evaluation of the grant program as a whole. Lack of a comprehensive picture leaves out valuable opportunities to understand national impact and how policies may diffuse across states, especially in states that do not win funding. Further, many of these grants focus on creating high quality preschool, and it would be valuable to understand what quality changes were implemented and how that related to child outcomes.

Quality Considerations. It is important to note that this study focuses solely on the quantity side of the PDG-E grant, and does not include analyses to determine its effect on quality of funded seats. Many quality indicators were required as part of the grant and states who won were accountable to provide these quality measures. For instance, PDG-E funded seats had to be in programs that ran the same amount of hours as public elementary schools in the state, high-quality professional development, and be staffed by lead teachers with at minimum a bachelor's degree in early childhood (or equivalent) (Applications for New Awards; Preschool Development Grants-Development Grants, 2014). Annual progress reports required PDG-E states to document evidence of quality. Meanwhile, states who expanded enrollment without PDG-E funding had no accountability mechanism for quality. Evidence from the policy diffusion literature highlight that ideas might diffuse, but how they are adopted may differ (Karch, 2007). Thus, while states seem to have increased their pre-k slots despite not receiving PDG-E funds, they may not have had the same quality expectations as the PDG-E winners or sustained them. Thus, it should not be assumed that quality improved along with the percentage of slots. Future research is warranted to understand whether the grant's quality mechanisms also diffused, or if quality improved in PDG-E states that had oversights mechanisms in place due to grant requirements.

Exploring Impacts on the Wider ECE Market. This study's findings provide insights into potential unintended consequences of a policy (i.e., diffusion) within a specific age band (4-year-olds). This age represents merely one year in the five years before starting kindergarten, yet much of ECE policy and funding focuses on this age range. This hyper-focus on 4-year-olds is problematic as it ignores the care of infants and toddlers and also opens up the strong potential for unintended consequences in the precarious infant and toddler care market, such as reducing the slots available for infant and toddler care (Sipple et al., 2020). Understanding potential ripple effects of PDG-E would be an important avenue to explore. Few studies have examined the impacts of prioritizing funding for care of 4-year-olds on other segments of the child care market, specifically access to infant and toddler care, though it is a noted concern (Schilder et al., 2011). Given that the supply of infant and toddler care has historically been inadequate and that infant and toddler care is expensive to provide, funding for 4-year-olds may prioritize care of these preschool-age children at the expense of younger children. Anecdotal evidence also suggests that crowd-out is a concern for private providers of infant and toddler care (Capizzano, Bhat, et al., 2019; Malik, 2018; Meteer, 2019; Roh, 2017).

Future research could explore two potential unintended consequences. One is “crowd-out” in which public funding for 4-year-olds “crowds out” infant and toddler care (Bassok et al., 2014; Payne, 2009). If new funding is distributed in a mixed-delivery system where private providers and local education agencies receive funding and implement slots, it may incentivize serving 4-year-olds rather than infants and toddlers. First, 4-year-olds are less costly to serve because the student to teacher ratio is higher than for young children. Second, pre-k funding serves as a consistent, adequate source of funding compared to tuition from parents or Child Care Development Fund (CCDF) subsidies.

The other possible unintended consequence would emerge if the bulk of new pre-k slots were concentrated in public schools. Most states use a mixed-delivery system to provide state pre-k (Samuels, 2014) in which providers can include public schools, private providers, and community-based organizations. Yet the extent to which states rely on public schools varies, with some emphasizing spots in public schools and other distributing more heavily to non-public school sites. As seen in **Appendix J** (Table J-2), seven of the 13 PDG-E states placed more than

50% of Expansion spots in public schools, with four states (AR, IL, ME, VT) exceeding 90%. These settings do not serve infants and toddlers, but because they could entice movement of 4-year-olds to a public school, private providers would potentially lose the 4-year-olds that offset the cost of infant-toddler care and be “starved” to the point of closing. Both are concerning for the already problematic lack of affordable and high-quality infant and toddler care, yet there is a lack of data on the supply and configurations of infant-toddler care. Only two studies have looked at this issue, with both centered in New York (Brown, 2018; Sipple et al., 2020), finding evidence of negative implications for very young children. Future research should be directed towards disentangling effects of pre-k policy on other ages in the ECE system to understand the comprehensive impact on the system.

Limitations

Caution should be taken given the sole focus on one policy in this paper. State policy contexts are nuanced and while PDG-E was implemented, other policies may have impacted pre-k enrollment patterns and approaches. My analyses use an on/off function of the policy that masks nuances in heterogenous state policies, such as intensity of adoption, funding received, dosage, or other metrics that could account for differences in implementation among PDG-E states (Kelchen et al., 2019). Further, this paper estimates impacts of enrollment patterns for 4-year-olds as a result of PDG-E, finding a diffusion effect. This paper provides quantitative indication of diffusion, but lacks insight into the processes that led control states to increase their pre-k enrollment. Interviews with actors and stakeholders in these states would identify future directions to illuminate the policymaking and decisions processes of these states (Mossberger, 2000).

Further, other components of PDG-E are not tested, such as quality (discussed early). Given that the grant process and requirements were a high bar to reach, it likely attracted only states with the capacity to apply and demonstrate ability to successfully implement. While this paper approximates a comparison group, there is a lack of a true counterfactual condition because a change mechanism itself was the high stakes demand of the grant process in which only some states were positioned to apply based on unknown factors beyond the variables used in this study. Finally, the PDG-E grant provided grant funding that was sufficient to fund high-quality pre-k seats for 4-year-olds –interest to engage in the strenuous grant application would probably be greatly lower if the funding levels was not viewed as adequate. It is likely that the competition process itself may not lead to diffusion without appropriate funding levels.

Conclusion

The Preschool Development Grant – Expansion (PDG-E) competition provided direct funding for new pre-k slots in the 13 states that applied and won. Despite the novelty of the competitive approach (McGuinn, 2010), prior to this study there was no evaluation of the policy’s effectiveness in increasing enrollment of 4-year-olds in public pre-k compared to other states. This study addressed this gap by employing an event study approach to identify the extent to which this federal funding stimulated increased enrollment when compared to a group of 14 states who applied but did not receive funding. Results indicate that states who were not awarded a PDG-E grant increased their rate of enrollment of 4-year-olds regardless, and did so to a slightly greater extent than states who did receive PDG-E grants. It is possible that policy diffusion effects played a role through the signaling of a federal priority for pre-k enrollment, or that the competition process itself, positioned states to pursue other sources of funding for expansion.

Chapter 5: Conclusion

The trajectories of children's cognitive, health, and social-emotional development begin to diverge before entering formal schooling in kindergarten (Williams et al., 2019). These differences continue through later grades, as those who enter school with stronger skills continue to accrue skills at a disproportionately higher rate than their peers (Clements & Sarama, 2016; Duncan et al., 2007; Williams et al., 2019). In mathematics, children arrive in kindergarten with varying levels of mathematical knowledge (Lee & Pant, 2017). It is concerning that these gaps start early; yet, the earliest years also are a prime age span in which to prevent these gaps. Children's brain plasticity is highest during infancy and toddlerhood, making it more malleable to growth in response to their environment (Pace et al., 2017; Park & Mackey, 2021; Shonkoff, 2010). Children's uneven starting points at elementary school indicate that the environments they inhabit from birth to age five matter greatly.

Bioecological theory highlights the roles of home, school/child care, community, and even distal policies in shaping the environments of young children (Bronfenbrenner, 1974; Bronfenbrenner & Morris, 2006). Thus, my three studies used a bioecological lens to explore environments, and access to environments, that shape children's school readiness: home exposure to mathematics and policy influences on access to pre-k learning experiences. Study 1 shed light on the ways parents of infants and toddlers pair math talk with gestures. Study 2 highlighted the linguistic affordances of Spanish that parents use when engaged in spatial talk with their infants. Study 3 drew attention to potential diffusion effects that increase enrollment of 4-year-olds in pre-k, which focuses on school readiness, as a result of a federal competitive grant. These dissertation findings indicate that children experience different mathematical environments at home and that policy matters for access to pre-k learning environments. The importance of these findings is described below.

Heterogenous Mathematical Environments Prior to School Entry

Nonverbal Mathematical Inputs – Infrequent, though Variable

Across two waves of data, when the child was 9 months and then 18 months, the use of gesture paired with math talk was infrequent, though gesture use did increase between these time points as the child aged. When gestures did occur, they were often paired with spatial language. Interestingly, gestures indicating counting, cardinality, and number recognition were very infrequent and collecting/grouping gestures were nearly non-existent, despite the availability of toys that could elicit these types of gestures (e.g., counting fruit in the play fruit set). These findings imply that children infrequently receive input that infuses a math word with a physical representation of its meaning (e.g., counting objects using fingers to indicate 1-1 correspondence while saying the count words) at these young ages. This is concerning because prior research indicates that gestures support math knowledge (Cartmill et al., 2010; Gibson et al., 2019) and general language development (Bakeman & Adamson, 1986; Goldin-Meadow & Singer, 2003; Iverson & Goldin-Meadow, 2005); thus, while gestures could be used to support school readiness skills in mathematics, they seldomly are employed.

However, the data show variability – with some parents using no gestures and others using up to 15 math-related gestures in a 10-minute period – highlighting that some children receive more math gesture input then others. This raises the question of why some parents use more gestures than others and to what extent frequency of gestures support math readiness as children enter kindergarten.

Parental Expression of Spatial Concepts Differs Between Spanish and English

Math talk by adults (i.e., parents, family members, and teachers) informally teaches young children mathematical vocabulary and communicates math concepts to support their math development (Purpura & Reid, 2016). In my second study, I explored how spatial concepts expressed via math talk may manifest differently depending on whether the language typically frames spatial actions in a verb (e.g., Spanish) or preposition (e.g., English) (Talmy, 1991). To do this, I examined how results differed from coding schemes using an English-created-then-translated coding scheme for spatial talk compared to one that was Spanish-informed.

Results showed that the English-informed coding scheme tended to undercount the use of spatial talk by Spanish-speaking parents, who often expressed spatial concepts through verbs. While useful in highlighting the need for ensuring constructs are conveyed equivalently in coding scheme across languages, the findings also lead to a number of conceptual considerations. While out of the scope for the current study, findings do raise questions around whether embedding spatial concepts in a verb leads to different conceptualization of the spatial world. Considering the relationship between early spatial language exposure, early spatial skills, and later math skills (Bower et al., 2020; Casasola et al., 2020; Mix, 2019), it is worthwhile to understand how Spanish-speaking children are exposed to spatial relationships linguistically. Given different levels of school readiness for Spanish-speaking children (Reardon & Galindo, 2009), understanding connections between language and spatial concepts is important to contextualizing these school readiness findings. It also provides considerations for how language of instruction in pre-k can facilitate math readiness skills, as pre-k instruction in Spanish for Spanish-speaking children is linked to higher math scores in pre-k (Burchinal et al., 2012). It is possible that instruction in Spanish provides more opportunities for implicit spatial language that connects with language input received in the home, which future research can explore.

Policy Considerations in Children’s Access to Pre-K Environments

Where children spend their time outside the home has consequences for their learning environments and trajectories (Bratsch-Hines et al., 2020; Dearing et al., 2009; NICHD Early Child Care Research Network, 2003; Vandell et al., 2010). Thus, it is important to understand whether federal attempts to bolster enrollment of 4-year-olds in publicly funded pre-k are successful, as these settings are often associated with quality and related to children’s school readiness at kindergarten entry (Carr et al., 2019). While federal programs such as Head Start have undergone whole program evaluation studies (Puma et al., 2010), this has not been the case in federal funding of pre-k initiatives (e.g., Race to the Top – Early Learning Challenge, Preschool Development Grants) (Farran, 2016).

To address this paucity, Study 3 leveraged a natural experiment in which a set of states applied to receive a federal grant to expand 4-year-old pre-k, with some states winning the funding and others not. Using an event study framework, I found evidence of a diffusion effect – the estimates for the recipient states were lower than the non-recipient states, though these differences were not significantly different. This finding is useful to policy conversations on how federal and state government can stimulate policy change in lower levels of government while dealing with the reality of limited budgets. Because pre-k experiences are linked to academic skills that factor into school readiness, including math (DeAngelis et al., 2020), understanding the extent to which federal policy can fund increased opportunities for school readiness development via increased availability of pre-k is important.

Contributions

These studies contribute to the developmental and policy research literatures, and can be of use to curriculum and assessment designers, as well as educators. Findings demonstrate that researchers should pursue approaches that provide a more comprehensive understanding of what young children’s home experiences look like and what they mean for child development. For instance, expanding samples of parents to include fathers, multilingual families, and families born in and outside of the US can provide a more comprehensive picture of children’s early learning contexts. Researchers have frequently called for a deeper understanding of early mathematical environments that include parental contributions and embrace diversity within typical homogenous groupings by race, ethnicity, and language (Hornburg et al., 2021). The children who enter schools in the US will increasingly be non-white, bilingual, and from families of varying acculturation in the country (Johnson, 2020); thus, it is imperative for researchers to study the school readiness contexts of children who represent a more diverse demographic profile. Thus, a contribution of this dissertation is the use of a sample for both Studies 1 and 2 that was racially, ethnically, and linguistically diverse, and included families of varying degrees of acculturation in the US. Further, research that informs our knowledge of school readiness environments has primarily focused on mothers and rarely includes fathers or couples (Cabrera et al., 2017; Tamis-LeMonda et al., 2004).

