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Exploring the nature of engineering during home-based engineering activities designed for Spanish- and English-speaking families with young children (Fundamental, Diversity)

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Introduction

In recent years, there has been an increasing emphasis on exploring engineering with early childhood learners [1], [2]. The majority of these studies have focused on observing young children playing with building materials [3], [4] or examining engineering in the preschool classroom[5]–[7]. However, few studies [8]–[10] have focused on exploring engineering in the home setting, which is a powerful yet often overlooked learning environment for early STEM learners. Developing a deeper understanding of the engineering talk and practices that can take place during engineering activities designed specifically for family use in the home can lead to key insights that inform more broadly the design of new activities for early childhood engineering experiences. Moreover, exploring the engineering that happens when families engage collaboratively on design challenges can provide new perspectives on definitions of engineering as well as beliefs about how engineering intersects with their everyday lives.

In this paper, we present the findings of a secondary analysis of qualitative data [11] that explores the nature of the engineering talk and practice demonstrated by families engaging in engineering activities designed for the home. The data used in this secondary analysis was originally collected as part of a design-based research study [12], [13] that iteratively investigated the ways that specific elements of engineering activities - such as the narrative context, materials, and the design challenge - could influence the ways that families engaged in engineering while using the activity together. Here, we explore specifically how family engagement with an engineering activity might be distributed across several different engineering practices, and how that distribution might change across different activities and over time.

Background and Literature Review

Learning in early childhood happens across a range of settings, including early childhood programs, early learning centers, and community-based contexts such as storytimes at public libraries and family-focused drop in programs at community centers. However, an essential learning context for young children that can be particularly understudied in STEM education is the home - the everyday environment where children interact with and explore the world around them with their caregivers, siblings, and other extended family members.

The growing body of research on early childhood engineering has investigated a number of aspects related to young children engaging in engineering tasks and practices. Early work by Brophy and Evangelou [14] illustrated how early learners could access and participate in engineering through block play. More recent work has examined early engineering experiences with peers [15], with different materials [4], [16], within pre-school settings [5], [17], [18], and through the development and implementation of pre-Kindergarten focused curriculum materials and packages [6], [19]. Yet, despite evidence that parents and caregivers can play significant roles in the development of young people's interest in and perceptions of engineering [20]–[22], few studies [8]–[10], [23]–[26] have focused on exploring the engineering that can occur when young learners engage together with their parents and families on engineering activities.

When considering ecological models of learning and development [27], [28], it follows that early engineering experiences with parents and other family members can be formative for young learners. Some of the earliest research on parent-child interactions around engineering focused on activities and exhibits within a museum context [24]–[26]. This study identified ways that elements of the engineering design process could be leveraged by family groups with very young children, particularly between the ages of 3 and 5, while engaging in developmentally-appropriate, character-based engineering design challenges using large blocks and other building materials. In particular, families demonstrated the engineering practices of *problem scoping* (defining and understanding the boundaries of the problem), *idea generation* (brainstorming), *materials exploration, design evaluation* (testing out design ideas), *design revision* (looking at changes in the design as a result of feedback), and *reflection* (reflecting on design aspects or design decisions). The study also examined parent facilitation techniques during the engineering experiences and the ways in which older children demonstrated moments of agency during interactions with a parent at an interactive engineering exhibit [29].

Moving beyond the designed informal learning context [30] of the museum, more recent work as part of the Head Start on Engineering (HSE) Project and Research Exploring Activity Characteristics and Heuristics for Early Childhood Engineering (REACH-ECE) Project has gone on to explore how families engage in engineering across a number of different settings, including community programs, early education programs, and the home [8], [10]. These projects have been deep collaborations between researchers, community partners, and early childhood educators, with some collaborative relationships dating back well over ten years. Although the specific composition of individuals and specifics about each project have necessarily changed over time, each study has been driven by a commitment to asset-based approaches [31], [32] at all levels, with a focus on valuing and centering the voices of families and structuring highly-collaborative project leadership teams that value and center the expertise of community partners and educators. In addition, each study has intentionally focused on engaging both Spanish-speaking and English-speaking family participants, often from underserved communities in the Portland, Oregon area. Based on these commitments, these studies have been able to explore family engagement, learning, and interest development around engineering in a number of ways, including positioning early childhood engineering interest as a family-level systems phenomenon [8], [10], [33], [34].

Central to each of these studies is a set of developmentally-appropriate engineering activities that allow parents and young children to access and engage in engineering practices. While there are now options for pre-kindergarten engineering curriculum packages and activities [19], [35] and design principles outlined for K-12 engineering experiences [36], most are intended for traditional classroom contexts with a teacher or early childhood educator facilitating groups of young students moving through a structured set of lessons. Given our focus on family learning and engagement around engineering, it was essential to create and refine activities that were flexible, accessible, and able to be used without educator facilitation. Building on the activities used in early work [24], [25], members of our current research team - along with our community partners, early childhood educators, other research collaborators, and of course, the family participants in our studies - have collaboratively designed, tested, refined, and examined such activities in order to better understand engineering interactions, learning, and interest development that can happen for early learners and their families.

In this paper, we examine the different types of engineering practice that were observed during family interactions while engaging in engineering activities designed specifically for unfacilitated use in their homes. This analysis is part of a larger design-based research (DBR) study [12], [13] that seeks to identify a set of design principles and heuristics specifically for early childhood engineering activities, that can inform the development or refinement of future engineering experiences for young learners and their families. Our specific research questions for this paper are:

- RQ1: What is the nature of the engineering talk and practice demonstrated by families engaging in engineering activities designed for family use in the home?
- RQ2: Did the nature of the engineering shift across three rounds of activity testing, as activities were responsively refined as part of the DBR study? If so, in what ways?

Methods

This paper focuses on a secondary analysis of qualitative data [11], conducted by the two first authors and a team of undergraduate research assistants at the University of Notre. Because of the importance of situating secondary analyses of qualitative data appropriately [37], we share the following overview of author engagement, a description of the primary study, and the specific foci and connections between the primary study and the present, secondary analysis that provides essential context to this work.

Author Context and Engagement

The first two authors are part of the REACH-ECE project leadership team, consisting of key project leaders from three collaborating organizations, that collectively designed and implemented the larger DBR study mentioned above. The first author led the work with the undergraduate research team, and the second author is the named principal investigator on the REACH-ECE project. The next four authors are the members of the undergraduate team who engaged in additional data analysis of videos shared by families in the original DBR study.

