Integrating Science, Mathematics, and Engineering:

Linking Home and School Learning for Young Learners

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Children explore ramps and pathways in the classroom.

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Why Early Science?

There is growing recognition of the need and importance for high-quality science teaching and learning in early childhood. The increased emphasis on science stems from recognition of the following: (1) young children are curious and interested in making sense of the world around them (Larimore, 2020), (2) early science experiences not only support children's later science learning but also promote and strengthen young children's learning and development in other key areas (Bustamante et al., 2018; Bustamante, White, & Greenfield, 2017; Sarama et al., 2017; Conezio & French, 2002; Wheatley et al., 2016), and (3) young children have the right to learn about science phenomena and develop problem-solving skills that will allow them to be problem solvers and active citizens in their communities (NASEM, 2022).

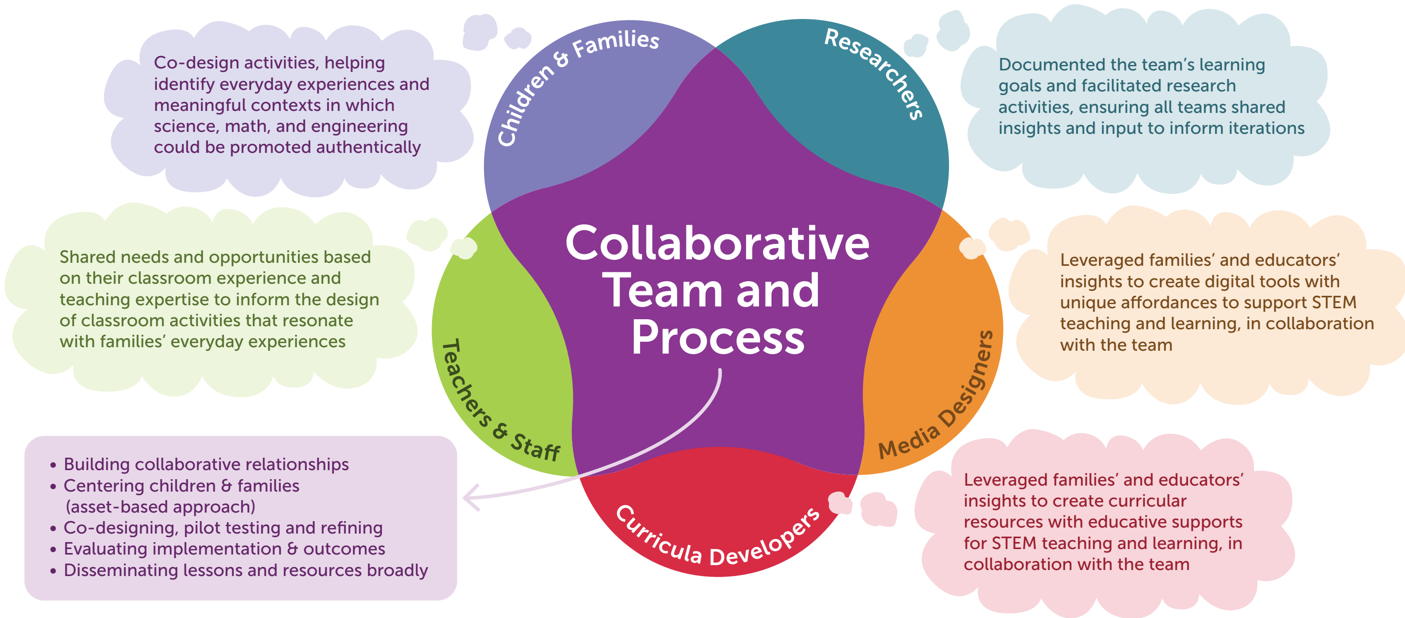
Although science is increasingly recognized as a key dimension of early learning, young children, especially those in programs serving historically excluded communities, continue to have few opportunities to engage in high-quality science activities (Dominguez & Stephens, 2022; Morgan et al., 2016; NASEM, 2022). Early childhood educators are interested and find science valuable for young children, but adding science into an already packed curriculum can be challenging, especially given the lack of resources that can be feasibly integrated into existing whole-child curricula. To address this need, our project aimed to generate resources that leverage children's everyday experiences and families' funds of knowledge to feasibly promote science across home and school.

Project and Approach

With funding from the National Science Foundation (NSF), our team co-designed a preschool science program that: (1) promotes early science learning across home and school through playful activities that resonate with young children and leverage their experiences at home and in their community, (2) links science with engineering and math, strengthening children's opportunity to meaningfully learn across domains, and (3) leverages digital tools with unique affordances for STEM learning to strengthen (not replace) hands-on exploration.