By including fathers in my sample, Study 1 was able to discern differing patterns in nonverbal math communication by parent gender. In considering early home math environment, these data underscore the need to look at both parents as they engage in different rates of math talk and gestures. Mothers, no matter if the language was in English, Spanish, or a bilingual mix (e.g., English-Spanish), were more likely to engage in, and use gestures more frequently, than fathers. Interestingly, the range for fathers (n=18 gestures) was slightly higher than mothers (n=16), suggesting that some fathers do gesture frequently, though on average it is low. A next step is to understand how these different gestures patterns relate to children's school readiness in math.

Study 2 findings provide evidence of the need for caution about the commonplace practices in developmental science of simply translating materials, rather than using more culturally-sensitive procedures. When coding for math talk that expressed spatial relations, nearly half of the amount of discourse was missed when using just a translated coding procedure. Importantly, these findings demonstrate that children in Spanish-speaking interactions with their parents receive some spatial concepts explicitly through prepositions and others implicitly through verbs. This leads to a question of whether explicit or implicit use of spatial talk matters for children's spatial development. Further, whether this translates to a different conception of space, and how that is captured or considered in school readiness is another important future step.

Study 2 also contributes knowledge to curriculum and assessment designers, and professionals working with Spanish-speaking children, as they review their approach to translation and how spatial concepts could be expressed in languages other than English. Math-specific curriculum supports math development better than whole child curricula (Nguyen et al., 2018). Findings from Study 2 support a consideration of whether math-specific curricula also include implied spatial concepts (i.e., verbs) when they are translated to Spanish. Further, assessments that measure school readiness, if derived from an English-framing, may miss out on the ways Spanish-speaking children engage in spatial talk, which may underreport their school readiness levels.

While Studies 1 and 2 provide contributions to understanding of the home mathematical environments of diverse families at the lower end of the economic spectrum, Study 3 contributes to the knowledge of where children age 4 spend their time outside the home. Pre-k programs are typically required to follow early learning standards in a state, which include mathematics. Thus, policies that can increase access to pre-k also, by default, increase opportunities for mathematical learning. Study 3 demonstrates that federal competitive grants and encouragement of increased pre-k enrollment can positively impact the enrollment of 4-year-olds not only in states that receive funding, but other states as well. However, questions remain about the quality of those programs added in states that did not receive federal dollars, especially around early math learning.

Future Studies

These studies provide insights into some aspects of young children's early learning environments, but also prompt many questions for future research to address. Although mostly exploratory, findings from Studies 1 and 2 indicate there is a rich opportunity for future study of math gestures, both parent and child-produced, as well as conceptual discussions regarding the linguistic affordances of mathematics. While additional descriptive analyses would illuminate current practices within homes, a more pressing need to is to disentangle what types of verbal and nonverbal communication drive positive school readiness outcomes in mathematics.

A critical next step is to examine what matters for math skill development. Future directions include assessing whether certain gestures in certain domains matter for math development overall and for specific skills and, further, whether the age when children receive them matter. For example, cardinality is important for children's math development, but parents rarely verbally communicate this concept (e.g., "One. Two. Three. *There are three trees.")* (Sarnecka & Wright, 2013). Would a gesture indicating a set, such as a sweeping motion while saying "three trees," help solidify this concept and at what age would it be most useful? It may be more relevant for children who are in the 3-to-4-year age range when this skill emerges (Lee & Sarnecka, 2010). Evidence indicates cardinality onboards at different times depending on grammatical structure of the language in terms of whether it marks plural (e.g., two or more) or singular (e.g., no distinction between one or more) (Sarnecka et al., 2007). Exploring whether other grammatical cues play a role in mathematical development is worth exploring further, such as multiple cues in Spanish for plurality (the green chairs v *las sillas verdes* in Spanish). Similarly, counting objects would theoretically help build one-to-one correspondence knowledge. Spatial gestures seem particularly useful for parental support of children's spatial sense (Cartmill et al., 2010). Further, if and how parental gestures predict children's use of gestures should be explored as well as whether parental and child gestures predict children's mathematical skills. Given that mathematics is a core school readiness skill, unpacking how specific practices (e.g., math talk, gestures, using implicit spatial sense) facilitate meeting school readiness goals is critical.

In addition to home environment, researchers should also consider policies that influence where children spend their time outside the home. Researchers should pursue a more holistic approach, such as identifying whether policies diffuse to other states or local governments. While monitoring and compliance reporting serves a role in documenting raw numbers and experiences, comprehensive evaluations can place the overall impact and unintended (potentially positive) consequences in a larger context. For example, while PDG-E states provided data to the federal government as part of an annual progress report, and some states pursued internal evaluations (Goodson et al., 2018; U.S. Department of Education & U.S. Department of Health and Human Services, 2017), there was no overarching evaluation of the grant to better understand the experience across states (Farran, 2016). This masked an understanding of possible diffusion to states who did not receive funding. It may be that early childhood policy researchers are hesitant to estimate multi-state impacts because policies vary so greatly across, and even within, states. Where researchers have explored diffusion effects of the federal K-12 Race to the Top grant, its early childhood companion, the Race to the Top - Early Learning Challenge, has not (McGuinn, 2012). Future research should also include questions and methods that address how policy decisions are made to more robustly document policy changes (e.g., interviews with state leaders to understand politics and policymaking decisions). Further, while my study examined enrollment, it did not explore whether non-awarded states also funded high-quality seats as the PDG-E awardees did. Examining quality in addition to access is an important future direction. Legacies of these policies are also important, such as whether recipient states sustained funding and what factors helped or hindered sustainability. Ideally, these grant opportunities build on each other but there is little knowledge of whether that has happened – rarely are the threads that potentially connect these grant opportunities explored and how they relate to children’s school readiness outcomes.

Most importantly, when considering school readiness, Study 3 provides insight into enrollment trends, but it does not explore quality implications. While states with PDG-E had to meet certain quality indicators, there was no such requirement in the states who did not win but expanded anyway. This is a critical consideration because high quality pre-k and child care environments are associated with higher levels of school readiness (Carr et al., 2019; McCormick et al., 2022). Thus, while understanding enrollment patterns is a first step, further work must take a more holistic approach that takes quality into account and links to school readiness.

Despite the differing natures of these studies, two in home environments and one policy-related, they highlight that how early childhood experiences unfold in dynamic environments. This includes interactions with parents in home environments and policy decisions that influence availability of outside-of-home early learning experiences. Further, policymakers should make decisions informed by evidence, and that evidence should reflect the heterogeneity of young children and families and how those difference influence experiences in those environments. Conversely, developmental researchers should be aware of the role policy plays in influencing access to different early learning experiences.

Despite the nearly five decades since its inception, Bronfenbrenner's bio-ecological theory, along with the addition of consideration of culture in the microsystem, still rings true: children's development is an ongoing and bidirectional confluence of direct home and school environments, interactions between those environments, and the policies that influence children's experiences in them (Bronfenbrenner, 1974; Bronfenbrenner & Morris, 2006; Vélez-Agosto et al., 2017). By exploring how these systems shape children's experiences, a more vivid and comprehensive picture of children's environments prior to school emerges - one that aids in contextualizing children's school readiness. The three studies in this dissertation provide evidence that children are exposed to varying levels of practices (e.g., math gestures), linguistic inputs (e.g., how spatial talk is conveyed in language), and access to pre-k. These studies do not claim to identify what is "better" but they do provide evidence that understanding the nuances of children's experiences is important. Children's environments differ in a multitude of ways that may influence their school readiness.

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Appendix A

Early Mathematical Knowledge Items in English and Spanish with Percentage Answering Correctly

Table A-1. Early Mathematical Knowledge Items

Statement	% Answered Correctly (n=286)
Las palabras "más pequeño" y "más grande" enseñan a los niños sobre tamaños, no matemáticas. The words "smallest" and "biggest" teach children about size, not math.	39.16%
Comparar cosas es enseñar sobre matemáticas a los niños. Comparing things is teaching children about math.	72.03%
Los padres deben decir el número total de cosas antes de contarlas una por una. Parents should say the total number of things before counting them one at a time.	49.30%
Preguntarle a los bebés que está adentro o afuera de una canasta es enseñar matemáticas. Asking babies what is inside or outside of a basket is teaching math.	63.29%
Palabras como "encima" o "bajo" son palabras de matemáticas. Words such as "on" or "under" are math words.	41.61%
Hablar sobre el tiempo es hablar sobre matemáticas. Talking about time is math talk.	73.78%
Los bebés son muy pequeños para aprender sobre relaciones espaciales. Babies are too young to learn about spatial relationships. (Reverse-coded)	64.56%
Clasificar ropa enseña a bebés sobre matemáticas. Sorting laundry teaches babies about math.	52.45%
Ningún bebé es muy pequeño para aprender matemáticas. No baby is too young to learn math.	67.30%

Note. Source is Baby Books 2 – Wave 1 (9 months) Measures

Appendix B

Study 1 Descriptive and OLS Analyses

Comparison of Rates and Means of Gesture Use

Table B-1. Percent of Parents who Used Math-Related Gestures in an Observation

	Child at 9 Months				Child at 18 Months			
	All (n=286)	English (n=151)	Spanish (n=97)	Bilingual (n=38)	All (n=286)	English (n=147)	Spanish (n=96)	Bilingual (n=43)
All	75.87%	74.83%	79.38%	71.05%	79.72%	79.59%	80.21%	79.07%
Mothers	81.21%	78.48%	85.71%	80.95%	85.91%	85.53%	88.24%	81.82%
Fathers	70.07%	70.83%	72.92%	58.82%	72.99%	72.24%	71.11%	76.19%

Notes. W1 conducted child 9 months; W4 conducted child 18 months. Differences between languages were not significant.

Table B-2. Mean Number of Gestures Used by Parents Who Used Gestures

		Parent Gender		Language of Observation		
	Overall	Fathers	Mothers	English	Spanish	Bilingual
Child 9 mo	3.92 (3.04)	3.62 (2.79)	4.17 (3.22)	3.96 (3.20)	3.98 (2.94)	3.56 (2.70)
Child 18 mo	5.00 (3.61)	4.32 (3.60)	5.52 (3.54)	5.98 (3.80)	3.87 (3.18)	4.15 (2.92)

Notes. Does not include data from parents who used 0 gestures. 10 minute observation; Child 9 months, n=217 parents used at least one gesture with no statistically significant differences by parent gender or language; Child 18 months, n=228 parents used gesture and difference was significant by gender (t(226)=2.53, p<0.01).

Proportions of Math Concepts Referred to in Gesture

Table B-3. Child at 9 Months: Proportions of Math Concepts Used

	All (n=217)	English (n=113)	Spanish (n=77)	Bilingual (n=27)
Counting	0.14 (0.26)	0.10 (0.10)	0.18 (0.28)	0.17 (0.27)
Cardinality	0.03 (0.13)	0.02 (0.10)	0.04 (0.17)	0.03 (0.10)
Number Recognition	0.28 (0.35)	0.22 (0.31)	0.41 (0.38)	0.24 (0.30)
Collecting/Group	0.00 (0.05)	0.00 (0.01)	0.00 (0.00)	0.02 (0.13)
Spatial	0.54 (0.39)	0.66 (0.36)	0.35 (0.36)	0.55 (0.38)

Notes. n=217. Of the 287 parents, 69 used no gestures and are not included.

Table B-4. Child at 18 Months: Proportions of Math Concepts Used

	All (n=228)	English (n=117)	Spanish (n=77)	Bilingual (n=34)
Counting	0.17 (0.27)	0.12 (0.19)	0.22 (0.33)	0.22 (0.30)
Cardinality	0.02 (0.09)	0.03 (0.12)	0.01 (0.02)	0.01 (0.03)
Number Recognition	0.19 (0.32)	0.15 (0.28)	0.23 (0.35)	0.24 (0.35)
Collecting/Group	0.00 (0.02)	0.00 (0.02)	0.00 (0.01)	0.00 (0.00)
Spatial	0.62 (0.37)	0.69 (0.33)	0.54 (0.40)	0.54 (0.41)

Notes. n=228. Of the 256 observations, 58 had no gestures and are not included.