The remaining six authors are all involved in the REACH-ECE project, either as a member of the project leadership team or the broader research team. Focused on exploring multiple dimensions of family learning around engineering, REACH-ECE is an ongoing collaboration between Ready, Set, Go! Engineering (RSG), an early childhood education (ECE) program in Portland, Oregon, researchers from TERC, a non-profit STEM education research organization, and researchers at the University of Notre Dame. For almost two decades, RSG has supported parents and caregivers - the children's first educators - by providing free, culturally-responsive programming to support kindergarten readiness and socioemotional development for three- to five-year olds. RSG, which provides experiences such as parent-child interaction groups, parent workshops, and home visits, is housed within Metropolitan Family Service (MFS), a wide-reaching community organization in Portland, OR, that provides low-income, racially, and ethnically diverse communities with a wide range of family services.

Description of Primary Study: REACH-ECE

REACH-ECE is positioned at the intersection of families, communities, asset-based approaches, and engineering. REACH-ECE is focused particularly on working with and supporting low-income families and families that identify as Latinx or Hispanic, which are primary audiences for RSG. Children from these families face a variety of barriers to engaging with engineering and STEM more broadly [38], [39]. Nevertheless, our experience working with these communities has highlighted the incredible creativity and resilience of families and their deep commitment to their children's learning and development. The team collaborated closely with community partner staff and families throughout the planning, implementation, and analysis phases of the REACH-ECE project and used a variety of strategies to ensure that the activities and research methods supported an equitable vision of STEM education, including collecting and analyzing data in the language of participants with a bilingual and bicultural research team, using strength-based approaches to conceptualizing and supporting family engineering engagement, and ensuring that community partners and families were meaningful collaborators in the research process [40], [41].

The primary design-based research study in REACH-ECE involved three mini-cycles of activity testing that were focused on exploring a broad research question: *How do the elements or characteristics of family-based engineering activities (e.g., activity materials, design/solution space, challenge prompts, narrative framing) influence the ways that families with preschool-age children engage with and become interested in elements of the engineering design process?* In order to address this question, sixteen families, balanced by Spanish- and English-speaking language preferences, were recruited in collaboration with MFS to participate in the study. By the end of the approximately five months of data collection, fifteen families had participated in all three rounds of the project.

Of the 15 families that completed the entire study, eight of the parents we spoke with reported preferring Spanish at home while seven reported preferring English. The activity videos suggested that many families spoke both English and Spanish with their families. When asked an open-ended question about how the parents would identify themselves related to race and ethnicity, 10 parents indicated they identify themselves as either Latino or Hispanic, with four adding that they are from Mexico or also identify as Mexican. Three parents identified as White or Caucasian and two identified with multiple racial categories or as biracial (White and Asian, White and Black). Many parents also shared information about the different ways their partners or children identify (e.g., *"Dad is one third Italian, one third White, and one third Mexican"* or *"I would describe myself as bi-racial as half black and half white, but husband is white, and my child looks white, but I don't know how he will identify himself when he's older"*). Several parents also used this question to share information about languages in their household (e.g., *"My kids are Latinos, but they don't speak Spanish. We are working on it."*) or other aspects of their family structure (e.g., *"Our son is an Asian male, so we are an adopted family"* or *"Somos multicultural y diferentes generaciones. Mi mamá vive con nosotros."* [We are multicultural and from different generations. My mom lives with us.]).

All 15 participating families had at least one child enrolled in the preschool RSG program. Two of the families had two children enrolled. Age of primary child in the study ranged from 3 to 5 years, with the majority of children being 4 years old (9 of 15) and only one child being 3 years old. The number of years that families had participated in the RSG program ranged from 1 to 5, with an average of 2.5 years. Although we did not ask about occupation or income during the study, the majority of families participating in the RSG program are at or below the federal poverty line (33%) or receive some type of income-based assistance (56% qualifying for public assistance such as WIC or SNAP). Interviews with parents suggested that families in the study represented a range of income levels.

As part of the DBR mini-cycles, families received three separate engineering activity kits in their home over the span of four months: March 2021 (Round 1), May 2021 (Round 2), and June 2021 (Round 3). Using their phones, families recorded themselves the first time using each activity kit in their homes and shared these videos with the bilingual REACH-ECE project research team. Families also participated in interviews with bilingual members of the research team. Between the first and second rounds of testing, as well as the second and third rounds, video data and interviews were analyzed by the REACH-ECE bilingual research team, and modifications were made to each of the activities in order to potentially deepen and enhance the nature of the engineering talk and practice shared by the families in their videos.

After the completion of the DBR mini-cycles, the REACH-ECE research team engaged in a retrospective analysis [42] in order to more fully understand the engineering present in the family interactions. Because a specific goal of the retrospective analysis was to more closely examine the range of engineering talk and practice observed in the videos shared by families, the REACH-ECE research team focused on a subset of ten family videos from the third round of activity testing. The team intentionally made these decisions around data reduction in order to a) observe families after they had more comfort with the study procedures and the style of engineering activities involved in the study; b) observe the families using the refined activities in their final iteration for the DBR study; and c) to simultaneously balance the family data with REACH-ECE research team capacity and by Spanish- and English-language preferences. Table 1 shows the family composition and languages spoken by the ten families in each of the three rounds.

Table 1

Family Composition and Language Preferences for Each Round

Family ID	Language(s) Spoken	Family Composition
1	Spanish and English	Adult and child
5	Spanish and English	Adult and three children
6	Spanish*	Adult and three children**
7	Spanish and English	Adult and two children
10	English	Adult and child
11	English	Adult and child
13	English	Two adults and child***
14	Spanish and English	Adult and child
15	English	Adult and two children****
16	English	Adult and child

Notes

*In Round 2, the family also spoke some English. **In Round 2, one child was not present.
***In Round 1, one adult was not present. ****In Round 3, another child was present.

For each of the ten family videos in Round 3 included in the retrospective analysis, a minute-by-minute video description, typically consisting of one to three sentences, was written to summarize the family interactions - behavior, talk, and affect observed in each video. Additional contextual information, including the number of family members in the video and a summary of family dynamics (e.g., if the child or parent/caregiver tended to lead the interaction over the course of the video) were added to each video description document as well. Each of the video descriptions and coding spreadsheets were written in English for clarity across the research team during data discussions, although direct quotations were included in Spanish to preserve the original interactions of the families. Once completed, the video descriptions were coded, in the original language of the family participants, by the REACH-ECE research team for engineering practices using the coding scheme described in Table 2 below.