To achieve these goals, the team engaged in a collaborative process that involved:

- **Building collaborative relationships**: bringing together researchers, educators, families, curriculum designers, and media developers to engage in co-design and design-based research
- **Centering children and families**: identifying families' funds of knowledge and children's everyday experiences that could be leveraged to feasibly and meaningfully introduce science, engineering, and mathematics
- **Co-designing** playful activities that reflect families' traditions and children's interests, are practical and easy to implement, and are consequential for learning
- **Evaluating** not just outcomes but also implementation and process
- **Disseminating** lessons and resulting products to all broad audiences



Building Relationships, Centering Children and Families, and Co-Designing Resources

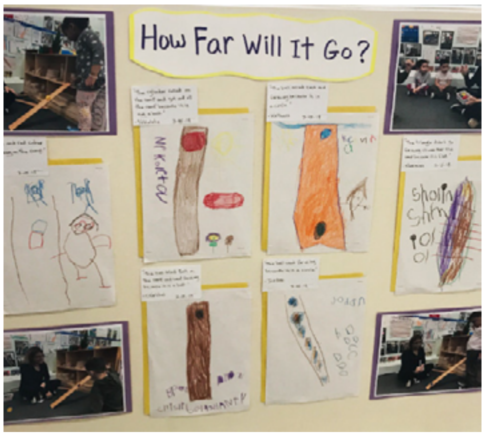
The first phases of the project involved building relationships, centering children and families' experience and assets, agreeing on learning goals, and engaging in a series of co-design activities to generate and pilot test draft resources in classrooms and homes. Initial meetings were structured so that all team members could share their unique insights and experiences in an open and generative environment. Special attention was given to power dynamics that needed to be addressed to ensure an inclusive and collaborative process. A learning blueprint was created to articulate agreed learning goals. Using the learning blueprint as a guide, the team brainstormed activity ideas to address these goals. A series of hands-on design workshops were conducted to brainstorm ideas and create prototype activities and resources. A variety of materials commonly found in partner educators' classrooms and families' homes were available to inspire creativity. As activities and resources were designed, the team conducted user and pilot studies in classrooms and homes and evaluated data from these studies to guide and inform iterative revisions.

Example: Force & Motion Through Ramp Investigations and Designs

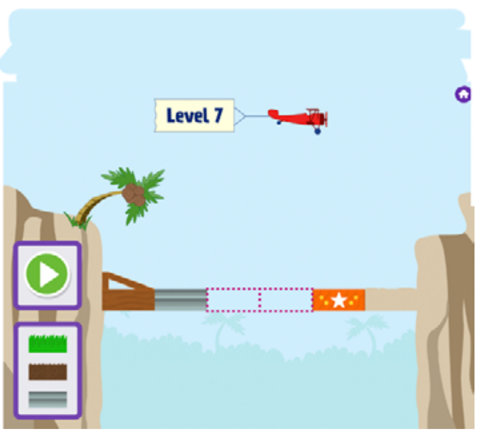
As an example, the team engaged in the process described above as they discussed physical science activities that could be feasibly implemented across home and school. During one of the co-design workshops, the team discussed the concept of force and motion. Teachers shared that children in their classrooms often learned about force and motion as they played with ramps in the block area. Teachers and families also noted these playful activities naturally included engineering design. Initially, teachers and families reported feeling less familiar with engineering but through the discussions were able to identify instances where their children engaged in engineering practices.

Children explore ramps in the community.

Co-design team testing ideas.



Classroom chart.



Screenshot of Coconut Canyon.
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Teachers shared that at school children often designed ramps and pathways to meet a goal. Meanwhile, families discussed that children often noticed ramps in their neighborhood and these could lead to discussions about how they solved problems or addressed a need. Inspired by this, the team developed a related set of activities to explore ramps across home and school. In one activity enacted both at school and at home, children went outside to find ramps in their everyday world. This provided them with the opportunity to describe the ramps and discuss how different ramps are used to solve everyday problems. Through the testing, we gathered feedback from teachers and families on what worked well and what could be improved. In addition, their feedback provided insights into what science core ideas were most relevant to the activities, as well as the potential math and engineering learning opportunities present. As a result of this co-design and iterative refinement process, the final version of this activity, *Ramp Hunt*, was included in the Teacher's Guide and Family Science Fun Guide, along with hands-on activities that invited children to build ramps and engage in investigations to observe, compare and test how different objects moved on ramps with different steepness and/or surface textures.

Example: Growth and Transformation Through Plant Investigations and Support Designs

Another activity that was developed during the initial phase was around plants' needs. This activity presented challenges that the team addressed over multiple rounds of testing and revision.

The initial activity idea was identified during co-design workshops when the team was brainstorming ideas that could provide children opportunities to explore and learn about plants' needs. Families shared that they enjoy growing different types of plants at home (often inside their homes or in small patios), and teachers expressed that they often grow plants in the classroom as part of science investigations. This prompted a discussion about what different plants need, including the amount of sun and/or water as well as supports and/or space needed. Multiple families mentioned the need for trellises to provide support and nets to provide protection to plants as they grew. For example, multiple families talked about engaging in engineering as they designed a trellis to help tomato plants grow. This idea ultimately inspired the design of a classroom arts and engineering activity: creating supports for a floppy tomato plant. While the team initially observed promise during pilot tests, as the activity was developed and tested, some challenges surfaced.