Descriptive Statistics: By Language

Table B-5. Child at 9 months: Frequency of Gestures by Math Concept

	All (n=286)		**English (n=151)**		**Spanish (n=97)**		**Bilingual (n=38)**	
	m(sd) or %	Range	m(sd) or %	Range	m(sd) or %	Range	m(sd) or %	Range
Total #	2.98 (3.14)	[0, 15]	2.97 (3.26)	[0,15]	3.17 (3.07)	[0,14]	2.53 (2.80)	[0, 12]
Construct								
Counting	0.48 (1.17)	[0,10]	0.27 (0.66)	[0,4]	0.75 (1.56)	[0, 10]	0.61 (1.44)	[0,7]
Cardinality	0.08 (0.36)	[0,4]	0.07 (0.39)	[0,4]	0.10 (0.33)	[0,2]	0.08 (0.39)	[0,2]
Group/Sort	0.01 (0.14)	[0,2]	0.01 (0.08)	[0,1]	0.01 (0.10)	[0,1]	0.05 (0.32)	[0,5]
Number Rec	0.82 (1.18)	[0,6]	0.64 (1.10)	[0,6]	1.17 (1.30)	[0,5]	0.66 (0.94)	[0,3]
Spatial	1.60 (2.18)	[0,11]	1.99 (2.48)	[0,11]	1.17 (1.80)	[0,8]	1.18 (1.39)	[0,5]

Notes. Language refers to language used by parent in the observation.

Table B-6. Child at 18 Months: Frequency of Gestures by Math Concept

	All (n=286)		**English (n=147)**		**Spanish (n=96)**		**Bilingual (n=43)**	
	m(sd) or %	Range	m(sd) or %	Range	m(sd) or %	Range	m(sd) or %	Range
Total	3.98 (3.80)	[0, 18]	4.76 (4.16)	[0,18]	3.10 (3.24)	[0,15]	3.28 (3.10)	[0, 12]
Construct								
Counting	0.74 (1.36)	[0,7]	0.74 (1.42)	[0,7]	0.70 (1.19)	[0,5]	0.84 (1.50)	[0,6]
Cardinality	0.08 (0.35)	[0,4]	0.12 (0.43)	[0,4]	0.04 (0.25)	[0,2]	0.02 (0.15)	[0,1]
Group/Sort	0.01 (0.08)	[0,1]	0.01 (0.08)	[0,1]	0.01 (0.10)	[0,1]	0.00 (0.00)	[0,0]
Number Rec	0.58 (1.14)	[0,9]	0.62 (1.26)	[0,9]	0.55 (1.09)	[0,5]	0.53 (0.77)	[0,2]
Spatial	2.59 (2.98)	[0,19]	3.31 (3.42)	[0,19]	1.80 (2.13)	[0,9]	1.88 (2.32)	[0,10]

Notes. Language refers to language used by parent in the observation.

Descriptives: By Parent Gender

Table B-7. Child at 9 Months: Total Gestures Produced, Separate Analyses for Mothers and Fathers

	Moms (n=149)		**Dads (n=137)**		
	m(sd)	Range	m(sd)	Range	t-test
Total Gestures	3.38 (3.33)	[0,15]	2.53 (2.86)	[0, 15]	t(284)=2.31*
By Category					
Counting	0.61 (1.41)	[0, 10]	0.33 (0.81)	[0, 5]	t(284)=2.05*
Cardinalty	0.10 (0.45)	[0, 4]	0.05 (0.25)	[0, 2]	t(284)=1.22
Group/Sort	0.01 (0.08)	[0, 1]	0.02 (0.19)	[0, 2]	t(284)=-0.89
Numbr Rec	0.87 (1.23)	[0, 5]	0.77 (1.12)	[0, 6]	t(284)=0.76
Spatial	1.81 (2.16)	[0, 10]	1.39 (2.18)	[0, 11]	t(284)=1.64

Note. Language refers to language used in interaction. * p<0.05, ** p<0.01, *** p<0.001.

Table B-8. Child at 18 Months: Total Gestures Produced, Separate Analyses for Mothers and Fathers

	Moms (n=149)		**Dads (n=137)**		
	m(sd)	Range	m(sd)	Range	t-test
Total Gestures	4.75 (3.81)	[0, 16]	3.15 (3.63)	[0, 18]	t(284)=3.61***
By Category					
Counting	0.96 (1.50)	[0, 6]	0.50 (1.14)	[0, 7]	t(284)=2.88**
Cardinalty	0.10 (0.42)	[0, 4]	0.05 (0.25)	[0, 2]	t(284)=1.21
Group/Sort	0.01 (0.12)	[0, 1]	0.00 (0.00)	[0, 0]	t(284)=1.36
Numbr Rec	0.58 (1.09)	[0, 5]	0.58 (1.10)	[0, 9]	t(284)=1.36
Spatial	3.09 (2.97)	[0, 14]	2.04 (3.00)	[0, 19]	t(284)=3.00**

Note. Language refers to language used in interaction. * p<0.05, ** p<0.01, *** p<0.001.

Descriptive Statistics: By Parent Gender, Language of Interaction

Table B-9. Child at 9 Months: Gestures Produced by Parent Gender and Language of Interaction

	English				**Spanish**				**Bilingual**			
	Moms (n=79)		**Dads (n=72)**		**Moms (n=49)**		**Dads (n=48)**		**Moms (n=21)**		**Dads (n=17)**	
	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range
Total Gestures	3.22 (3.30)	[0, 15]	2.69 (3.21)	[0, 15]	3.80 (3.43)	[0, 14]	2.52 (2.54)	[0, 9]	3.05 (3.23)	[0, 12]	1.88 (2.06)	[0, 7]
By Category												
Counting	0.33 (0.75)	[0,4]	0.19 (0.55)	[0,3]	0.98 (1.88)	[0,10]	0.52 (1.13)	[0,5]	0.81 (1.86)	[0,7]	0.35 (0.61)	[0,2]
Cardinality	0.10 (0.52)	[0,4]	0.03 (0.17)	[0,1]	0.13 (0.39)	[0,2]	0.06 (0.25)	[0,1]	0.05 (0.22)	[0,1]	0.12 (0.49)	[0,2]
Group/Sort	0.00 (0.00)	[0,0]	0.01 (0.12)	[0,1]	0.02 (0.14)	[0,1]	0.00 (0.00)	[0,0]	0.00 (0.00)	[0,0]	0.12 (0.49)	[0,2]
Number Rec	0.63 (1.05)	[0,5]	0.65 (1.15)	[0,6]	1.31 (1.44)	[0,5]	1.02 (1.13)	[0,4]	1.31 (1.45)	[0,5]	1.02 (1.13)	[0,4]
Spatial	2.16 (2.44)	[0,10]	1.81 (2.52)	[0,11]	1.40 (1.83)	[0,8]	0.94 (1.77)	[0,7]	1.43 (1.56)	[0,5]	0.88 (1.17)	[0,4]

Table B-10. Child at 18 Months: Gestures Produced by Parent Gender and Language of Interaction

	English				**Spanish**				**Bilingual**			
	Moms (n=76)		**Dads (n=71)**		**Moms (n=51)**		**Dads (n=45)**		**Moms (n=22)**		**Dads (n=21)**	
	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range
Total Gestures	5.62 (3.96)	[0, 16]	3.85 (4.40)	[0, 18]	3.76 (3.39)	[0, 15]	2.36 (2.91)	[0, 12]	4.00 (3.60)	[0, 12]	2.52 (2.34)	[0, 7]
By Category												
Counting	1.00 (1.53)	[0,6]	0.47 (1.25)	[0,7]	0.92 (1.37)	[0,5]	0.44 (0.89)	[0,4]	0.91 (1.72)	[0,6]	0.76 (1.26)	[0,4]
Cardinality	0.17 (0.55)	[0,4]	0.06 (0.23)	[0,1]	0.02 (0.14)	[0,1]	0.07 (0.33)	[0,2]	0.05 (0.21)	[0,1]	0.00 (0.00)	[0, 0]
Group/Sort	0.01 (0.11)	[0,1]	0.00 (0.00)	[0,0]	0.02 (0.14)	[0,1]	0.00 (0.00)	[0, 0]	0.00 (0.00)	[0, 0]	0.00 (0.00)	[0, 0]
Number Rec	0.61 (1.10)	[0, 5]	0.63 (1.42)	[0,9]	0.57 (1.20)	[0,5]	0.53 (0.94)	[0,4]	0.55 (0.80)	[0,2]	0.52 (0.75)	[0,2]
Spatial	3.83 (3.09)	[0,14]	2.75 (3.69)	[0,19]	2.24 (2.30)	[0,9]	1.31 (1.82)	[0,7]	2.50 (2.70)	[0,10]	1.24 (1.67)	[0,5]

Descriptive Statistics: By Child Gender, Language of Interaction

Table B-11. Child at 9 Months: Gestures Received by Child Gender and Language of Interaction

	Full Sample				English				Spanish				Bilingual			
	Girls (n=151)		Boys (n=135)		Girls (n=77)		Boys (n=74)		Girls (n=55)		Boys (n=42)		Girls (n=19)		Boys (n=19)	
	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range
Total	3.27	[0,15]	2.65	[0,13]	3.21	[0, 15]	2.72	[0, 13]	3.60	[0, 14]	2.60	[0, 9]	2.53	[0, 9]	2.53	[0, 12]
Gestures	(3.42)		(2.76)		(3.67)		(2.78)		(3.35)		(2.61)		(2.52)		(3.12)	
By Category																
Counting	0.63	[0,10]	0.30	[0,5]	0.36	[0,4]	0.16	[0,3]	1.00	[0,10]	0.58	[0,5]	0.63	[0,7]	0.58	[0,5]
	(1.44)		(0.75)		(0.78)		(0.50)		(1.92)		(1.22)		(1.67)		(1.22)	
Cardinality	0.11	[0,4]	0.04	[0,1]	0.13	[0,4]	0.00	[0,0]	0.09	[0,2]	0.11	[0,1]	0.11	[0,2]	0.05	[0,1]
	(0.47)		(0.19)		(0.55)		(0.00)		(0.35)		(0.30)		(0.45)		(0.23)	
Group/Sort	0.03	[0,2]	0.00	[0,0]	0.01	[0,1]	0.00	[0,0]	0.02	[0,1]	0.00	[0,0]	0.11	[0,2]	0.00	[0,0]
	(0.20)		(0.00)		(0.11)		(0.00)		(0.14)		(0.00)		(0.46)		(0.00)	
Number Rec	0.80	[0,5]	0.85	[0,6]	0.55	[0,5]	0.74	[0,6]	1.22	[0,4]	1.10	[0,5]	0.58	[0,3]	0.74	[0,3]
	(1.15)		(1.21)		(1.05)		(1.15)		(1.23)		(1.38)		(0.90)		(0.99)	
Spatial	1.72	[0,10]	1.49	[0,11]	2.16	[0,10]	1.82	[0,11]	1.31	[0,8]	0.99	[0,7]	1.11	[0,5]	1.26	[0,4]
	(2.35)		(1.98)		(2.73)		(2.19)		(1.91)		(1.66)		(1.29)		(1.52)	

Note. Language is language used by parent in observation.

Table B-12. Child at 18 Months: Gestures Received by Child Gender and Language of Interaction

	Full Sample				English				Spanish				Bilingual			
	Girls (n=151)		Boys (n=135)		Girls (n=76)		Boys (n=71)		Girls (n=55)		Boys (n=41)		Girls (n=20)		Boys (n=23)	
	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range	m(sd)	Range
Total	4.10	[0,18]	3.85	[0,14]	5.12	[0, 18]	4.38	[0, 14]	3.09	[0, 15]	3.12	[0, 12]	3.00	[0, 12]	3.52	[0, 11]
Gestures	(3.90)		(3.68)		(4.42)		(3.85)		(3.09)		(3.45)		(2.79)		(3.40)	
By Category																
Counting	0.68	[0,6]	0.81	[0,7]	0.79	[0,6]	0.69	[0,7]	0.62	[0,5]	0.81	[0,4]	0.45	[0,3]	1.17	[0,6]
	(1.29)		(1.43)		(1.44)		(1.42)		(1.18)		(1.21)		(0.95)		(1.80)	
Cardinality	0.11	[0,4]	0.04	[0,1]	0.18	[0,4]	0.04	[0,1]	0.06	[0,2]	0.02	[0,1]	0.00	[0,0]	0.04	[0,1]
	(0.44)		(0.19)		(0.56)		(0.20)		(0.30)		(0.16)		(0.00)		(0.21)	
Group/Sort	0.01	[0,1]	0.01	[0,1]	0.01	[0,1]	0.00	[0,0]	0.00	[0,0]	0.02	[0,1]	0.00	[0,0]	0.00	[0,0]
	(0.08)		(0.09)		(0.12)		(0.00)		(0.00)		(0.16)		(0.00)		(0.00)	
Number Rec	0.64	[0,5]	0.52	[0,9]	0.67	[0,4]	0.56	[0,9]	0.64	[0,5]	0.44	[0,5]	0.55	[0,2]	0.52	[0,2]
	(1.08)		(1.20)		(1.12)		(1.39)		(1.10)		(1.05)		(0.82)		(0.73)	
Spatial	2.68	[0,19]	2.48	[0,14]	3.51	[0,19]	3.09	[0,14]	1.78	[0,8]	1.83	[0,9]	2.00	[0,8]	1.78	[0,10]
	(3.08)		(2.87)		(3.65)		(3.17)		(2.05)		(2.26)		(2.15)		(2.50)	

Note. Language is language used by parent in observation.