The REACH-ECE research team met several times during the retrospective analysis to develop a shared understanding of the engineering codes, come to agreement about how to apply them, and ultimately discuss the emergent design principles evident in the families' interactions while engaging in the engineering design activities. After the application of the engineering codes to the Round 3 videos, the REACH-ECE research team engaged in additional coding focused on emergent examples of how specific activity elements may have influenced engineering talk or practice. Preliminary findings from the REACH-ECE retrospective analysis have been presented elsewhere [43].

Engineering Activities

The three engineering activities in the DBR study in REACH-ECE were in different stages of iteration and development at the start of the study. However, from the beginning of the study, all three activities included a bilingual (Spanish/English) book or storyboard, a one-page bilingual activity guide to support parents and caregivers in engaging with the activity at home, and materials for completing the engineering design challenges.

The first of the activities, originally called *Fox and Hen*, had been created for an earlier study in the museum context [24]. Initially in a monolingual format (English text only), *Fox and Hen* was revised both for the home context and bilingual use as part of a subsequent project [8], [10]. In addition, the first version of an activity guide was created, and a colorful storybook with Spanish translations added by the project team was also included. The version of *Fox and Hen* at the beginning of REACH-ECE was very similar in format, with two main changes: an updated activity guide (based on feedback from families) and the inclusion of a new bilingual book.

A second activity, originally called *Dragon Tacos* and focusing on the process engineering involved with making several tacos using play materials, was also developed in a bilingual format for a previous study. For REACH-ECE, the initial version of this activity brought in a different text - the bilingual *How to Fold a Taco* by Naibe Reynoso - which shifted the narrative context for the design challenge. In addition, a few of the materials for the taco ingredients were modified. Finally, a third activity, originally called *A Couch for Fred and Ted*, involved the characters of two dogs who are friends, was developed as a completely new bilingual activity at the start of REACH-ECE.

Based on the data analysis and input from families during the DBR study, the final iterations of the three activities, shown in Figure 1 below, were notably different from the original versions. The final iteration of *Fox and Hen*, ultimately named ***Pollitos*** (Spanish for "baby chicks"), included strong ties to the popular Spanish language song, "Los Pollitos Dicen," and asked families to use wooden blocks to keep a family of baby chicks safe and cozy - a design challenge markedly different from the original one included with *Fox and Hen*. The ***Tacos*** activity did not change significantly in terms of the materials used to build the tacos, but the design challenge and activity guide were heavily revised to focus on asking families to plan a taco party and test different processes for helping guests assemble their tacos. The third activity, ultimately named ***Doggies****,* involved the most revision, with the materials, design challenge, and activity guide all majorly revised to invite families to use craft materials (e.g., popsicle sticks, index cards, sticky dots) to build beds or houses that are just the right size for a small and large stuffed dog.

Figure 1. Images of the three activities developed through the study (from left to right): *Pollitos*, *Tacos*, and *Doggies*.

Qualitative Coding Scheme

Using the code definitions in **Table 2**, each one-minute segment of each video description was coded for the following engineering practice codes: *context setting, materials exploration, problem-scoping, planning, evaluation and revision, modifying problem space,* and *user-centered design*. These codes built on an earlier coding scheme [25] and were refined by the REACH-ECE research team during the initial phase of the retrospective analysis. In order for an engineering practice to be coded, engineering "talk" needed to be observed, in order to avoid making assumptions about non-verbal behaviors in the video analysis. For example, for something to be coded as 'evaluation and revision,' the family must discuss testing, evaluating, or revising their design for this practice to be coded; merely observing a family watch a tower of blocks fall down and begin to rebuild without any verbal turns of talk would not be sufficient evidence to apply this code.

Table 2
Engineering Practice Codes, Definitions, and Examples

Engineering Practice Code	Definition	Examples
Context Setting	Talk about the story or context motivating the design challenge and not necessarily specific to a particular engineering practice, including reading the activity book.	*- During the process of making tacos, the son says, "Now I fold it" in reference to the tortilla, and then the mom asks, "How do they fold it in the book?" (F16R3, min 6-7)* *- Mom and kids sing the Los Pollitos Dicen song together. (F5R3, min 4-6)*
Materials Exploration	Talk related to using or exploring the properties of the materials, without referencing a specific design or engineering goal. This category focuses on comments about the function of the materials, rather than the aesthetics.	*- In the Doggies activity, the son is playing with popsicle sticks and they start talking about how to use them and how to put them together. (F7R3, min 1-2)* *- The mom asks her child in the Tacos activity what the shredded green paper looks like. (F16R3, min 1-2)*
Problem-scoping	Talk about the boundaries or constraints of the problem or challenge, including restating the goal and discussing the materials that are needed or available for the challenge/problem.	*- The mom defines the space where they are going to build during the Pollitos activity: "Este es el lugar seguro para los pollitos" (F5R3, min 11-12)* *- Mom references the activity guide again and asks "What does the mom chick need to keep her chicks and nest safe?" (F11R3, min 1-2)*
Planning	Talk about design ideas and what the family is going to do or build to address the design goal.	*- Mom offers to help her son and tells him what they should do together in the Doggies activity: "Yo voy a agarrar este y tu cojes*

		estos." She says that they should build the bed since daughter is building a house. (F7R3, min 12-13)
Evaluation and Revision	Talk about testing, evaluating, or revising the current design, including considering tradeoffs or planning changes to a design as a result of testing feedback or new considerations. The family must discuss their evaluation of the current design and/or discuss how they are testing the design and/or modifying it in response.	*- A daughter says that her structure is too short as she puts the chick inside it. She begins to make it bigger by adding more blocks. (F5R3, min 21-22)* *- The dad describes where to add the stabilizing bottom piece for the daughter's design in the Doggies activity. The daughter instead wants to make it more stable by adding sticky dots to both sides, so begins doing this. (F13R3, min 31-32)*
Modifying Problem Space	Talk about changing or shifting the design challenge by adding new constraints or a new goal. This category includes both large shifts or changes in goals and constraints as well as more subtle additions or changes to the engineering goal, constraints, or context.	*- In the Pollitos activity, the daughter says they can build anything they want and then don't have to follow what others want to make. She later goes on to protect the chicks from imaginary zombies. (F14R3, min 6-7)* *- During the Tacos activity, the son grabs another tortilla to make a quesadilla. (F15R3, min 24-25)*
User-centered Design	Talk referencing the goals, needs, or experiences of a character, person, or community that informs the design challenge, process, or solution. The characters or persons can be real or imaginary, but they must be a “user” of the design and not just a reflection of personal preference.	*- The daughter mentions "I need your measurements" to the little doggy as she's making his house during the Doggies activity. (F13R3, min 16-17)*