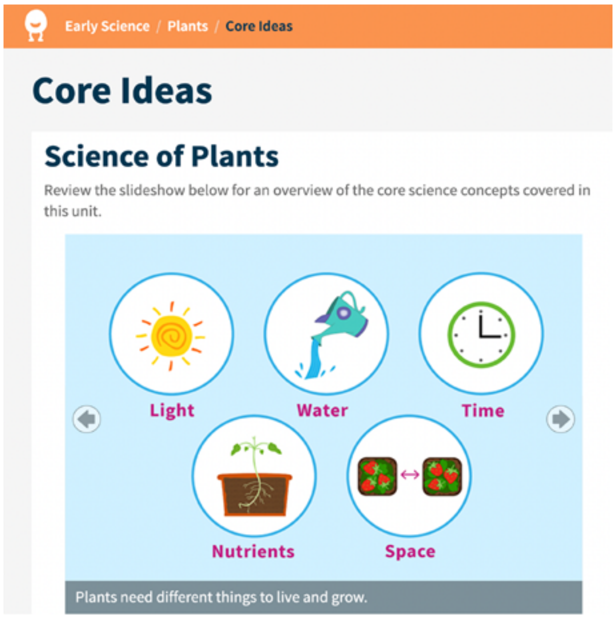
In the first round of testing in classrooms, children encountered multiple challenges. Some children did not seem to understand the engineering design problem to build a support for a floppy tomato plant. While they were engaged in exploring the different materials, they could use to create a support structure (e.g., glue, tape, string, sticks), they rarely focused on how those items could be used to design a support or *why* this was a meaningful problem to solve. The materials themselves also presented challenges, such as children using too much glue or not building a strong enough base. As a result, the team designed various introductory activities to set the stage, including book readings that provided examples and a whole class discussion that allowed children to hear ideas from classmates to better understand the need and jointly brainstorm ideas for solutions. The team also tested alternative materials that could provide more sturdy supports, such as clay or play dough.

During the final round of classroom testing, teachers shared feedback about this refined activity. They expressed that children enjoyed the hands-on investigation and indicated that many children seemed to understand the problem (to create support for a drooping tomato plant) and were able to use materials to explore and design a solution. They also mentioned that this activity tended to resonate more with children who have had similar experiences in their lives, such as children who grew plants at home or had seen an example of such support for a plant. Children who had less experience with plants needed more scaffolding. To this end, teachers appreciated the approach of introducing the activity with a larger group so that children could hear each other's ideas, and then explore and work together in smaller groups to design solutions. Teachers also noted that this activity was very language-rich and really required explanation for children to understand the problem, which could be a challenge for multilingual learners. This was something to consider in how to provide guidance for teachers and perhaps more suggestions for scaffolding. All of this feedback was considered for the final version of the activity, *Build a Support for Floppy Tomato Plant*, included in the Teacher's Guide along with many activities to document plant observations, measurement activities to track plant growth over time and plant experiments where children made predictions.

Model floppy tomato plant.

Program Description: Early Science with *Nico & Nor*®

The outcome of the first years of research and design was an engaging science program for home and school: Early Science with Nico & Nor®. The program includes a Teacher's Guide, a Family Science Fun Guide, three digital science journals, and eight digital games. The guides are now freely available via WGBH Education Foundation's First 8 Studios® website, and iPad apps are freely available via the Apple store.



Screenshot of Teacher's Guide.
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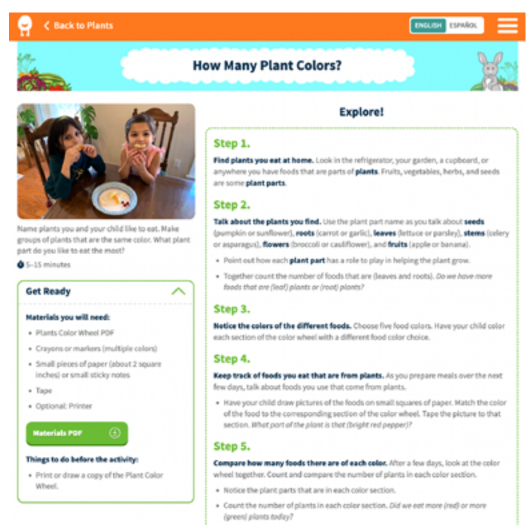
The Early Science Teacher's Guide is a digital resource where teachers can access many activities across three curricular units—Plants, Ramps, and Shadows. Activities within each unit are broken down into four weeks and match common preschool formats like circle time, small group time, and learning centers (referred to as choice time in some preschool settings). Each activity includes step-by-step directions with suggested verbal prompts, materials needed, common vocabulary, and the targeted learning goals. Importantly, all activities aim to promote science, math, and engineering in meaningful and playful ways. The guide also contains other information helpful to teachers who are looking to implement the program in their classroom. For example, it has a preparation guide for each of the three units containing an overview and general tips for that unit's content area. It also provides a concise visual and written overview of the core science concepts covered in each unit along with descriptions of the embedded key science practices. Lastly, the guide provides explanations of the math and engineering concepts that are addressed in the curriculum.