OLS Regression Output, Parental Characteristics Predicting Gesture Use

Table B-13. Child 9 months: Parental Math Knowledge Predicting Total # Gestures

	Full Sample		**English**		**Spanish**		**Bilingual**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mothers	Fathers	Mothers	Fathers	Mothers	Fathers	Mothers	Fathers
Early Math Knowledge	0.02	0.28*	-0.10	0.19	0.37	0.38	-0.52	0.17
	(0.14)	(0.13)	(0.18)	(0.20)	(0.26)	(0.23)	(0.61)	(0.59)
Education								
<HS	-0.89	-0.00	-4.54	0.07	1.45	0.97	-3.84	3.35
	(1.16)	(0.82)	(3.55)	(1.63)	(1.48)	(1.20)	(7.08)	(2.87)
Some College	-0.46	0.06	-0.76	0.02	2.74	-0.42	0.79	2.13
	(0.84)	(0.73)	(1.18)	(1.14)	(1.54)	(1.37)	(3.42)	(3.27)
College degree	-0.95	-0.42	-1.74	-0.71	1.58	-2.11	-3.99	-1.23
	(0.81)	(0.72)	(1.17)	(1.18)	(1.32)	(1.86)	(4.90)	(3.58)
Income								
<$20K	-0.79	0.54	-0.72	0.55	-3.35	-1.11	-2.09	2.86
	(1.03)	(1.25)	(1.42)	(2.70)	(1.93)	(1.81)	(4.64)	(7.04)
$20-50K	-1.71	1.01	-3.31*	1.54	-4.27*	0.17	3.45	-1.69
	(0.92)	(1.15)	(1.29)	(2.65)	(1.83)	(1.76)	(4.15)	(3.60)
>$50	-1.88	0.87	-3.47*	1.33	-2.14	1.08	-1.60	-1.42
	(1.01)	(1.13)	(1.34)	(2.55)	(2.27)	(1.55)	(2.62)	(4.43)
Parent born in the US	0.39	-0.11	0.86	-1.57	0.70	0.00	-1.86	1.76
	(0.64)	(0.53)	(0.91)	(0.99)	(1.61)	(.)	(3.74)	(1.35)
Treatment Condition	0.36	-0.40	2.05*	-0.38	0.00	0.50	-0.40	-1.28
	(0.64)	(0.57)	(0.91)	(1.03)	(1.05)	(0.90)	(3.53)	(2.85)
Child Boy	-0.97	-0.30	-0.81	-0.42	-2.35*	-0.44	-2.11	2.43
	(0.59)	(0.52)	(0.82)	(0.85)	(1.10)	(0.98)	(3.67)	(3.13)
Child Temperament								
Shyness	0.20	-0.27	0.79	0.09	-0.77	-1.36	1.09	0.11
	(0.46)	(0.42)	(0.65)	(0.81)	(0.81)	(0.68)	(1.36)	(1.74)
Emotionality	-0.18	-0.55	-0.90	-0.98	1.00	-0.37	-2.40	-1.48
	(0.40)	(0.40)	(0.57)	(0.61)	(0.66)	(0.82)	(1.95)	(1.40)
Sociability	0.13	0.18	0.56	0.95	-0.17	-0.73	-0.26	1.10
	(0.52)	(0.55)	(0.77)	(1.09)	(0.82)	(0.85)	(2.14)	(1.82)
Activity	-0.58	0.13	0.57	-0.41	-1.96*	0.21	0.06	-0.20
	(0.52)	(0.48)	(0.76)	(1.02)	(0.81)	(0.74)	(2.16)	(2.81)
Observations	149	137	76	71	51	45	22	21

Notes. Standard errors in parentheses; p=* p<0.05, ** p<0.01, *** p<0.001; Reference groups: Condition: Control; Income: Missing income; Child gender: Girl; Education level: High School Diploma or Equiv.

Table B-14. Child 18 Months: Parental Math Knowledge Predicting Total # Gestures

	Full Sample		**English**		**Spanish**		**Bilingual**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mothers	Fathers	Mothers	Fathers	Mothers	Fathers	Mothers	Fathers
Early Math Knowledge	0.00	0.38*	-0.22	0.42	0.37	0.33	0.71	0.55
	(0.16)	(0.16)	(0.22)	(0.27)	(0.28)	(0.26)	(0.74)	(0.56)
Education								
<HS	-2.83*	-0.56	-4.17	0.01	-1.15	-0.82	-13.21	-0.20
	(1.29)	(1.02)	(4.40)	(2.17)	(1.63)	(1.34)	(8.63)	(2.74)
Some College	-0.06	0.84	-1.06	0.66	1.07	1.60	-2.21	1.56
	(0.94)	(0.92)	(1.47)	(1.52)	(1.70)	(1.51)	(4.17)	(3.12)
College degree	0.64	1.39	0.46	2.29	1.89	0.26	-3.76	-0.90
	(0.90)	(0.91)	(1.45)	(1.57)	(1.46)	(2.06)	(5.97)	(3.42)
Income								
<$20K	-1.48	1.14	-3.32	3.51	0.25	0.55	-4.69	-2.47
	(1.14)	(1.57)	(1.76)	(3.61)	(2.13)	(2.01)	(5.65)	(6.72)
$20-50K	-1.33	-0.28	-2.18	2.34	-0.35	-0.86	-2.19	-3.79
	(1.02)	(1.44)	(1.60)	(3.54)	(2.02)	(1.95)	(5.05)	(3.44)
>$50	-1.51	0.08	-2.67	2.65	-0.45	0.71	-0.90	-1.98
	(1.12)	(1.41)	(1.67)	(3.41)	(2.50)	(1.72)	(3.19)	(4.23)
Parent born in the US	0.27	0.34	0.07	-0.07	-1.47	0.00	-5.69	0.57
	(0.72)	(0.66)	(1.13)	(1.32)	(1.78)	(.)	(4.55)	(1.29)
Treatment Condition	1.19	0.13	2.00	0.57	0.67	1.00	0.27	-3.55
	(0.71)	(0.71)	(1.13)	(1.38)	(1.16)	(1.00)	(4.31)	(2.72)
Child Male	-0.66	0.08	-1.43	0.04	-0.08	1.23	-1.64	-0.57
	(0.66)	(0.65)	(1.02)	(1.13)	(1.21)	(1.09)	(4.47)	(2.99)
Child Temperament								
Shyness	0.14	-0.07	1.27	0.70	-0.78	-0.22	-2.78	-1.30
	(0.51)	(0.53)	(0.80)	(1.08)	(0.90)	(0.76)	(1.66)	(1.66)
Emotionality	-0.79	0.35	-1.82*	0.23	-0.48	-0.34	1.08	1.67
	(0.45)	(0.50)	(0.71)	(0.81)	(0.73)	(0.91)	(2.38)	(1.33)
Sociability	0.49	-0.30	0.39	0.59	0.06	-1.55	-0.83	-0.54
	(0.58)	(0.69)	(0.95)	(1.45)	(0.90)	(0.95)	(2.61)	(1.74)
Activity	-0.06	0.56	0.62	0.04	-0.95	0.62	1.37	-1.43
	(0.58)	(0.60)	(0.94)	(1.37)	(0.90)	(0.82)	(2.64)	(2.68)
Observations	149	137	76	71	51	45	22	21

Notes. Standard errors in parentheses; p=* p<0.05, ** p<0.01, *** p<0.001; Reference groups: Condition: Control; Income: Missing income; Child gender: Girl; Education level: High School Diploma or Equiv.

Appendix C

Math Talk Preposition Words

Math Talk Coding Words Spatial Original (Spanish) n=344 words

a lo largo del
al lado
abajito/a/os/as/e/es
abajo
adelante
adentro
afuera
alrededor
anterior
anteriormente
arriba
atrás
bajo
borde/bordes
bulto/os/e/es
centro
cerca/o/a/as/e/es
cerquita
chato/a/os/as/e/es
chichón
chichones
chatos
cimas
curvo/a/os/as/es
cima
curvas
de lado
debajo
dentro
derecha/o/as/os/e/es
detrás
diagonal
diagonales
en
enfrente
encima
entre
en la mitad
esquina
esquinas
en el centro
en metida el medio
fila/filas
fondo/fondos
frontera/fronteras
girar*
hacia
hacia adelante
hacia atrás
horizontal/horizontales
izquierda/o/as/os/e/es
lateral/laterales
lado/lados
lejano/a/os/as/e/es
lejos
limite
limites
línea
líneas
lisa/o/as/os/e/es
llano/a/os/as/e/es
mas allá de
metida/metidas
metido/a/as/os/e/es
medio/a/os/as/e/es
mitad/mitades
norte/nortes
oeste
ola/o/as/os/e/es
onda/ondas
opuesto/a/os/as/e/es
paralela/o/as/os/e/es
perpendicular/ perpendiculares
puntita/o/as/os/e/es
plana/o/as/os/e/es
por
punta/o/as/os/e/es
recta/o/as/os/e/es
redonda/o/as/os/e/es
reversa/o/as/os/e/es
revés
sobre
suficiente/suficientes
sur/sures
vertical/verticales
verticales
voltear*
vuelta/o/as/os/e/es

Notes. *For the list used with the script, all conjugated forms of the verb were included. The list also included pairing of direct and indirect objects with infinitive, gerund, and affirmative commands forms. Reflexive forms were also run.

Appendix D

Spatial Verb Coding Scheme

Spanish Verb with Spatial Concepts – Modified Coding Scheme

- Code a “1” for *“Spatial Verb”* on the coding sheet if you hear a spatial verb (see example list below, these are just some examples). Then, in the “Spatial Verbs Description” section, write down the full sentence said by the parent.
- If the parent uses a gesture, then select “1” for gesture and write a brief description.
- For “Other/Not sure” - enter verbs you think might be a spatial verb but aren’t sure about. You can also enter other verbs that have math concepts outside of spatial so that we can go back and think about expanding this work in the future.
- Only code for play with toys. You may want to fast forward a bit to see when the toy bag comes out.

Verb w spatial concept	**Sample sentence**
“Up/Down” concepts	
Bajar	Bajen los libros
Agacharse	Me agaché para atarme los cordones del zapato.
Bajar	Va bajar la gradas para acá
Brincar	¿Cuáles son los tipos de cosas que te han hecho brincar de gozo?
Caer	Se va a caer
Descender	Necesitas descender cinco tramos de escaleras
Tumbarse	Tumba la pelota.
Sentar	Se puede sentar.
Alzar	Alza los brazos
Ascender	El niño vio como su globo ascendía
Aupar	Ella aupó a su bebé
Elevar	Eleva sus manos
Empinar	Tienes que empinar un poco más la botella
Encaramar	Ella encaramó a su hija
Erguirse	Tienes que erguir la cabeza

Verb w spatial concept	Sample sentence
Escalar	Escaló la pared utilizando una cuerda.
Levantar	Levanta la mano
Subir	Va subiendo
Trepar	Los niños treparon a un árbol
“On/off” concepts	
Echar	-y esto para echarle a la pizza
Montar	Aquí se volvió a montar al perro
Poner	Se pone en un plato y se come
Quitar	Te lo vas a quitar
Tapar	Tapé la sartén
“In/out” concepts	
Entrar	Puede entrar este edificio.
Extraer	Extraer la tarjeta
Sacar	-que vas a sacar?
Salir	El uno salir las manzanas
Vaciar	Ayuda a vaciar esto
Other	
Atravesar	No puedes atravesar esa puerta
Derramar	Ella derramó su jugo.
Saltar	El gato salta de la mesa
Rotar	Utiliza las herramientas de rotar
Tirar	El niño tiré la pelota
Arrimar	Arrima las frutas al suelo

Appendix E

Early Mathematical Knowledge Items

Table E-1. Early Mathematical Knowledge Items

Statement
Las palabras “más pequeño” y “más grande” enseñan a los niños sobre tamaños, no matemáticas. The words "smallest" and "biggest" teach children about size, not math.
Comparar cosas es enseñar sobre matemáticas a los niños. Comparing things is teaching children about math.
Los padres deben decir el número total de cosas antes de contarlas una por una. Parents should say the total number of things before counting them one at a time.
Preguntarle a los bebés que está adentro o afuera de una canasta es enseñar matemáticas. Asking babies what is inside or outside of a basket is teaching math.
Palabras como “encima” o “bajo” son palabras de matemáticas. Words such as "on" or "under" are math words.
Hablar sobre el tiempo es hablar sobre matemáticas. Talking about time is math talk.
Los bebés son muy pequeños para aprender sobre relaciones espaciales. Babies are too young to learn about spatial relationships. (Reverse-coded)
Clasificar ropa enseña a bebés sobre matemáticas. Sorting laundry teaches babies about math.
Ningún bebé es muy pequeño para aprender matemáticas. No baby is too young to learn math.