Secondary Analysis of Qualitative Data

Following the extensive retrospective analysis of Round 3 data completed by the full REACH-ECE research team, a secondary analysis of the Round 1 and Round 2 video data was conducted. The first two authors of the present paper led a team of IRB-trained undergraduate research assistants in the work of the secondary analysis. After an introduction to REACH-ECE and the research foci of the broader study, the first two authors trained the undergraduates in creating minute-by-minute video descriptions for the Round 1 and Round 2 video data using a similar protocol to the one developed by the full REACH-ECE research team. In order to be consistent with the Round 3 data, only the videos from the same subset of ten families in the retrospective analysis were examined in the secondary analysis.

While the video descriptions for the Round 1 and Round 2 English-speaking family videos were distributed across the three monolingual English-speaking undergraduates, the video descriptions for Spanish-speaking family videos were created by a bilingual exchange student from Chile who spoke Spanish as her first language. In a similar manner to the Round 3 video descriptions, she wrote the documents in English for clarity across the undergraduate research team during data discussions.

As the video descriptions were being completed, the first author trained the undergraduates on the coding scheme described in Table 2 above. The first author trained the bilingual graduate student first, using a previously coded video from the REACH-ECE retrospective analysis to check the bilingual undergraduate's application of codes and discussing discrepancies until the bilingual undergraduate was consistently and reliably applying the coding scheme. The bilingual undergraduate then proceeded to code all of the video descriptions she prepared for the Spanish-speaking family videos before completing her research internship.

The first author also led the three monolingual/English-speaking undergraduates in an interrater reliability process as the final part of their training on the coding scheme. (It should be noted that the bilingual undergraduate researcher was unable to engage in the IRR process because she had completed her research internship at this point of the work.) Across the training segments, the lead author and the three undergraduates were fully consistent in the application of their codes 74% of the time. Three of the four coders rated consistently across 81% of the training segments, and two of the four coders rated consistently across 90% of the training segments. The four coders then divided the rest of the video descriptions and completed the coding.

Descriptive Exploration of Codes from Secondary Analysis

Upon completion of each minute-by-minute coding spreadsheet, descriptive analysis of coding frequencies across all three rounds of data was completed. Each video description was analyzed for how many times each engineering code appeared as well as the percentage of each individual code from the overall engineering codes. These percentages were compared across rounds for each of the three activities, for all seven of the engineering codes, in order to better articulate the nature of the engineering observed in the videos shared by the family participants in the study.

Findings of the Secondary Analysis

The secondary analysis conducted by the first two authors and the undergraduate research team addressed the two focused research questions posed earlier in the paper. Families engaged in a wide range of engineering talk and practice in engineering activities designed for the home. The distribution of the engineering talk and practice across the engineering codes varied by activity and round. Notably, for user-centered design, a consistent trend appeared: the percentage of segments coded for user-centered design seemed to increase across the three rounds of testing. Below, we present our findings for each research question in more detail using examples from families across the three rounds and activities.

Finding 1: Families engaged in a wide range of engineering talk and practice.

Across all three activities and all three rounds, families engaged in a wide range of engineering talk and practices, responding to Research Question 1 and providing a sense of the nature of the engineering talk and practice demonstrated by families in the study. Each of the families exhibited numerous instances of engineering as they engaged in the activities at home, although these moments varied in the type and relative amount based on the activity and round of the DBR cycle, as seen in Table 3 (*Pollitos*), Table 4 (*Doggies*), and Table 5 (*Tacos*).

Table 3

Engineering Practice Codes for the Pollitos Activity across the Three Rounds

		Round		
Engineering Practice Code	Average	1	2	3
Context Setting	19.8%	18.0%	27.0%	14.3%
Materials Exploration	9.2%	9.5%	11.3%	6.7%
Problem-Scoping	19.3%	23.0%	13.3%	21.7%
Planning	8.7%	14.0%	5.7%	6.3%
Evaluation and Revision	21.8%	28.5%	15.3%	21.7%
Modifying Problem Space	12.2%	2.5%	18.7%	15.3%
User-Centered Design	9.4%	5.3%	9.3%	13.7%

While interacting with the *Pollitos* activity, families exhibited a wide range of engineering practices. For example, in Round 1, when a child tries to stack two cylindrical blocks on top of her structure, as seen in the screenshot in Figure 2, the tower falls down. The mom asks her daughter how they can make it stronger so that the tower does not fall (F1R1, min 14-15), providing an example of the engineering code **evaluation and revision**. In Round 2, as a child is playing with the chicks and an egg, one of the eggs starts to roll off the table; the mom exclaims, “Oh no! It’s the egg that got away!” referencing back to the book they read earlier, providing an example of **context setting** (F16R2, min 10-11). Families were very creative in how they modified the problem space. In Round 3, as one child was midway through building her structure, she said, “We need blocks here to protect [the chicks] from the zombies” (F14R3, min 8-9), **modifying the problem space** to include zombies as a potential predator of the chicks.

Figure 2

Family 1 engages in evaluation and revision during the Pollitos activity (F1R1)

Table 4

Engineering Practice Codes for the Doggies Activity across the Three Rounds

		Round		
Engineering Practice Code	Average	1	2	3
Context Setting	17.8%	28.5%	15.0%	9.8%
Materials Exploration	14.9%	12.2%	18.0%	14.5%

Problem-Scoping	17.7%	23.3%	11.0%	18.8%
Planning	10.4%	4.8%	16.0%	10.5%
Evaluation and Revision	21.5%	20.6%	17.5%	26.5%
Modifying Problem Space	10.8%	9.4%	16.5%	6.5%
User-Centered Design	7.3%	1.2%	7.0%	13.8%

As families explored the *Doggies* activity, they engaged in a variety of engineering. In Round 1, a mom exhibits **problem-scoping** as she sets the stage for her son and daughter to understand the design challenge. She reads from the activity guide, then asks them, "So what are we trying to do?" and the son replies, "Build them a couch!" (F15R1, min 3-4). The mom then uses her hands to show their goal of having the two stuffies be "at the same height" (F15R1). In Round 2, a mom shows **planning** as she asks "¿Quieres construir una casa al perro grande o al perro pequeño?" (Should we build a house for the little dog or the big dog?) to which her daughter responds by choosing to build the house for the little dog first (F14R2, min 6-7). In Round 3, as a family reads the book, as seen in the screenshot in Figure 3 - an instance of **context setting** - the son asks, "¿Quién es Fred?" (Who is Fred?) (F7R3, min 7-8), showing that he is engaged and also striving to learn about the characters he has in front of him in the two doggies.