The Family Science Fun Guide is a digital resource available in English and Spanish where parents can access brief, adaptable activities to do with their children either at home or out in their communities. The activities are also structured around the three topics—Plants, Ramps, and Shadows—and aim to inspire families to engage in science, math, and engineering in playful ways. Activities are organized according to type and location, including categories for hands-on indoor and outdoor activities as well introduction support for the digital apps.



Screenshot of Family Science Fun Guide.
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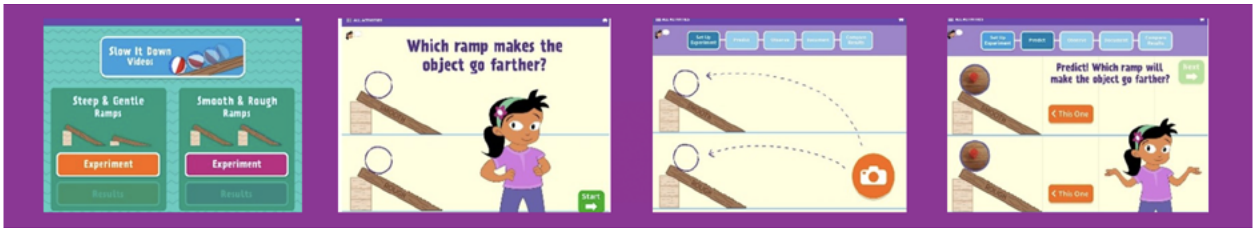
Activities include simple, easy-to-read steps and provide an overview of suggested materials and actions that can be taken to prepare beforehand. Similar to the Teacher's Guide described above, the Family Science Fun Guide also provides a visual and written overview of the core science concepts covered in each unit for parents who are interested in digging a little deeper into the targeted learning areas. All of the material presented in the guide were developed with the intention of helping parents and caregivers feel prepared to engage in rich conversations with their children.

Early Science with *Nico and Nor*® contains a **digital science journal** for each of the three units to support engagement in science practices and promote collaborative classroom science learning. The journals leverage innovative technology to support observation, data collection, analysis, and reflection during science investigations. For example, the Ramps Journal invites children to record, predict, and compare how objects moved on ramps and pathways. Another unique feature of this app is the use of slow-motion video to help children closely observe how two objects moved down different ramps. Finally, in the Plants Journal, children use the photo function of touchscreen tablets to save images of plants they grow in order to observe and measure growth over days and weeks. The journal then automatically generates a graph for children to visualize their measurement data over time.



Screenshot of Ramps Journal. ©WGBH Educational Foundation, 2023

The Nico and Nor program also developed and published eight **Digital Games** to support and strengthen children's hands-on learning across school and home. The games provide children opportunities to observe and explore science phenomena through interactive simulations and easily test and revise solutions. Like the digital science journals described above, some of them also support engagement in the science practices. For example, the Wonder Farm app invites children to explore how different environmental variables (sunlight, water, animals) affect the growth of plants over time. By using this simulation, children are able to isolate variables that affect growth in ways that can be challenging in real life. Another example is the Coconut Canyon app which invites children to explore using different textured materials to build a pathway that will make a coconut roll onto the star. They choose and test using bumpy grass and less bumpy dirt to see how far the coconut will roll.

Screenshot of Coconut Canyon Digital Game. ©WGBH Educational Foundation, 2023

Field Study

Recruitment and Sample Adjustments Due to COVID-19

In the fall of 2021, our team created recruitment materials and began initial outreach with four early childhood centers to share details about the study and better understand what COVID guidelines may affect in-person data collection. All four centers agreed to participate in the study as long as the team was able to adjust protocols as needed given that a variety of health-related restrictions were still in place.

Across the four centers located in New York, Massachusetts, Washington, D.C., and California, we were able to recruit a total of 14 classrooms: eight intervention classrooms and six comparison classrooms (fewer classrooms than originally planned). The teacher sample varied in terms of years of teaching experience, highest education level completed, and race/ethnicity. Teaching experience ranged from less than one year up to 35 years with the mean years of teaching experience being 11.4 and 10.6 years for treatment and comparison teachers, respectively. The highest education level completed ranged from "Some College" to a "Master's Degree" with a "Bachelor's Degree" most commonly reported. Teachers' reported races/ethnicities included White (42%), Asian (26%), Hispanic/Latino (21%) or Other Race (11%). Across conditions, the majority of teachers indicated speaking another language other than English. Of these 11 teachers, six teachers (four=treatment, two=comparison) indicated some level of Spanish fluency.