Note. Source is Baby Books 2 – Wave 1 (9 months) Measures

Appendix F

Datavyu Scripts

Datvyu Script for “as usual” spatial words

```
content_file = '~/Desktop/ Spanish Spatial NOT Verbs.csv'
punctuation_list = %w[? ! , .]
require 'Datavyu_API.rb'
require 'csv'
transcribe = get_column('Parent_Utterance')
key_content = CSV.read(File.expand_path(content_file)).map { |r| r[0] }
key_content[0] = 'achicar'
content_length = key_content.map { |c| c.split(' ').length }.uniq
spanish_spatialnotverb. = new_column(' spanish_spatialnotverb,'words')
transcribe.cells.each do |tcell|
  content = tcell.content
  content_words = content.split(' ')
  content_words = content_words.map { |cw|
    (punctuation_list.include?(cw[-1]) ? cw[0..-2] : cw) }
  content_words = content_words.map { |cw|
    (cw[-2..-1] == "'s" ? cw[0..-3] : cw) }
  key_words = content_words.select{ |cw| key_content.include?(cw) }
  content_length.each do |x|
    ix = 0
    while ix < content_words.length - x
      content_phrase = content_words[ix..ix+x].join(' ')
      p content_phrase
      if key_content.include?(content_phrase)
        key_words << content_phrase
      end
      ix += 1
    end
  end

  unless key_words.empty?
    words_code = key_words.join(', ')
    ncell = spanish_spatialnotverb.new_cell()
    ncell.onset = tcell.onset
    ncell.offset = tcell.offset
    ncell.words = words_code


    end

end

set_column(‘spanish_spatialnotverb', spanish_spatialnotverb)
```

Datvyu Script for spatial verbs

```
content_file = '~/Desktop/Spanish Spatial Verbs Datavyu.csv'
punctuation_list = %w[? ! , .]
require 'Datavyu_API.rb'
require 'csv'
transcribe = get_column('Parent_Utterance')
key_content = CSV.read(File.expand_path(content_file)).map { |r| r[0] }
key_content[0] = 'achicar'
content_length = key_content.map { |c| c.split(' ').length }.uniq
spanish_mathverbs. = new_column('spanish_mathverbs','words')
transcribe.cells.each do |tcell|
  content = tcell.content
  content_words = content.split(' ')
  content_words = content_words.map { |cw|
    (punctuation_list.include?(cw[-1]) ? cw[0..-2] : cw) }
  content_words = content_words.map { |cw|
    (cw[-2..-1] == "'s" ? cw[0..-3] : cw) }
  key_words = content_words.select{ |cw| key_content.include?(cw) }
  content_length.each do |x|
    ix = 0
    while ix < content_words.length - x
      content_phrase = content_words[ix..ix+x].join(' ')
      p content_phrase
      if key_content.include?(content_phrase)
        key_words << content_phrase
      end
      ix += 1
    end
  end

  unless key_words.empty?
    words_code = key_words.join(', ')
    ncell = spanish_mathverbs.new_cell()
    ncell.onset = tcell.onset
    ncell.offset = tcell.offset
    ncell.words = words_code


    end

end

set_column('spanish_mathverbs', spanish_mathverbs)
```

Appendix G

Description of Results from Preposition-Based Coding

Approximately 68% of observations used a spatial word that would be picked up in the "as usual" preposition-based coding. A higher percentage of mothers (72%) used gestures compared to fathers (62%). Over half (52%) of the parents who used Spanish and English in the observation used at least one spatial word, compared to 76% of parents who only used Spanish. Additionally, those born outside the US (68%) had a higher frequency of parents that used a spatial word than those born in another country (58%). A higher percentage of girls (75%) received any spatial words with prepositions from their parents than boys (57%). None of the variables differentially predicted the likelihood of a parent using spatial talk or not.

On average, parents who used a spatial preposition also tended to talk more (m=210 utterances, sd=79.21) during the 10-minutes observation than parents who did not use any spatial prepositions (m= 160.02 utterances, sd=92.69). These differences were statistically significant (t(142)=3.53, $p<0.001$), indicating that the parents who used spatial prepositions in general talked more, whether math-related or not, during the observations than those who did not use spatial prepositions. For the 96 observations that had one or more spatial prepositions, there was an average of 3.85 utterances with spatial preposition words (sd=3.56), with a range of 1 to 18. Descriptive analyses showed a right-skewed distribution.

Appendix H

Study 2 - Descriptive Analyses

Descriptive Statistics for Spatial Words

Table H-1. Comparison of Total Spatial Talk with and without Verbs

	Parent Gender				Child Gender				Language			
	Mothers (n=74)		Fathers (n=70)		Girls (n=66)		Boys (n=78)		Spanish (n=88)		Eng/Sp (n=56)	
	m (sd)	Range	m (sd)	Range	m (sd)	Range	m (sd)	Range	m (sd)	Range	m (sd)	Range
Prep-only	2.96 (3.80)	[0, 18]	2.16 (2.96)	[0, 12]	2.09 (3.06)	[0, 14]	2.97 (3.68)	[0, 18]	3.15 (3.62)	[0, 17]	1.66 (2.90)	[0, 14]
Verbs + Prep	5.15 (5.60)	[0, 33]	4.24 (5.74)	[0, 23]	4.41 (5.60)	[0, 23]	4.96 (5.75)	[0, 33]	5.71 (5.82)	[0, 33]	3.14 (5.09)	[0, 23]
Diff	2.19 (3.21)	[0, 15]	2.09 (3.87)	[0, 21]	2.32 (3.99)	[0, 21]	1.99 (3.12)	[0, 15]	2.56 (3.38)	[0, 15]	1.48 (3.70)	[0, 21]

*Note*s. Diff is the difference between a parent's total with and without spatial verbs included. Language is language of observation.

Appendix I

Study 3 – Descriptive Analyses

State Pre-k – Total Enrollment of 4-Year-Olds and Percentage of 4-Year-Olds in States Served in State Pre-k

Table I-1. Number & Percentage of State 4-year-olds Enrolled in State Pre-k

	10-11		11-12		12-13		13-14		14-15		15-16		16-17		17-18		18-19		19-20	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Received																				
AR	17470	44.1	15284	37.4	13240	33	14632	37.7	14735	38.5	12314	32.0	12094	31.4	12261	32	12256	32	12784	33
CT	5517	13.0	5396	12.9	5302	13	5381	13.6	8976	23.1	9222	23.7	11558	30.2	11226	30	11528	31	7986	21
IL	49112	28.9	46897	27.7	45324	27	43778	27.1	43387	27.0	41397	26.1	40461	26.0	41622	27	47360	31	50680	33
LA	20258	32.8	20421	31.6	19871	31	19768	31.8	19732	31.9	19860	32.2	19054	31.1	18911	31	18841	30	20455	33
MA	11181	15.0	10714	14.3	10499	14	10201	14.1	5238	7.2	5681	7.6	5935	8.1	21722	30	21642	30	21614	30
MD	27071	37.1	25678	34.5	26402	35	26358	36.1	26631	36.0	27003	35.7	27496	37.2	27588	38	27780	38	30669	41
ME	3905	26.9	4505	31.6	4850	34	4721	35.1	4797	36.2	5177	40.2	5142	38.6	5551	42	5805	44	5886	44
NJ	30802	27.9	31234	28.2	31020	28	31138	29.3	30703	28.6	31800	29.1	31667	29.8	29733	28	31221	30	33154	32
NY	103445	45.1	102367	44.2	103132	45	98695	43.8	111973	48.7	118560	49.9	119424	51.6	117851	51	121610	54	109416	48
RI	126	1.0	108	0.9	144	1	234	2.1	306	2.8	594	5.4	1008	9.0	1080	10	1080	10	1420	13
TN	17697	21.5	17893	21.6	17893	21	17893	22.1	15648	19.3	17419	21.8	17833	21.6	18024	22	17812	22	18257	22
VA	15881	15.5	16618	16.0	17313	17	18021	17.8	18250	17.9	18356	17.8	18023	17.5	17959	18	17657	17	19159	19
VT	4387	66.9	4352	65.2	4601	71	5592	90.6	5038	83.9	4096	66.7	4696	75.1	4609	76	4818	78	4622	76
Didn't Receive																				
CA	95376	18.8	93866	18.1	79474	15	88708	17.8	87794	17.5	178821	35.0	181112	36.6	184816	37	187565	38	182391	37
CO	14820	21.2	14908	21.0	14789	21	15259	22.3	15913	23.3	15704	23.1	15614	23.1	15324	23	15616	23	16538	24
DE	843	7.4	843	7.4	843	7	635	5.8	843	7.5	843	7.3	831	7.4	586	5	581	5	582	5
GA	82608	59.3	82868	58.7	81683	58	81453	60.2	80430	58.8	80825	59.7	80874	60.0	80536	61	80493	60	80328	59
KY	18116	31.9	17477	30.4	16639	29	16470	30.0	14229	25.8	14132	25.8	14232	25.8	15910	29	16497	29	16729	30
MN	1067	1.5	1044	1.0	1044	1	940	1.3	735	1.0	858	1.2	3891	5.6	6964	10	7613	10	7586	10
NM	4264	14.7	4591	15.5	5331	18	7674	27.4	8397	30.0	9254	33.3	9287	35.4	8228	31	9987	38	10497	41
NC	30767	24.2	24836	19.2	29572	23	26617	21.2	26851	21.5	26851	21.9	27019	22.3	28385	23	29509	24	31059	25
OH	3572	2.4	3564	2.4	3457	2	5789	4.1	6654	4.8	10846	7.8	15566	11.2	16176	11	16091	11	16083	11
OR	3663	7.7	4729	9.7	4716	10	4627	9.8	4674	10.0	4626	9.9	5829	12.3	5848	12	5767	12	5774	12
PA	23757	16.0	20712	14.0	17910	12	17025	11.8	17093	12.0	16820	11.6	18844	13.2	19726	14	29141	20	32046	22
SC	24267	40.7	26610	42.6	24929	40	23251	38.6	28102	46.9	23536	40.0	24079	40.6	27253	46	28137	47	28683	47
TX	200181	51.7	203143	51.4	205056	52	203648	52.0	189796	47.8	194861	48.7	196526	49.4	198917	49	203650	49	196635	47
WA	6650	7.7	7367	8.2	7241	8	7055	7.9	7128	8.0	7702	8.6	7581	8.0	8019	9	8432	9	8666	9

Notes. Source: NIEER State of Preschool Yearbooks Table 2. Some years did not report by tenths (2012-13; 2017-18; 2018-19; 2019-20).

State Population

Table I-2. State Population

	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
Received										
AR	2940667	2952164	2959400	2967392	2978048	2989918	3001345	3009733	3017804	3011524
CT	3588283	3594547	3594841	3594524	3587122	3578141	3573297	3571520	3565287	3605944
IL	12867454	12882510	12895129	12884493	12858913	12820527	12778828	12723071	12671821	12812508
LA	4575625	4600972	4624527	4644013	4664628	4678135	4670560	4659690	4648794	4657757
MA	6613583	6663005	6713315	6762596	6794228	6823608	6859789	6882635	6892503	7029917
MD	5839419	5886992	5923188	5957283	5985562	6003323	6023868	6035802	6045680	6177224
ME	1328284	1327729	1328009	1330513	1328262	1331317	1334612	1339057	1344212	1362359
NJ	8828117	8844942	8856972	8864525	8867949	8870827	8885525	8886025	8882190	9288994
NY	19499241	19572932	19624447	19651049	19654666	19633428	19589572	19530351	19453561	20201249
RI	1053649	1054621	1055081	1055936	1056065	1056770	1055673	1058287	1059361	1097379
TN	6399291	6453898	6494340	6541223	6591170	6646010	6708799	6771631	6829174	6910840
VA	8101155	8185080	8252427	8310993	8361808	8410106	8463587	8501286	8535519	8631393
VT	627049	626090	626210	625214	625216	623657	624344	624358	623989	643077
Didn’t Receive										
CA	37638369	37948800	38260787	38596972	38918045	39167117	39358497	39461588	39512223	39538223
CO	5121108	5192647	5269035	5350101	5450623	5539215	5611885	5691287	5758736	5773714
DE	907381	915179	923576	932487	941252	948921	956823	965479	973764	989948
GA	9802431	9901430	9972479	10067278	10178447	10301890	10410330	10511131	10617423	10711908
KY	4369821	4386346	4404659	4414349	4425976	4438182	4452268	4461153	4467673	4505836
MN	5346143	5376643	5413479	5451079	5482032	5522744	5566230	5606249	5639632	5706494
NC	9657592	9749476	9843336	9932887	10031646	10154788	10268233	10381615	10488084	10439388
NM	2080450	2087309	2092273	2089568	2089291	2091630	2091784	2092741	2096829	2117522
OH	11544663	11548923	11576684	11602700	11617527	11634370	11659650	11676341	11689100	11799448
OR	3872036	3899001	3922468	3963244	4015792	4089976	4143625	4181886	4217737	4237256
PA	12745815	12767118	12776309	12788313	12784826	12782275	12787641	12800922	12801989	13002700
SC	4671994	4717354	4764080	4823617	4891938	4957968	5021268	5084156	5148714	5118425
TX	25645629	26084481	26480266	26964333	27470056	27914410	28295273	28628666	28995881	29145505
WA	6826627	6897058	6963985	7054655	7163657	7294771	7423362	7523869	7614893	7705281