Figure 3

Family 7 engages in context setting as the mother reads the story in the Doggies activity (F7R3)

Table 5
Engineering Practice Codes for the Tacos Activity across the Three Rounds

		Round		
Engineering Practice Code	Average	1	2	3
Context Setting	29.4%	41.7%	17.8%	28.7%
Materials Exploration	15.5%	11.7%	17.8%	17.0%
Problem-Scoping	9.7%	10.7%	7.8%	10.7%
Planning	9.7%	9.3%	12.5%	7.3%
Evaluation and Revision	15.4%	16.3%	16.8%	13.0%
Modifying Problem Space	8.6%	8.0%	11.0%	6.7%
User-Centered Design	11.7%	2.7%	16.0%	16.3%

While engaging in the *Tacos* activity, families also showed a variety of engineering practices. In Round 1, after finishing reading the book, the mom exhibits **planning** as she tells her three children to distribute the tacos ingredients to get ready to make the tacos (F5R1, min 17-18). One family has a brief discussion about the identity of the ingredients in Round 2 as part of **materials exploration**; the daughter suggests the red pom poms are cherries, to which the mom responds “Do we put cherries on tacos?” (F10R2, min 1-2), and they soon agree upon tomatoes (red pom poms) and onions (white pom poms). Another family celebrates their son’s birthday party for the tacos activity in Round 3, as seen in the screenshot in Figure 4, during which the mom encourages her son to ask for whatever tacos he wants so that his sister can make them, showing **user-centered design** as his preferences are taken into account in the creation of his taco (F6R3).

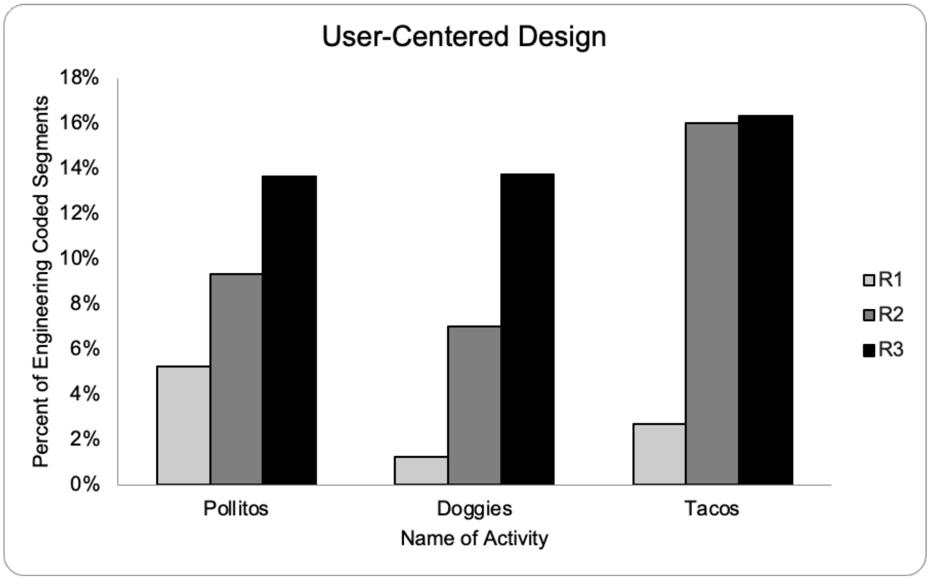
Figure 4
Family 6 shows user-centered design while planning a taco party as they consider the son's taco preferences (F6R3)

Finding 2: The percentage of segments coded for user-centered design appeared to increase across the three rounds of testing.
As seen above, the distribution of the engineering talk and practice varied by activity and round, thereby addressing the first part of Research Question 2. Notably, for the engineering practice of user-centered design, the data suggests a consistent trend: the percentage of segments coded for user-centered design appeared to be more frequent as the rounds of testing progressed. This finding addresses the second part of Research Question 2, providing a richer description of how the nature of the engineering families engaged in changed across the different rounds of activity testing.

As seen in Figure 5, the percentage of user-centered design seen for each activity seemed to increase across the three rounds. Of all the engineering practices coded in the *Pollitos* activity, user-centered design appeared in 5% of the total engineering codes in Round 1 (R1) on average. This increased to 9% in R2 and 14% in R3. For *Doggies*, user-centered design appeared in only 1% of all engineering codes in R1; this rose to 7% in R2 and then to almost 14% in R3. For *Tacos*, user-centered design appeared in 3% of the engineering codes, jumped to 16% in R2, and then to just over 16% in R3.

Figure 5

Percentage of User-Centered Design across each Round and Activity



<u>Examples from the *Doggies* Activity</u>

When using the *Doggies* activity in Round 1, families rarely engaged in user-centered design, and most instances were primarily discussing the safety of one of the two stuffed dogs. For example, in one family, as a child constructs a couch for the doggy, the mom asks, "Can you think of a way that is safer? Because it looks like the dog can easily fall off" (F15R1, min 10-11). In Round 2, user-centered design was more present in the family videos, particularly when families were talking about the doggies' sleep and hygiene. For example, one mom asks her daughter, "¿Estás haciendo un muñequito para que el perrito pueda dormir?" (Are you making a stuffie so the dog can sleep?) (F14R2, min 19-20). The daughter mentions a minute later that the dog needs a toothbrush (F14R2, min 20-21). Another family also considers what the doggy needs when the son mentions the dog "needs to be warm" (F11R2, min 6-7) and then later in this same video reiterates that the dog needs to be warm and also considers another need when he says that he will make the doggy a toilet so that he can go potty (F11R2, min 12-13).