Across the eight intervention classrooms, we recruited a total of 28 families (more families than originally planned). Of the 28 families, 15 families are Spanish-speaking families, so they were paired with a study team member fluent in Spanish. Parent education level ranged from "Some High School" to a "Master's Degree" with an "Associate Degree" most commonly reported. Parents reported ethnicities included those who identified as Hispanic, Latino, or Spanish origin (64%), Asian (18%), and Black or African American (7%). Of the three remaining families, one parent each identified as White, Other Race, or indicated a preference to not respond. All families reported engaging in learning activities at home with their children prior to participating in the study. Most families in the sample support learning in the social emotional, literacy, and math domains, and some also mentioned supporting science and engineering learning as well. While the nature and frequency varied across participating families, most parents reported that their children use technology at home for learning and for entertainment. This included playing apps and watching videos on a tablet or mobile device and watching videos on YouTube. Most families reported having multiple technology devices in their home, and almost all had reliable Internet at home.

Table 1. Study Sample

Locations	Classrooms		Families
	Intervention	Comparison	Intervention
New York	3	3	12
Massachusetts	2	0	4
Washington, D.C.	2	2	8
California	1	1	4
Total	**8**	**6**	**28**

Methods

Data Collection Procedures

The study started in February 2022, after obtaining consent from all teachers and families. Initially participating teachers and families were going to implement the 12-week program at the same time, starting in late February. Due to various logistical constraints, such as an in-person closure resulting from COVID-19 at one center, a weeklong break at two centers, and an iPad shipping delay, we adopted a staggered approach. The implementation initiation ranged from the last week of February to mid-March.

Prior to implementation, researchers administered a teacher pre-survey and delivered study materials, including hands-on curricular materials and iPads, to participating classrooms. Prior to the start of each unit, researchers also facilitated an interactive orientation session (oftentimes remotely) with individual teachers and parents to review and discuss target science ideas and practices as well as review a few of the unit's activities and the digital apps.

Trained researchers with experience in early childhood assessment conducted science and math assessments with a subset of children in all participating classrooms (8=treatment, 6=control) both pre- and post-implementation. Throughout implementation, researchers conducted observations in all eight intervention classrooms with the aim to observe at least one classroom activity per unit (for a total of 24 observations). After each unit, intervention teachers participated in a 30-minute interview (for a total of three interviews per teacher). Once classroom implementation was completed, all teachers were invited to respond to a post-survey.

All data collection with the subset of families participating in the home component (n=28) was conducted virtually/remotely to reduce potential COVID-related risks for families. Throughout implementation families were invited to share videos and/or photos via a secure online system. After a few weeks engaging with each unit, families completed a brief survey and participated in a follow-up debrief session with a researcher to discuss artifacts shared (if any) and discuss feedback, insights, and successes and challenges they experienced while implementing the unit. During debrief sessions, implementation support was also provided if needed.

Measures

Science Assessment. For the purpose of the study, the team modified an existing science assessment developed and validated during a prior National Science Foundation grant. The modified assessment includes a total of 26 items. Items include visuals (e.g., graphics or photos) or manipulatives and ask children to select a response either by physically indicating (e.g., pointing to) their response and/or responding verbally. Six are multiple part items; the first part of the item may prompt the child to select a response option while the second part elicits an open-ended response to elaborate on how or why. To support virtual administration in the event of COVID-related constraints, the team generated a version that could be administered remotely. This adapted version included 18 items as well as an orientation to first familiarize children with each of the colors that children needed to recognize to be able to select response options. Items requiring physical manipulatives were omitted in the virtual version.

Assessors administered the assessments one-on-one with each child and recorded the child's response on a scoring sheet. All science assessments were conducted in person, with the exception of two classrooms where the pre-assessment was administered via Zoom. After administration, assessors reviewed the scoring sheet and entered the data online into a secure Qualtrics form. Of the 87 children who completed the science assessment prior to the study, 80 (92%) also completed the assessment at the end of the study.

A subgroup of researchers with science expertise met to discuss and create a coding rubric to code open-ended qualitative responses. To examine item performance of dichotomous or coded items, descriptive analyses and item-test correlations were conducted using post-assessment scores. Results showed four items with item-test correlations below .20, warranting further examination. All four items related to the shadows unit and included photographs that could have been confusing to children. After removing the four items, we examined the internal consistency of the retained set of items. The Cronbach's alpha coefficient, $\alpha = .752$, indicates the set of items has adequate reliability. A total score was calculated for this set of items and included in analyses to examine improvements in learning.

Table 2. Distribution of Science Assessment Items

	Ramps	Shadows	Plants	Practice Only	Total
Observing & Describing	1	3	2	3	**9**
Comparing & Contrasting	1	N/A	1	N/A	**2**
Sorting	N/A	N/A	N/A	N/A	**N/A**
Questioning	N/A	N/A	N/A	N/A	**N/A**
Predicting	3	3	2	N/A	**8**
Experimenting	1	N/A	N/A	1	**2**
Documenting Observations & Recording Data	N/A	N/A	1	N/A	**1**
Analyzing & Interpreting Data	3	N/A	1	N/A	**4**
Total	**9**	**6**	**7**	**4**	**24**

Math Assessment. Because existing early math assessments focus on a comprehensive set of math skills and are not able to generate sub scores for specific math skills emphasized in this program, our team developed a set of math assessment items (19) targeting the math concepts addressed in the curriculum: measurement (standard and nonstandard), visual and spatial thinking, and comparison of quantities (more/less). Assessment items were designed to address these concepts but not to align to specific learning activities in the program. The majority of items developed included visuals (e.g., graphics or photos) or manipulatives. Items asked children to select a response from three choices either by physically indicating (e.g., pointing to) their response or responding verbally. A few measurement items included follow-up prompts such as, "*How do you know?*" or "*How tall is it?*" (after asking children to choose correct placement of measuring tools). The distribution of individual and multiple part items across the three math concepts is shown in the table below.