Note. Source: University of Kentucky Center for Poverty Research. (2022). UKCPR National Welfare Data, 1980-2020. Lexington, KY. Available at http://ukcpr.org/resources/national-welfare-data

State Unemployment Rate

Table I-3. Percent State Unemployment Rate

	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
Received										
AR	8.3	7.6	7.2	6.0	5.0	4.0	3.7	3.6	3.5	6.1
CT	8.8	8.3	7.8	6.6	5.7	5.1	4.7	4.1	3.7	7.9
IL	9.7	9.0	9.0	7.1	6.0	5.8	4.9	4.3	4.0	9.5
LA	7.8	7.1	6.7	6.4	6.3	6.1	5.1	4.9	4.8	8.3
MA	7.3	6.7	6.7	5.7	4.8	3.9	3.7	3.4	2.9	8.9
MD	7.2	7.0	6.6	5.8	5.1	4.5	4.2	3.9	3.6	6.8
ME	7.9	7.5	6.6	5.6	4.4	3.8	3.4	3.2	3.0	5.4
NJ	9.3	9.3	8.2	6.8	5.8	5.0	4.6	4.1	3.6	9.8
NY	8.3	8.5	7.7	6.3	5.3	4.9	4.7	4.1	4.0	10.0
RI	11	10.4	9.3	7.7	6.0	5.2	4.4	4.0	3.6	9.4
TN	9.0	7.8	7.8	6.6	5.6	4.7	3.8	3.5	3.4	7.5
VA	6.6	6.1	5.7	5.2	4.5	4.1	3.7	3.0	2.8	6.2
VT	5.5	5.0	4.4	3.9	3.6	3.2	2.9	2.5	2.4	5.6
Didn't Receive										
CA	11.7	10.4	8.9	7.5	6.2	5.5	4.8	4.3	4.0	10.1
CO	8.4	7.9	6.9	5.0	3.9	3.3	2.8	3.2	2.8	7.3
DE	7.5	7.2	6.7	5.7	4.9	4.5	4.5	3.8	3.8	7.8
GA	10.2	9.2	8.2	7.1	6.0	5.4	4.7	3.9	3.4	6.5
KY	9.4	8.2	8.0	6.5	5.3	5.1	4.9	4.3	4.3	6.6
MN	6.5	5.6	5.0	4.2	3.7	3.9	3.4	2.9	3.2	6.2
NM	7.5	7.1	6.9	6.7	6.5	6.6	5.9	4.9	4.9	8.4
NC	10.3	9.3	8.0	6.3	5.7	5.1	4.5	4.0	3.9	7.3
OH	8.8	7.4	7.5	5.8	4.9	5.0	5.0	4.5	4.1	8.1
OR	9.5	8.8	7.9	6.8	5.6	4.8	4.1	4.1	3.7	7.6
PA	7.9	7.8	7.4	5.9	5.3	5.4	4.9	4.2	4.4	9.1
SC	10.6	9.2	7.6	6.5	6.0	5.0	4.3	3.5	2.8	6.2
TX	7.8	6.7	6.3	5.1	4.4	4.6	4.3	3.8	3.5	7.6
WA	9.3	8.1	7	6.1	5.6	5.3	4.7	4.5	4.3	8.4

Note. Source: University of Kentucky Center for Poverty Research. (2022). UKCPR National Welfare Data, 1980-2020. Lexington, KY. Available at http://ukcpr.org/resources/national-welfare-data

State Poverty Rate

Table I-4. State Poverty Rate

	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
Received										
AR	18.7	20.1	17.1	18.4	16.1	16.0	14.8	15.9	14.1	14.2
CT	10.1	10.3	11.3	8.6	9.1	9.8	10.9	10.2	8.3	11.2
IL	14.2	12.6	13.3	13.7	10.9	12.1	10.9	10.3	9.3	8.0
LA	21.1	21.1	19.2	23.1	18.6	20.2	21.4	19.0	17.9	15.4
MA	10.6	11.3	11.9	13.6	11.5	9.6	10.6	8.7	7.5	8.4
MD	9.3	9.9	10.3	9.8	9.6	7.1	7.8	8.0	7.0	9.2
ME	13.4	12.8	12.3	14.6	12.3	12.7	12.0	11.6	10.4	8.0
NJ	11.4	9.3	11.1	11.3	11.2	9.4	8.6	8.2	6.3	8.2
NY	16.0	17.2	14.5	14	14.2	11.9	13.4	11.1	12.5	11.8
RI	13.4	13.6	13.5	11.3	11.8	11.4	12.2	8.9	9.2	8.5
TN	16.3	18.6	18.1	17.3	14.7	14.9	11.5	12.0	13.1	13.2
VA	11.4	10.6	10.4	10.2	10.9	11.4	10.3	9.8	8.8	7.8
VT	11.6	11.2	8.7	9.3	10.7	9.6	10.2	9.7	8.6	8.6
Didn't Receive										
CA	16.9	15.9	14.9	15.8	13.9	13.9	12.4	11.9	10.1	11.0
CO	13.2	11.9	10.6	12.3	9.9	8.5	7.7	9.1	9.3	9.5
DE	13.7	13.5	14.0	11.0	11.1	11.6	9.2	7.4	6.5	10.5
GA	18.4	18.1	16.3	16.8	18.1	15.4	13.3	14.8	12.1	13.2
KY	16.0	17.9	20.0	20.0	19.5	15.2	14.4	15.7	13.6	13.9
MN	10.0	10.0	12.0	8.3	7.8	8.7	9.2	7.9	5.7	8.4
NM	22.2	20.4	21.7	20.0	19.7	17.8	18.6	16.6	15.3	16.5
NC	15.4	17.2	18.6	17.1	15.3	13.6	14.5	13.1	12.7	13.7
OH	15.1	15.4	13.7	15.6	13.6	13.7	12.7	11.9	12.4	12.7
OR	14.4	13.5	15.1	14.4	11.9	11.8	10.2	9.7	8.1	9.4
PA	12.6	13.9	12.4	12.5	12.3	11.1	11.2	11.8	8.7	10.6
SC	19.0	16.7	15.9	16.5	14.3	14.1	15.6	12.8	15.1	13.3
TX	17.4	17.0	16.8	16.4	14.7	13.8	13.4	13.7	11.1	14.0
WA	12.5	11.6	12.0	12.0	11.4	11.0	9.9	8.6	7.0	8.3

Source: University of Kentucky Center for Poverty Research - National Welfare Data.

Gross State Product

Table I-5. Gross State Product (Millions of Dollars)

	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
Received										
AR	105108	107719	112765	116152	117734	119192	122979	127761	130954	130751
CT	236816	244114	244128	248779	262373	266747	272570	279782	287822	276423
IL	687951	720882	734809	766121	795326	803944	823776	863040	885583	858367
LA	229215	233481	228688	237717	231752	223410	235712	253236	256919	235437
MA	426013	444478	455653	473052	503179	519144	539973	570464	596593	582477
MD	327727	334556	340706	353249	370768	387620	399738	411619	426747	410675
ME	51867	52867	53671	55827	57560	59754	61672	64557	67717	69272
NJ	498959	519569	537346	545465	569117	581504	590697	612979	634784	618579
NY	1237278	1323401	1361963	1425724	1485621	1545988	1608890	1705010	1772261	1724759
RI	50170	51607	52798	54298	56561	57529	58117	59925	61884	60556
TN	267488	283482	293265	303789	323659	334436	346283	362737	376582	369574
VA	433010	445121	455167	464514	484531	496570	511876	533510	556905	549536
VT	28135	28894	28966	29691	30664	31430	32041	32981	34013	33435
Didn't Receive										
CA	2049337	2144090	2261511	2399078	2559643	2671101	2831038	2975083	3132801	3007188
CO	264310	273594	288384	305691	317992	327757	348176	372453	392986	382585
DE	60822	61867	61008	67550	71548	69284	69899	74187	77082	75787
GA	427827	443566	459579	485283	515753	541292	568399	602024	625714	622628
KY	170005	176323	182471	186419	192819	195840	200346	207849	215399	212540
MN	285408	296273	308785	322690	333066	341696	353416	371930	383777	373739
NM	86683	87645	88533	92586	91322	91240	94457	100080	105143	98472
NC	426569	439540	455267	476260	502808	520357	541041	567452	591601	589829
OH	523355	540882	560937	592876	609322	621543	642351	675030	695362	677561
OR	170621	174428	179390	188778	202719	214618	227042	241978	253623	243777
PA	618555	640663	663335	691173	711787	726885	745141	778375	808738	771898
SC	170078	175329	182837	191982	204000	213585	223414	235287	247544	244882
TX	1331138	1410448	1500554	1568071	1564374	1567687	1665428	1795635	1843803	1775588
WA	379796	400623	419671	442930	471703	493635	527708	575417	612997	604254

Source: University of Kentucky Center for Poverty Research - National Welfare Data.

State Median Income

Table I-6. State Median Income

	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
Received										
AR	47638	44070	43825	49165	46760	49518	52535	51316	55220	50540
CT	75450	72566	77120	76788	79637	81895	78462	75057	88380	79043
IL	58405	58437	60031	60103	66006	66215	69660	72307	75328	73753
LA	46895	44146	51671	46412	50173	45515	46003	51514	52352	50935
MA	73025	71898	69594	69116	77951	74143	80509	89007	88802	86725
MD	79442	81137	77189	83359	80407	79562	86687	88881	96765	94384
ME	57316	55523	61167	56594	55455	54857	56299	60471	67377	63440
NJ	71901	75327	70958	71406	74685	73854	75226	76463	88821	85239
NY	58404	53854	55612	59440	63375	66270	64987	69348	72752	68304
RI	56555	63324	62687	64171	60858	66368	69061	64186	71027	80012
TN	48765	48562	48260	47845	51712	55383	58401	57788	57334	54665
VA	72222	73001	73354	72404	67178	71678	74773	79529	82328	81947
VT	59818	62779	72915	66442	65002	65623	67245	72226	75233	66902
Didn’t Receive										
CA	61554	64403	67663	66201	69527	71879	73957	72662	79080	77358
CO	67623	64668	75586	66696	72761	76117	79180	75285	73404	82611
DE	63045	55313	60203	62955	63103	62612	68596	67016	75120	69132
GA	53025	54352	52302	54236	55468	57738	61230	57542	57335	58952
KY	45970	46406	49950	46828	46311	48938	52451	56237	56357	56525
MN	66690	69796	71592	73596	75093	75742	73890	74031	82443	78461
NM	48422	49047	44704	51096	49296	52262	48153	49771	53776	50822
NC	52141	46933	51573	51203	55500	57993	52319	55014	61922	60266
OH	51497	50121	56482	54333	58235	58232	64084	63533	65470	60110
OR	59430	58479	54536	64436	66466	63787	65995	71297	75342	76554
PA	57566	58625	61388	60385	65980	65776	64714	66513	71463	70117
SC	46233	50150	48485	49173	50652	58610	57589	59215	62803	60097
TX	56571	58649	57215	58964	61701	62720	63454	61628	68286	68093
WA	65571	70239	71145	64647	73468	75841	75543	82184	83483	81083

Notes. Source: FRED. Real Median Household Income by State, Annual in 2020 CPI-U-RS Adjusted Dollars