In Round 3, there are even higher levels of user-centered design present as families focus on both the comfort and safety of the dog. When her child lays an index card down to make a bed for the doggy, one mom asks, "¿Tu crees que va a estar cómodo ahí?" (Do you think it will be comfortable there?) (F1R3, min 69-70). Another family acknowledges the comfort of the doggy as a child says, "Let's put the dog on the bed so he can be nice and comfy" (F11R3, min 17-18). When creating additional items that go beyond the given engineering design challenge, new considerations can come into play for families. In one instance, a child shows user-centered design as she rebuilds a new trampoline so that her doggy does not fall (F1R3, min 84-85). All of these instances suggest that families make different design decisions based upon the needs of the user - who, in the case of this engineering activity, is the stuffed doggy - in mind.

Examples from the *Pollitos* Activity

The Round 1 *Pollitos* activity invited families to work together to build a structure out of blocks to protect a hen's nest and eggs from a hungry fox. When engaging in user-centered design during Round 1, the focus was on the appearance of the design structure. In Family 7, the daughter wanted the castle she was building to look nice for the eggs (F7R1, min 2-3). In Round 2, which saw the addition of small stuffed baby chicks to the kit, the nature of the user-centered design shifted to focus primarily on the needs and protection of the chicks. In one family, the mother explains that she made a ladder for the chicks, "something for them to hop down" from the tall tower she and her son created (F16R2, min 18-19). In another family, the son decided "we need a door that's safe so that only the chickens can get through" and begins building a ramp to get into the chicken coop he and his sister were building around their nest of eggs and chicks (F15R2, min 28-29).

The nature of the user-centered design in Round 3 varied from protection of the chicks (similar to Round 2) to other unique needs, ranging from a bed for the chick (F5R3), stairs (F11R3), a hot tub (F5R3) and even protection from wolves (F5R3) and a zombie attack (F14R3). Some children spoke directly to the chicks such as one child who said, "Don't worry, little chickies," as he was working to build another roof on top of his structure to keep them dry from the rain (F11R3, min 6-7). The variety of needs for the baby chicks that families considered in this final round, including those needs that stemmed from modifying the design challenge to suit their own interests, demonstrated a deep connection to the "user" of the chick in the *Pollitos* activity which often aligned with design decisions and design moves for families.

Discussion

The secondary analysis of family videos during Rounds 1 and 2 of the DBR study in REACH-ECE allowed us to more robustly understand the nature of the engineering that happened while families engaged in developmentally-appropriate engineering activities designed for unfacilitated family use in the home. The findings suggest that families did engage together in a wide range of engineering practices across all three activities and all three of the rounds of activity testing. Interestingly, the findings also suggest that the nature of the engineering did shift across the rounds, with the particular example of user-centered design increasing from round to round. In this section, we share additional reflections on the data and findings, particularly as they relate to the broader research aims of REACH-ECE beyond the scope of the secondary analysis and existing frameworks for designing K-12 engineering experiences.

Activity components may have contributed to these increases in user-centered design

Part of the broader research question for REACH-ECE seeks to examine how specific characteristics of engineering activities can influence the engineering practices that families might engage in while using such activities together. The secondary analysis points to potential connections between increases in user-centered design and the intentional revisions to the elements of the activities - the materials, design challenge, and narrative supports - between rounds. Specifically in the *Pollitos* examples presented above, the Round 1 activity version consisted of the following materials: wooden eggs, a nest basket, a paper fox, and wooden blocks. Their first challenge was to build a one-foot tall structure, roughly the height of the paper fox. The data suggested that families did not feel the connection between the story, the printed paper fox, and the design challenge, as families' use of the fox varied, with some families not using it at all.

In Round 2, in order to clarify the narrative context, multiple wind-up, stuffed chicks were added to the kits, the fox was removed, and the design challenge changed to instead build something tall that would keep the chicks and eggs safe. The activity guide included with the kit was also changed to include a "Let's Explore" and "Let's Design" format, as seen in Figure 6, which allowed for time to explore the materials of the chicks, wooden eggs, and nest. The nature of the user-centered design shifted with these changes to focus primarily on the needs and protection of the chicks, who became the main attraction as families were encouraged in the "Let's Explore" part of the activity guide to tell a story with the chicks. Some families also engaged more deeply in the design context by singing the "Los Pollitos Dicen" song together (F6R2). The different components - from adjusting the guide to adding the chicks - may have contributed to the families' stronger connection with the "user" of the chicks in Round 2.

Figure 6

Bilingual (Spanish/English) Pollitos activity guides for Round 2

In Round 2, families seemed to greatly enjoy the stuffed chicks, engaging in extended imaginative play with them before getting started on the design challenge. In contrast, the families used the eggs in the kit far less. Following the lead of the families, in Round 3, the eggs were removed from the kit, allowing families to focus more specifically on the engaging chicks. The intentional changes made to this activity over the course of the three rounds suggests that the activity components may have played a key role in the increase in user-centered design for families using the activity.

Developing activities for families with young learners extends existing frameworks

The work involved with both REACH-ECE and this adjacent secondary analysis also suggests that existing frameworks for creating engineering activities for K-12 students can be further extended to be more applicable and relevant to early learners and early learning contexts, including the family learning context of the home. For example, Cunningham and Lachapelle's design principles for K-12 engineering experiences [36] outline a set of 14 principles spread across four wider categories: *1) setting learning in a real world context; 2) presenting design challenges that are authentic to engineering practice; 3) scaffolding student work;* and *4) demonstrating that everyone engineers and everyone CAN engineer.* REACH-ECE extends the first category of setting learning in a real-world context by presenting multiple examples of activities set in highly fictional contexts, driven by storybooks, characters, and in some cases, stuffed animals.

The families demonstrated high levels of engagement with the fictional activities, even pushing the engineering design challenges further than we originally intended through their imaginative and collaborative play. The family videos certainly suggested that authentic engineering practice was possible and accessible in the activities we designed, connecting to the second category in Cunningham and Lachapelle's framework. However, when working with young children with vivid imaginations, they may actually engage in a practice that typically is not seen in engineering - the practice of modifying the problem space, which we observed both in REACH-ECE and this secondary analysis when families would redefine design goals or constraints as they played together. The third category, scaffolding student work, may not seem particularly relevant to family-focused activities outside of the structured classroom, where a teacher would be carefully orchestrating lesson activities and instructional moves to build student learning towards a specific learning outcome. However, the findings from REACH-ECE and this secondary analysis suggest that the activity guide developed for parents and caregivers was an essential scaffold for the family unit as they engaged in the engineering activities. For example, parents and caregivers looked to the guides to find questions to ask their children to further engage them in new aspects of the activity, which would frequently lead to deeper and more extended use of engineering practices.