Table 3. Distribution of Math Assessment Items

	Individual items	Two-part items
Measurement	4	6
Connect the number of equal units in standard measurement tool to length	2	4
Correctly align tools to measure	1	2
Use nonstandard units to represent and compare length	1	N/A
Visual and Spatial Thinking	7	0
Between/in front/behind	3	N/A
Closer/farther	2	N/A
Under/over	2	N/A
Comparison of Quantity	2	0
More/less	2	N/A

As with the science assessment, assessors administered the assessments one-on-one with each child and recorded the child's response on a scoring sheet. Math assessments were conducted in person in all but two classrooms where it was not administered, given scheduling delays due to COVID-19. After administration, assessors reviewed the scoring sheet and entered the data online into a secure Qualtrics form. Of the 93 children who completed the math assessment prior to the study, 82 (88%) also completed the assessment at the end of the study.

A subgroup of researchers with math expertise met to discuss coding the open-ended follow up questions mentioned above and developed a coding rubric. Using the coding rubric, one researcher coded the open-ended responses, flagging any responses to discuss as a group in order to reach a consensus. To examine item performance for the dichotomous and coded items, descriptive analyses and item-test correlations were conducted using post-assessment scores. Results showed three items with item-test correlations below .20, warranting further examination. Of these three items, two focused on measurement while the other addressed visual and spatial thinking. Item 5M.a1, a measurement item, intended to have children correctly indicate which rope was aligned correctly to measure the toy rocket. Upon reviewing this item, the placement of the rope in each of the answer choices may have not been distinct enough for children to observe a notable difference. Another measurement item, 6M.a1, showed an image of a toy bear next to a standard measurement tool. The item prompted children to use a ruler to measure the height of the bear and select the numeral that represented the height out of three possible options (5, 0, 4). The visual spatial item, 9VST.a1, depicted three different images of a bird in relation to a box and prompted the child to select the image showing the bird under the box. The images did not have a noticeable floor (reference point), and the bird was holding the box up (rather than hiding under it) which may have been confusing to children. After removing these three items, we examined the internal consistency of the retained set of items. The Cronbach's alpha coefficient, α=.65, indicates the set of items has an acceptable reliability. A total score was calculated for this set of items and included in analyses to examine improvements in learning.

Classroom Observations. The in-person classroom observation protocol included an activity running record to complete at the time of the observation. It also included post-observation coding sections around children's overall engagement and their engagement with the science practices and core ideas, math concepts, and/or engineering practices; the teacher's use of technology and digital apps; and activity modifications. To ensure the overlap of activities observed, the team scheduled most observations during a specific two- or three-week window within each unit. Across all eight intervention classrooms, a total of 63 science activities/lessons were observed throughout implementation. The number of observed activities/lessons for each unit varied by classroom. See Table 4 below for a distribution of activities/lessons observed by classroom and unit.

Table 4. Number of observations by Classroom and Unit

	Ramps	Shadows	Plants	Total
Classroom A	3	2	3	8
Classroom B	3	3	3	9
Classroom C	1	2	2	5
Classroom D	2	2	3	7
Classroom E	2	3	3	8
Classroom F	2	2	3	7
Classroom G	4	4	2	10
Classroom H	1	4	4	9
Total	**18 activities/ lessons observed**	**22 activities/ lessons observed**	**23 activities/ lessons observed**	**63 activities/ lessons observed**

Activity formats observed included circle group activities, small group activities, and learning centers. See Table 5 below for a distribution of activities/lessons observed by unit.

Table 5. Number of observations by Classroom Context and Unit

	Ramps	Shadows	Plants	Total
Circle Time	6	7	5	18
Small Group	6	4	8	18
Learning Center	6	10	10	26
Wrap up	0	1	0	1
Total	**18 activities/ lessons observed**	**22 activities/ lessons observed**	**23 activities/ lessons observed**	**63 activities/ lessons observed**

Teacher Interviews. Interviews focused on teachers' experiences implementing the unit and perceptions of the extent to which activities and digital apps promote children's science learning as well as make the link between science and math and science and engineering. The final interview gathered additional feedback about the program resources overall. A total of 24 interviews (one interview at the end of each unit) were completed with one teacher from each intervention classroom. One teacher completed the first unit interview prior to leaving; as a result, another teacher from the classroom completed the remaining two interviews.