Percent of Population Accessing SNAP

Table I-7. Percent of Population Accessing SNAP

	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
Received										
AR	16.5%	17.0%	17.1%	16.6%	15.7%	14.3%	12.9%	12.4%	11.8%	13.1%
CT	10.6%	11.2%	11.8%	12.2%	12.3%	12.1%	11.5%	10.8%	9.5%	10.3%
IL	13.9%	14.5%	15.8%	15.6%	15.9%	14.9%	14.7%	14.4%	12.9%	14.6%
LA	19.3%	20.6%	20.3%	18.9%	18.4%	19.8%	19.9%	18.6%	16.1%	17.8%
MA	12.3%	12.9%	13.2%	12.8%	11.6%	11.4%	11.2%	11.2%	10.2%	11.7%
MD	11.4%	12.2%	13.0%	13.2%	13.0%	12.4%	11.4%	10.7%	9.4%	11.3%
ME	18.7%	19.0%	18.8%	17.3%	15.3%	14.2%	13.5%	12.5%	10.7%	11.7%
NJ	8.6%	9.3%	9.9%	10.0%	10.2%	9.9%	9.2%	8.6%	7.3%	7.5%
NY	15.4%	15.7%	16.2%	15.9%	15.5%	15.1%	14.9%	14.3%	13.7%	13.2%
RI	15.2%	16.4%	17.1%	16.9%	16.6%	16.2%	15.9%	15.0%	13.3%	13.3%
TN	19.9%	20.4%	20.7%	20.1%	18.7%	16.8%	15.6%	14.3%	12.2%	12.6%
VA	10.6%	11.2%	11.4%	11.1%	10.3%	9.8%	9.2%	8.7%	7.7%	8.5%
VT	14.7%	15.4%	16.1%	14.9%	13.6%	12.8%	12.3%	11.7%	10.9%	10.7%
Didn’t Receive										
CA	9.8%	10.4%	10.9%	11.3%	11.4%	11.1%	10.4%	10.0%	8.9%	10.9%
CO	8.8%	9.5%	9.6%	9.4%	9.1%	8.6%	8.2%	7.9%	7.2%	8.4%
DE	14.9%	16.2%	16.6%	16.1%	15.9%	15.6%	15.3%	14.5%	12.3%	12.2%
GA	18.2%	19.3%	19.5%	18.0%	17.7%	16.8%	15.6%	14.8%	12.6%	14.6%
KY	18.8%	19.4%	19.8%	18.8%	17.4%	15.0%	14.7%	13.8%	11.2%	12.3%
MN	9.5%	10.0%	10.2%	9.8%	9.0%	8.7%	8.1%	7.7%	6.8%	7.2%
NM	19.9%	21.0%	21.0%	20.6%	21.7%	22.5%	22.0%	21.8%	19.8%	22.1%
NC	16.5%	17.1%	17.3%	15.9%	16.4%	15.4%	14.2%	13.0%	11.7%	12.6%
OH	15.4%	15.7%	15.8%	15.1%	14.4%	13.8%	12.9%	12.2%	10.9%	11.8%
OR	20.0%	20.9%	20.8%	20.2%	19.4%	18.0%	16.4%	15.2%	13.2%	15.0%
PA	13.5%	14.1%	14.0%	14.0%	14.3%	14.6%	14.4%	14.2%	12.7%	13.8%
SC	18.1%	18.4%	18.4%	17.3%	16.4%	16.2%	14.3%	12.9%	10.9%	11.6%
TX	15.5%	15.5%	15.3%	14.3%	13.6%	13.5%	13.9%	13.6%	11.0%	12.2%
WA	15.4%	16.1%	16.0%	15.5%	14.9%	13.9%	12.5%	11.7%	10.9%	11.3%

Notes. SNAP is the federal Supplemental Nutrition Assistance Program. Source: University of Kentucky Center for Poverty Research - National Welfare Data.

State Ethnicity/Race Distribution: Pre-Implementation Years

Table I-8a. State Ethnicity/Race Distribution - Percent

	2010-11							2011-12							2012-13							2013-14							2014-15						
	W	B	H	A	AIAN	NHPI	M	W	B	H	A	AIAN	NHPI	M	W	B	H	A	AIAN	NHPI	M	W	B	H	A	AIAN	NHPI	M	W	B	H	A	AIAN	NHPI	M
Received																																			
AR	75	15	7	1	1	<1	2	74	15	7	1	1	<1	2	74	15	7	1	1	na	2	74	15	7	1	1	<1	02	73	16	7	1	1	<1	2
CT	71	9	14	4	<1	na	2	70	9	14	4	1	na	2	70	10	15	4	<1	na	2	69	10	15	4	<1	na	2	68	1	16	4	<1	na	2
IL	63	14	16	5	<1	na	2	63	14	17	5	1	na	2	63	14	17	5	<1	<1	2	62	14	17	5	<1	<1	2	62	14	17	5	<1	<1	2
LA	61	32	4	2	1	na	1	60	32	5	2	1	na	2	60	32	5	2	1	na	2	60	32	5	2	1	na	2	59	32	5	2	1	na	2
MA	76	6	10	6	<1	na	2	75	6	1	6	<1	na	2	75	6	11	6	<1	na	3	94	1	1	1	1	na	2	73	7	11	6	<1	na	3
MD	54	29	8	6	<1	<1	2	54	29	9	6	<1	na	3	53	29	9	6	<1	na	3	53	29	9	6	<1	na	3	52	29	10	6	<1	na	3
ME	95	1	1	1	1	na	2	94	1	2	1	1	na	2	94	1	1	1	1	na	2	74	7	11	6	<1	na	3	94	1	2	1	1	na	2
NJ	59	12	18	8	<1	na	2	58	12	19	9	<1	na	2	58	12	19	9	<1	na	2	57	13	19	9	<1	na	2	56	12	20	1	<1	na	2
NY	58	14	18	7	<1	<1	2	57	14	18	8	<1	na	2	57	14	18	8	<1	<1	2	56	14	19	8	<1	<1	2	56	14	19	9	<1	<1	2
RI	76	5	13	3	<1	na	3	75	5	14	3	<1	na	3	75	5	14	3	<1	na	3	74	5	14	3	<1	na	3	73	5	15	3	<1	na	3
TN	76	17	5	1	<1	na	2	75	17	5	2	<1	<1	2	75	17	5	2	<1	<1	2	75	17	5	2	<1	<1	2	75	17	5	2	<1	na	2
VT	94	1	1	1	<1	na	2	94	1	1	2	na	na	2	94	1	2	1	<1	na	2	93	1	2	2	1	na	2	94	1	2	1	na	na	2
VA	65	19	8	6	<1	1	3	64	19	8	6	<1	<1	3	64	19	9	6	<1	<1	3	63	19	9	6	<1	<1	3	63	19	9	6	<1	<1	3
Didn't Receive																																			
CA	40	6	38	13	<1	<1	3	39	6	38	13	<1	<1	3	39	6	39	14	<1	<1	3	38	5	39	14	<1	<1	3	38	5	39	14	<1	<1	3
CO	70	4	21	3	<1	<1	2	70	4	21	3	1	<1	2	69	4	21	3	1	<1	3	69	4	21	3	1	<1	3	69	4	21	3	1	<1	3
DE	65	21	9	3	<1	na	2	65	1	9	3	<1	na	3	64	21	9	4	<1	na	2	64	21	9	4	<1	na	2	63	21	9	4	<1	na	3
GA	56	30	9	3	<1	na	2	55	30	9	3	<1	na	2	55	30	9	4	<1	<1	2	55	31	9	4	<1	1	2	54	31	9	4	<1	na	2
KY	86	8	3	1	<1	na	2	86	8	3	1	<1	na	2	86	8	3	1	<1	na	2	86	8	3	1	<1	na	2	86	8	3	1	<1	na	2
MN	83	5	5	4	1	na	2	82	5	5	4	1	na	2	82	5	5	5	1	na	2	82	6	5	5	1	<1	2	81	6	5	5	1	na	3
NM	40	2	47	1	9	na	2	40	2	47	1	9	na	1	39	2	47	1	9	na	2	39	2	48	2	9	na	1	38	2	48	1	9	na	2
NC	65	21	9	2	<1	<1	2	65	21	9	2	1	<1	2	65	21	9	3	1	na	2	64	21	9	2	1	<1	2	64	21	9	3	1	na	2
OH	81	12	3	2	<1	<1	2	81	12	3	2	<1	<1	2	81	12	3	2	<1	<1	2	80	12	3	2	<1	na	2	80	12	4	2	<1	na	3
OR	78	2	12	4	1	<1	3	78	2	12	4	1	<1	3	78	2	12	4	1	<1	3	77	2	13	4	11	<1	4	77	2	13	4	1	<1	4
PA	80	10	6	3	<1	na	2	79	10	6	3	<1	na	2	79	1	6	3	<1	na	2	78	10	7	3	<1	na	2	78	1	7	3	<1	na	2
SC	64	28	5	1	<1	na	2	64	27	5	1	<1	na	2	64	27	5	1	<1	na	2	64	27	5	1	<1	na	2	64	27	5	1	<1	na	2
TX	45	11	38	4	<1	<1	2	44	11	38	4	<1	<1	2	44	11	39	4	<1	<1	2	44	11	39	4	<1	<1	2	43	12	39	5	<1	<1	2
WA	72	3	12	7	1	<1	4	72	3	12	7	1	1	4	71	3	12	8	1	1	4	70	3	12	8	1	1	5	70	4	12	8	1	1	5

Notes. W=White; B=Black or African-American, H=Hispanic/Latine/Latina/Latino/a, AIAN=American Indiana/Alaska Native, NHPI=Native Hawaiian/Pacific Islander, M=Multi-racial; Data only available up to 2019. Kaiser Family Foundation. Population Distribution by Race/Ethnicity. Estimates based on the 2008-2019 American Community Survey, 1-Year Estimates.

State Ethnicity/Race Distribution: Implementation and Post Years

Table I-8b. State Ethnicity/Race Distribution - Percent

	2015-16							2016-17							2017-18							2018-19						
	W	B	H	A	AI AN	NH PI	M	W	B	H	A	AI AN	NH PI	M	W	B	H	A	AI AN	NH PI	M	W	B	H	A	AI AN	NH PI	M
Received																												
AR	73	15	7	1	1	<1	2	73	15	8	2	1	<1	3	72	15	8	2	1	<1	3	72	15	8	2	1	<1	2
CT	68	10	16	5	<1	na	2	67	10	16	5	<1	na	3	66	10	17	5	<1	na	2	66	10	17	5	<1	na	3
IL	62	14	17	5	<1	<1	2	61	14	17	5	<1	na	2	61	14	18	6	<1	<1	2	61	14	18	6	<1	<1	2
LA	59	32	5	2	1	na	2	59	32	5	2	1	na	2	59	32	5	2	1	na	2	59	32	5	2	1	na	2
MA	73	7	11	6	<1	na	3	72	7	12	6	<1	na	3	71	7	12	7	<1	na	3	71	7	12	7	<1	<1	3
MD	51	29	10	6	<1	na	3	51	29	10	7	<1	<1	3	50	29	11	6	<1	na	3	50	30	11	6	<1	na	3
ME	94	2	2	1	1	na	2	94	1	2	1	1	na	2	93	1	2	1	<1	na	2	93	1	2	1	<1	na	2
NJ	56	13	20	10	<1	na	2	55	13	21	10	<1	na	2	55	13	21	10	<1	na	2	55	12	21	10	<1	na	2
NY	56	14	19	9	<1	<1	3	55	14	19	9	<1	<1	3	55	14	19	9	<1	na	3	55	14	19	9	<1	na	3
RI	73	6	15	3	<1	na	3	72	5	16	4	<1	na	3	72	6	16	3	na	na	3	71	6	17	3	na	na	3
TN	74	16	5	2	<1	na	2	74	16	5	2	<1	na	2	74	17	6	2	<1	na	2	74	16	6	2	<1	na	2
VT	94	1	2	1	1	na	2	93	1	2	2	na	na	2	93	1	2	2	<1	na	2	93	1	2	2	<1	na	2
VA	62	19	9	6	<1	<1	3	62	19	9	7	<1	<1	4	62	19	10	7	<1	<1	4	61	19	10	7	<1	<1	3
Not Received																												
CA	38	5	39	14	<1	<1	3	37	5	39	15	<1	<1	3	37	5	39	15	<1	<1	3	36	5	40	15	<1	<1	3
CO	69	4	21	3	1	<1	3	68	4	22	3	1	<1	3	68	4	22	3	<1	<1	3	68	4	22	3	<1	<1	3
DE	63	21	9	4	<1	na	3	63	21	9	4	na	na	3	62	21	10	4	<1	na	3	61	22	10	4	<1	na	3
GA	53	31	9	4	<1	<1	2	53	31	9	4	<1	na	2	53	31	10	4	<1	<1	3	52	31	10	4	<1	<1	3
KY	85	8	3	1	<1	na	2	85	8	4	2	<1	na	2	85	8	4	2	<1	na	2	85	8	4	2	<1	na	2
MN	81	6	5	5	1	na	3	80	6	5	5	1	na	3	8	7	5	5	1	na	3	79	6	6	5	1	na	3
NM	38	2	49	2	9	na	2	37	2	49	1	9	na	2	37	2	49	2	9	na	2	37	2	50	2	9	na	2
NC	64	21	9	3	1	<1	2	63	21	9	3	1	<1	3	63	21	10	3	1	<1	3	63	21	10	3	1	<1	3
OH	80	12	4	2	<1	<1	3	79	12	4	2	<1	<1	3	79	12	4	2	<1	na	3	79	12	4	2	<1	na	3
OR	76	2	13	4	1	<1	4	76	2	13	5	1	<1	4	75	2	13	5	1	<1	4	75	2	13	5	1	<1	4
PA	77	10	7	3	<1	<1	2	77	11	7	3	<1	na	2	76	10	8	4	<1	na	2	76	10	8	4	<1	na	2
SC	64	27	6	2	<1	na	2	64	27	6	2	<1	na	2	64	26	6	2	<1	na	2	64	26	6	2	<1	na	2
TX	43	12	39	5	<1	<1	2	42	12	40	5	<1	<1	2	41	12	40	5	<1	<1	2	41	12	40	5	<1	<1	2
WA	70	3	12	8	1	1	5	69	3	13	9	1	1	5	68	4	13	9	1	1	5	68	4	13	9	1	1	5

Notes. W=White; B=Black or African-American, H=Hispanic/Latine/Latina/Latino/a, AIAN=American Indiana/Alaska Native, NHPI=Native Hawaiian/Pacific Islander, M=Multi-racial; Data only available up to 2019. Kaiser Family Foundation. Population Distribution by Race/Ethnicity. Estimates based on the 2008-2019 American Community Survey, 1-Year Estimates.