Perhaps the category that most resonates between our overall work and the design principles articulated by Cunningham and Lachapelle is fourth one, focused on demonstrating that everyone engineers and everyone CAN engineer. In particular, Cunningham and Lachapelle call for activities that foster children's agency as engineers, cultivating environments where all students' ideas and contributions are valued, and creating design challenges that use everyday materials. While our work approaches this category from a more unstructured informal learning perspective, data from the interviews in REACH-ECE suggested that families recognizing elements of the engineering design process within their day to day contexts - as they worked to iteratively and creatively solve everyday problems within and around the home setting - was very empowering for parents and caregivers, leading them to see that everyone does indeed engineer and they have been doing it all throughout their lives. This powerful realization can carry over into the ways they position themselves and their children relative to engineering, seeing it as relevant and woven throughout their experiences, identities, and future selves.

Limitations, implications, and future work

The secondary analysis conducted for this paper has a number of limitations, including the predominantly monolingual, English-speaking composition of the first two authors and three of the four undergraduate research assistants who primarily engaged in the work. Although the bilingual undergraduate student both developed the video descriptions for the videos from Spanish-speaking families and applied the coding scheme to them, the later descriptive examination of the codes were conducted by the monolingual English-speaking undergraduates. Ideally, the bilingual undergraduate would have been able to participate both in the broader inter-rater reliability process of the group and then stayed on to do the descriptive analyses with us, but that was not possible.

Looking more broadly at REACH-ECE, additional limitations include the DBR study engaging a small sample of families all connected to the same early childhood education program, which limits the wide generalizability of these specific findings. In addition, it is important to acknowledge that each family that participated in the full three rounds of DBR activity testing would likely have demonstrated more engineering practices in each subsequent round merely based on repeated exposure to the type and genre of activities presented in the study, so some increase over time in the amount of engineering present in the videos would be expected, regardless of what modifications were made to the activities after each DBR mini-cycle.

Despite these limitations, this secondary analysis and REACH-ECE more broadly have a number of potential implications for both practitioners and researchers. This work can advance the knowledge of the field in terms of what engineering practices can look like for families with young children in the home context, which continues to be an understudied learning environment despite the evidence that these early interactions and experiences with family members can be quite impactful on future career and personal trajectories for young people. This work can also advance the articulation of more specific design principles for flexible engineering activities that engage not only parent-child dyads but also the wide range of configurations families with young children come to take up activities and play together. Moreover, this work can elevate the home as a powerful learning environment for STEM education, and position families from all backgrounds as experts in their own ways of creative and iterative problem solving - indeed, in their own ways of engineering everyday - within their daily lives. Future work involves further analyses of the data collected as part of REACH-ECE, additional examination of the emergent design principles for early childhood engineering activities, and the ongoing effort to broaden and democratize the boundaries of engineering to be more inclusive and empowering - particularly for traditionally marginalized communities.

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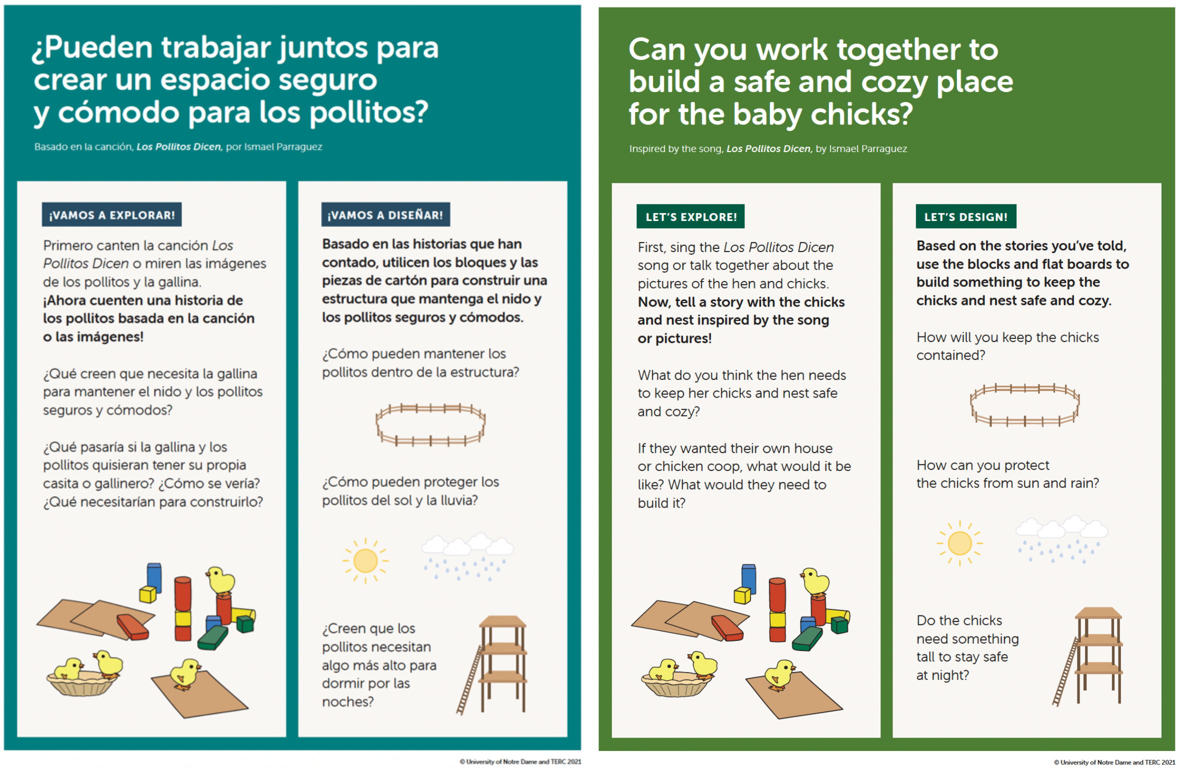
Appendix

Figure 7

Bilingual (Spanish/English) REACH-ECE Activity Guides for Round 3: (a) Pollitos, (b) Doggies, and (c) Tacos



(a)

¿Pueden construir una cama o una casa del tamaño apropiado para cada perrito?