Family Debrief Sessions with Photo and Video Artifacts. As part of the debrief sessions, researchers interviewed parents/caregivers to learn more about the experiences with each unit, including the extent to which they used the Family Guide and their successes and challenges with implementing the embedded activities and digital apps as well as their insights on their children's learning and engagement. The initial debrief session invited families to share about their background including the types of activities they like to do together. A total of 61 family debrief sessions were conducted during implementation. Of the 28 families consented, 22 families participated in at least one debrief session. While most families (18 of 22, 82%) participated in three debrief sessions (one per unit), three families participated in two sessions, and one family participated in only one session. During the study, families were invited to submit photo and video artifacts from their implementation to an individually assigned secure folder. Overall, 19 families successfully uploaded at least one photo/video artifact.

Findings: Assessments of Child Learning

To examine to **what extent the program supports children's science learning and how their learning compares with that of children in comparison (business as usual) classrooms**, we conducted two types of linear regressions models: one using score gains and controlling for age and another using the total post scores as the dependent variable and both the total pre-score and age as covariates.

Results from the **analyses of science data show a significant difference, with children in the intervention classrooms making significantly more improvement in science learning relative to children in the comparison (business as usual) classrooms** ($\beta = 1.33$, $p = < .01$ for the Score Gain model and $\beta = 1.16$, $p = < .05$ for the post-test model). Results from the analyses of math data show no significant difference overall. Although no statistically significant difference was evident using total scores, a few items (measuring visual spatial vocabulary and nonstandard measurement, which are less often promoted in preschool relative to counting) showed significant improvement for children in the treatment condition, relative to children in the comparison condition.

To examine **how consequential the home and school connection component of the program was for children's science learning**, we conducted additional linear regressions comparing the subsample of children in the intervention classrooms that had been randomly assigned to implement the home component of the program with a stratified random sample of children who had not been selected to implement the home component and had therefore only received the classroom portion of the program.

Results from the **analyses of science data show a significant difference, with children in the classroom + home condition making significantly more improvement in science learning relative to children in the classroom only condition** ($\beta = 1.50$, $p = < .05$ for the Score Gain model and $\beta = 1.93$, $p = < .004$ for the post-test model). Results from the analyses of math data show no significant difference overall.

Findings: Classroom Implementation

Overall Experience and Program Implementation

Overall teachers reported appreciating the program's resources and finding it easy to implement in their classroom. Interview data indicated that teachers found the program orientation meetings to be helpful and enjoyed meeting with other teachers to learn together and hear others' questions and suggestions. Teachers appreciated the introduction to the science practices and core ideas for each unit, as well as the walkthrough of digital apps. Teachers also reported feeling prepared to implement the program after participating in the orientation meetings but also shared a strong preference for in-person meetings (which had not always been possible given restrictions).

In addition, teachers described both the hands-on and digital resources as engaging. Teachers reported the hands-on activities were generally easy to implement given they fit the ecology of their classroom and involved materials and formats common in early childhood. Teachers tended to provide different contexts for children to engage with the digital resources. Some teachers introduced apps during small group activities or during circle time. Other times, teachers gave access to iPads during learning center or choice time and children played independently, or teachers sat with children to provide guidance and scaffolding as needed. On some occasions, children played collaboratively in pairs and provided support to one another.

Teacher’s Guide

Overall, teachers found the digital Teacher’s Guide to be well organized and include everything they needed to know about the program. Teachers shared that they tended to use the Teacher’s Guide in various ways to support different contexts. Regarding location, some teachers reported using it at school while others reported using it at home. In terms of timing, some teachers shared that they mostly referred to the guide before trying an activity to keep certain details fresh in their mind. Some teachers, however, said that they mostly used the guide during a lesson, such as circle time, to refer to the guiding questions in the moment.

Teachers also shared feedback on some of the specific features within the guide. Teachers shared that they liked to review the Unit Preparation section in advance of implementation and the Unit Overview section to see the progression of lessons over the four weeks of each unit. Teachers appreciated the series of pictures that were included with the activities and found that the lessons’ structure was helpful when integrating them into their existing practices. Teachers also found the activity descriptions/directions to be easy to follow and liked the step-by-step approach.

Teachers also provided feedback on the quantity of activities presented in the Teacher’s Guide. Some teachers appreciated that there were many activities. While a few teachers expressed wanting more, especially activities that integrate science and engineering, others noted that there are many activities included in each unit and it sometimes felt like “too much.” To address this, teachers suggested noting which activities are “anchor activities” for each unit.

Finally, teachers also described how they modified existing activities. As they were encouraged to do, most teachers made program activity modifications based on a variety of factors, including classroom setup and logistics, time factors and restrictions, existing classroom curricula, materials, and child interest. For all three units, some teachers made deliberate choices about which activities to implement or made modifications to activities.

Science Instruction Across Units

Most (76%) of the activities/lessons observed addressed ***science practices***. More specifically …

- 38% addressed one science practice
- 17% addressed two science practices
- 11% addressed three science practices
- 10% addressed five or more science practices

The practice cluster most often addressed across units was Observing and Describing, with 40% of the activities/lessons observed promoting engagement in this practice. Comparing/Contrasting (9%), Sorting (8%), Predicting (9%), Experimenting (13%) and Documenting (14%) were all infrequently promoted. Analyzing data (5%) and Questioning (3%) were rarely promoted.