CCDF Reimbursement Rates – Infant, Toddler, Preschool

Table I-9. CCDF Reimbursement Rates (in USD)

	2010-11			2011-12			2012-13			2013-14			2014-15			2015-16			2016-17			2017-18			2018-19			2019-20		
	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre	Inf	Tod	Pre
Received																														
AR	509	487	405	509	487	405	509	487	405	509	487	405	509	487	405	509	487	405	619	578	511	619	578	511	619	578	511	619	578	511
CT	744	744	744	744	744	744	744	744	744	744	744	744	830	830	765	925	925	787	1049	1049	808	1079	1079	834	1131	1131	877	1131	1131	877
IL	609	586	549	642	618	580	682	656	615	702	676	633	702	676	633	765	713	648	765	713	648	765	713	648	765	713	648	765	713	648
LA	352	352	330	352	352	330	352	352	330	352	352	330	352	352	330	352	352	330	352	352	330	352	352	374	396	396	374	396	396	374
MA	919	837	837	919	837	837	919	837	837	919	837	837	977	890	890	1002	913	913	1038	946	946	1033	731	731	1074	780	780	1074	780	780
MD	596	450	450	596	450	450	596	450	450	596	450	450	596	450	450	611	461	461	611	461	461	624	468	468	702	576	576	702	576	576
ME	650	650	585	650	650	607	650	650	607	693	672	650	693	672	650	693	672	650	780	693	693	953	867	802	953	867	802	953	867	802
NJ	655	514	514	655	514	514	655	514	514	655	514	514	670	527	527	670	527	527	670	527	527	670	527	527	670	527	527	670	527	527
NY	693	693	650	693	693	650	693	693	650	693	693	650	758	693	650	758	693	650	867	802	758	867	802	758	867	849	802	867	849	802
RI	672	672	650	672	672	650	672	672	650	672	672	650	672	672	650	672	672	650	736	736	669	736	736	669	789	789	710	789	789	710
TN	430	366	366	430	366	366	430	366	366	430	366	366	430	366	366	430	366	366	430	366	366	430	366	366	581	439	439	581	439	439
VA	802	715	715	802	715	715	802	715	715	802	715	715	953	802	802	953	802	802	953	802	802	953	802	802	1182	1075	1075	1182	1075	1075
VT	495	477	428	495	477	428	495	477	428	495	477	428	510	491	441	506	487	438	506	487	438	521	487	438	595	579	496	595	579	496
Didn’t Receive																														
CA	753	683	683	753	683	683	753	683	683	753	683	683	753	683	683	787	741	741	787	741	741	927	846	846	927	927	867	927	927	867
CO	610	506	506	549	456	456	549	456	456	693	585	585	693	585	585	693	585	585	693	585	585	639	580	574	775	650	650	775	650	650
DE	487	377	377	498	448	448	498	448	448	498	448	448	498	448	448	498	448	448	498	448	448	498	448	448	542	507	507	542	507	507
GA	477	433	416	477	433	416	477	433	416	477	433	416	477	433	416	477	433	416	477	433	416	477	433	416	542	520	455	542	520	455
KY	455	455	412	455	455	412	455	455	412	455	455	412	455	455	412	455	455	412	477	477	433	477	477	433	542	542	520	542	542	520
MN	724	631	631	724	631	631	706	615	615	706	615	615	706	615	615	706	615	615	706	615	615	706	615	615	706	615	615	706	615	615
NM	365	325	324	351	312	311	410	370	369	410	370	369	567	464	384	567	464	412	567	464	412	567	464	412	567	464	412	567	464	412
NC	446	423	404	446	426	404	446	426	404	519	504	480	519	504	480	580	550	522	580	550	522	740	743	522	740	743	699	740	743	699
OH	600	566	518	600	547	504	600	547	504	600	547	504	600	547	504	600	547	504	600	547	504	457	623	577	621	623	535	621	623	535
OR	860	745	688	860	745	688	860	745	688	900	900	785	900	900	785	900	900	785	1000	1000	870	1000	1000	870	1254	1140	1000	1254	1140	1000
PA	737	650	611	672	672	650	737	650	611	729	642	603	729	642	603	729	642	603	729	642	603	729	642	603	747	658	619	747	658	619
SC	377	377	347	377	377	347	377	377	347	377	377	347	377	377	347	377	377	347	498	498	464	498	498	464	585	585	542	585	585	542
TX	457	402	379	457	402	379	457	402	379	457	402	379	457	402	379	558	523	379	558	523	379	558	523	379	578	551	500	578	551	500
WA	881	645	645	881	645	645	881	645	645	898	658	658	977	716	716	1016	744	744	1226	920	920	1251	938	938	1251	945	945	1251	945	945

Source: CCDF Data Tables

Study 3 OLS Findings

Table I-10. OLS: PDG-E Recipient on Percentage of State 4-year-olds Enrolled in Pre-k

	(1) All Applied	(2) All Applied w/o CA IL	(3) RTT-PDG-E w CA IL	(4) RTT-PDG-E w/o CA IL
PDG Implemented	-0.02	-0.01	-0.04+	0.03
	(0.02)	(0.01)	(0.02)	(0.08)
Unemployment rate	-0.00	0.00	-0.00	-0.09**
	(0.01)	(0.00)	(0.01)	(0.03)
Poverty Rate	0.00	0.00	-0.00	0.02*
	(0.00)	(0.00)	(0.00)	(0.01)
Gross State Product	0.00	0.00	0.00	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
State Median Income	0.00	-0.00	0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
State % White	2.86	2.56	2.32+	8.43**
	(1.81)	(1.91)	(1.20)	(2.81)
State % Hispanic	3.36	3.30	2.52+	9.28**
	(2.06)	(2.16)	(1.38)	(3.12)
State % Black/AfAm	2.94+	3.04	2.40+	8.71**
	(1.78)	(1.92)	(1.35)	(3.11)
State % Asian	1.66	1.08	0.53	10.84*
	(1.49)	(1.76)	(1.49)	(4.27)
Population	-0.00	-0.00+	0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
SNAP (% Population)	0.99+	0.58	1.67*	1.78
	(0.54)	(0.44)	(0.65)	(1.19)
Base Rate - Infant	0.00*	0.00**	0.00	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
Base Rate - Toddler	-0.00	-0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Base Rate - Preschool	-0.00*	-0.00**	-0.00+	-0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
State Year Interaction	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
2010-11	-0.01	-0.01	0.01	0.34*
	(0.03)	(0.03)	(0.04)	(0.13)
2011-12	-0.02	-0.02	-0.00	0.25**
	(0.03)	(0.02)	(0.03)	(0.09)
2012-13	-0.02	-0.02	-0.01	0.15*
	(0.02)	(0.02)	(0.02)	(0.06)
2013-14	0.00	-0.00	0.01	0.07*
	(0.01)	(0.01)	(0.01)	(0.03)
2014-15	0.00	0.00	0.00	0.00
	(.)	(.)	(.)	(.)
2015-16	0.01	0.00	0.01	0.02
	(0.01)	(0.01)	(0.02)	(0.05)
2016-17	0.02	0.02	0.03	-0.01
	(0.02)	(0.02)	(0.02)	(0.06)
2017-18	0.04+	0.03	0.04	-0.04
	(0.02)	(0.02)	(0.03)	(0.10)
2018-19	0.05+	0.05+	0.06+	0.03
	(0.03)	(0.03)	(0.03)	(0.11)
2019-20	0.05*	0.04+	0.05	0.35*
	(0.03)	(0.02)	(0.03)	(0.14)
Observations	270	250	180	160

Notes. Standard errors in parentheses; Reference group for race/ethnicity is *Other* (Multi, Native Hawaiian/Pacific Islander, American Indian/Alaskan Native); + p<0.10, * p<0.05, ** p<0.01, *** p<0.001.

Study 3 Event Study Findings

Table I-11. Event Study – Percentage of 4-year-olds Enrolled in State Pre-k: Original and Robustness Checks

	(1) All Applied w CA IL	(2) All Applied w/o CA IL	(3) RTT-PDG-E w CA IL	(4) RTT-PDG-E w/o CA IL
Unemployment rate	0.00	0.00	0.01	0.01
	(0.01)	(0.00)	(0.01)	(0.01)
Poverty Rate	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Gross State Product	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
State Median Income	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
State % White	2.81	1.60	1.13	-1.31
	(2.46)	(1.96)	(2.14)	(1.62)
State % Hispanic	3.03	2.28	2.27	-0.77
	(3.07)	(2.57)	(3.72)	(3.28)
State % Black/AfAm	0.94	1.60	-0.40	-1.24
	(2.35)	(2.21)	(1.96)	(2.04)
State % Asian	0.84	-0.20	-1.70	-3.37*
	(2.57)	(2.35)	(1.38)	(1.51)
Population	-0.00	-0.00***	0.00***	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
SNAP (% Population)	1.02+	0.56	1.24*	1.00*
	(0.58)	(0.47)	(0.52)	(0.41)
Base Rate - Infant	0.00+	0.00*	0.00	0.00+
	(0.00)	(0.00)	(0.00)	(0.00)
Base Rate - Toddler	0.00	0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Base Rate - Preschool	-0.00*	-0.00**	-0.00	-0.00+
	(0.00)	(0.00)	(0.00)	(0.00)
State Year Interaction	0.00	0.00+	0.00	0.00+
	(0.00)	(0.00)	(0.00)	(0.00)
2010-11	-0.02	-0.02	-0.01	-0.01
	(0.04)	(0.03)	(0.04)	(0.04)
2011-12	-0.02	-0.01	-0.02	-0.02
	(0.03)	(0.03)	(0.04)	(0.03)
2012-13	-0.02	-0.02	-0.02	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)
2013-14	0.00	-0.00	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)
2014-15	0.00	0.00	0.00	0.00
	(.)	(.)	(.)	(.)
2015-16	0.00	-0.00	0.02	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
2016-17	0.03	0.02	0.04+	0.02
	(0.02)	(0.02)	(0.02)	(0.01)
2017-18	0.03	0.03	0.05+	0.03
	(0.02)	(0.02)	(0.03)	(0.02)
2018-19	0.05+	0.05+	0.08*	0.05+
	(0.03)	(0.02)	(0.03)	(0.03)
2019-20	0.04	0.03	0.03	0.03
	(0.03)	(0.02)	(0.04)	(0.04)

lead5	-0.01	-0.00	-0.01	-0.00
	(0.03)	(0.02)	(0.04)	(0.04)
lead4	-0.02	-0.01	-0.02	-0.01
	(0.02)	(0.02)	(0.04)	(0.05)
lead3	-0.01	-0.01	-0.02	-0.01
	(0.02)	(0.02)	(0.03)	(0.03)
lead2	0.00	0.00	0.01	0.02
	(0.01)	(0.01)	(0.01)	(0.02)
lag0	-0.03	-0.01	-0.05	-0.04
	(0.02)	(0.02)	(0.03)	(0.04)
lag1	-0.03+	-0.02	-0.03	-0.02
	(0.02)	(0.01)	(0.02)	(0.02)
lag2	-0.03	-0.02	-0.02	-0.01
	(0.02)	(0.02)	(0.03)	(0.03)
lag3	-0.04+	-0.03+	-0.02	-0.02
	(0.02)	(0.02)	(0.03)	(0.03)
lag4	-0.04+	-0.03	-0.03	-0.02
	(0.02)	(0.02)	(0.03)	(0.04)
Observations	270	250	180	160

Notes. Standard errors in parentheses; Reference group for race/ethnicity is *Other* (Multi, Native Hawaiian/Pacific Islander, American Indian/Alaskan Native); + $p<0.10$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Appendix J

Additional PDG-E State Data

Table J-1. New slots funded by PDG-E

	1516
Arkansas	1371
Connecticut	279
Illinois	2559
Louisiana	340
Massachusetts	850
Maryland	1459
Maine	434
New Jersey	883
New York	1021
Rhode Island	285
Tennessee	1648
Virginia	1230
Vermont	412

Notes. Source: State of Pre-K Yearbooks

Table J-2. Distribution of PDG-E Slots in Public School, Head Start, and Community-Based Programs.

State	**% Public School**	**% Head Start**	**% Community-Based**
MA	6%	n/a	67%
RI	28%	37%	35%
NY	33%	12%	41%
LA	43%	5%	44%
CT	55%	5%	40%
VA	50%	n/a	22%
MD	60%	10%	27%
TN	84%	0%	10%
NJ	89%	11%	0%
IL	94%	1%	1%
ME	95%	0%	0%
AR	95%	1%	0%
VT	97%	0%	0%