Basado en el libro, ***Perro Grande, Perro Pequeño,*** por P.D. Eastman

¡VAMOS A EXPLORAR!

Empiecen a explorar los materiales juntos. Intenten hacer paredes y carpas utilizando las tarjetitas.

Ahora intenten utilizar los puntitos de pegamento para pegar las tarjetas de diferentes maneras.

Ahora utilicen los puntitos de pegamento para pegar los palitos de madera o las tarjetas y hacer una estructura que se mantenga de pie.

¡VAMOS A DISEÑAR!

Utilicen lo que han aprendido sobre los materiales para diseñar una cama o una casa que sea del tamaño apropiado para los perritos.

Ayude a su niño(a) a diseñar para el perrito pequeño. Usted puede trabajar en un diseño para el perro grande o pueden guardarlo para luego.

Estos dibujos son solo ejemplos. ¿Pueden utilizar otros materiales que tengan en casa para ayudar a los perritos a sentirse más cómodos?

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Can you build a bed or house that is just the right size for each dog?

Inspired by the book, ***Perro Grande, Perro Pequeño,*** by P.D. Eastman

LET'S EXPLORE!

Start by exploring the materials with your child. Try making walls and tents with the index cards.

Try using the sticky dots to connect the index cards in different ways.

Now try using the sticky dots to attach the popsicle sticks or cards and make something stand up.

LET'S DESIGN!

Use what you've learned about the materials to design a bed or house that is just the right size for each dog.

Help your child work on a design for the small dog. You can work on a design for the large dog at the same time or save that for later.

These pictures are just examples. Can you use other materials from around your house to help the dogs feel cozy and comfortable?

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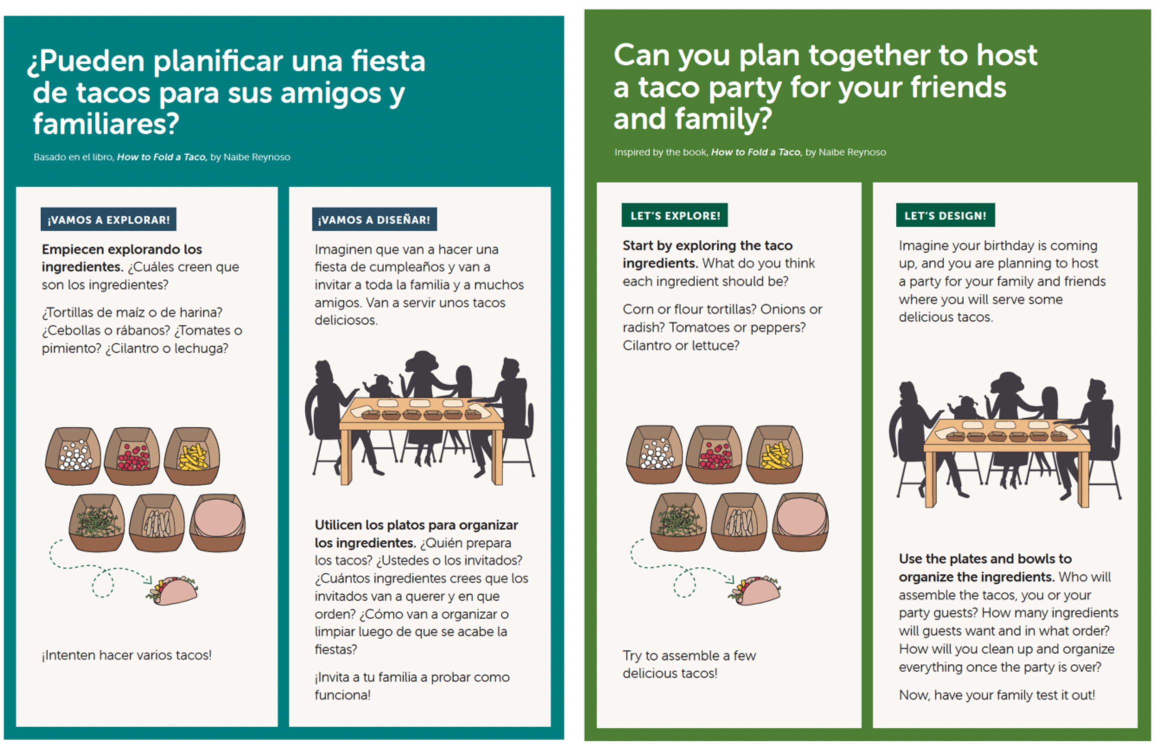
(b)



¿Pueden planificar una fiesta de tacos para sus amigos y familiares?

Basado en el libro, ***How to Fold a Taco,*** by Naibe Reynoso

¡VAMOS A EXPLORAR!

Empiecen explorando los ingredientes. ¿Cuáles creen que son los ingredientes?

¿Tortillas de maíz o de harina? ¿Cebollas o rábanos? ¿Tomates o pimiento? ¿Cilantro o lechuga?

¡Intenten hacer varios tacos!

¡VAMOS A DISEÑAR!

Imaginen que van a hacer una fiesta de cumpleaños y van a invitar a toda la familia y a muchos amigos. Van a servir unos tacos deliciosos.

Utilicen los platos para organizar los ingredientes. ¿Quién prepara los tacos? ¿Ustedes o los invitados? ¿Cuántos ingredientes crees que los invitados van a querer y en que orden? ¿Cómo van a organizar o limpiar luego de que se acabe la fiestas?

¡Invita a tu familia a probar como funciona!

Can you plan together to host a taco party for your friends and family?

Inspired by the book, ***How to Fold a Taco,*** by Naibe Reynoso

LET'S EXPLORE!

Start by exploring the taco ingredients. What do you think each ingredient should be?

Corn or flour tortillas? Onions or radish? Tomatoes or peppers? Cilantro or lettuce?

Try to assemble a few delicious tacos!

LET'S DESIGN!

Imagine your birthday is coming up, and you are planning to host a party for your family and friends where you will serve some delicious tacos.

Use the plates and bowls to organize the ingredients. Who will assemble the tacos, you or your party guests? How many ingredients will guests want and in what order? How will you clean up and organize everything once the party is over?

Now, have your family test it out!

(c)

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