While Observing/Describing was similarly promoted across units, other practice clusters varied by unit. Comparing/Contrasting, Sorting, Documenting and Analyzing was more often promoted in the Plants Unit. Questioning, Predicting and Experimenting, on other hand, was more often promoted in the Shadows Unit.

Most (80%) of the activities/lessons observed addressed ***science core ideas***. More specifically …

- 32% addressed two science core ideas
- 27% addressed one science core idea
- 21% addressed three science core ideas
- 2% addressed four science core ideas

Ramps Unit

Overall Learning. Almost all of the core ideas for the Ramps Unit were evident across the observed activities. The extent to which these core ideas were promoted varied and mostly aligned with the distribution in the learning blueprint. A majority of the observed ramps activities/lessons (88%) promoted at least one core idea. The core idea observed most frequently (20%) was *steeper ramps tend to make objects move faster*. This was not surprising given many of the activities involved children exploring how objects traveled down ramps and noticing which objects moved farther and faster. Other core ideas observed promoted understanding that *a force is a push or pull, a greater force will make an object move faster/farther, friction slows things down, and a stopper can slow down, stop movement, or change direction of an object.*

Teacher: And what is this one for? (showed a slide)

Child: Slide!!!!!

Teacher: And which slide would make you go faster?

Child: This one!

Teacher Why?

Child: Because it's higher!

Teacher: Yes, it's steeper. Which one is gentle?

Child: That one.

Hands-On Activities. Overall, teachers reported that the children in their classroom really enjoyed the hands-on activities in the Ramps Unit. Multiple teachers stated children "loved" the activities and that they felt the activities were easy to implement. Multiple teachers also noted that they appreciated that the ramp investigations become more complex over time, noting this allowed all children to engage and deepen their understanding progressively. A couple of teachers noted that they had done ramp activities before but not this deeply. A few teachers also noted that some concepts, such as gravity, were initially challenging for children but that they were able to build an understanding over time, as they engaged in the various investigations. For example, teachers facilitated discussions about the types of force children were learning about.

[Teacher directs focus to a piece of chart paper with three kinds of forces listed—similar to on core idea slides.]

Teacher: We learned the three kinds of forces; what are they?

Child: Pull.

Child: Fall.

Teacher: What helps things to fall?

Child: Gravity!

Teacher: What about the box? How is the box being moved? What kind of force are we applying to the box?

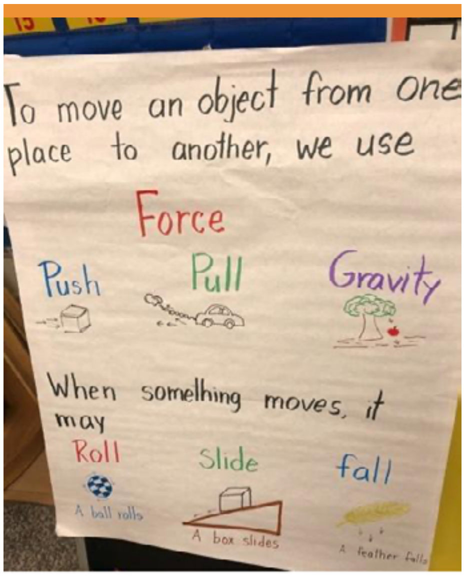
Teacher: Pushing, pulling, gravity. Who can remind me? When things are moving, how are they moving?

Child: Roll! Slide! (while making rolling motion with their hands).

Teachers also expressed liking the various materials (e.g., cardboard, foil, etc.) and activity ideas. While they had no concerns about materials or activity ideas, a few teachers did express wanting more time to implement the activities and struggling with space needed in the classroom. Below we share some of the modifications shared by teachers. Modifications include extensions, additional activities, and changes to formats.

For the **Ramps Unit**, modifications made included the following:

- One teacher noted adding videos to introduce some concepts; for example to introduce the concept of bowling to her children before the bowling activity.
- One teacher noted adding the creation charts about some of the main concepts and vocabulary words (ie. push, pull, big force, little force). She shared, "*This gave them very good ideas to start with—the vocabulary words stayed with them. They use these words. They now use the terms of why something goes slowly*."
- One teacher who really enjoyed the book reading component of the program decided to incorporate additional books because she felt like there were not enough.
- Although not required, several teachers created science areas in the classroom. For example, one teacher created a Ramp Center in her classroom where children could explore the unit's materials and variables in an ongoing and open-ended way.



Classroom chart about Force and Motion.

- A couple of teachers noted making modifications due to time and classroom space constraints. Some felt that some of the activities were long, particularly the engineering ones, and this required adaptation—for example, starting an activity discussion in circle time (as designed), but then extending it to small group time. One teacher stated, "*I think the biggest challenge was time. I feel like the ramp unit is time-intensive; building of the ramps takes time. And then experimenting with the ramps take time. And then sometimes, space got a little tricky. I mean, we're lucky in our classroom because we have that dedicated block area. But some days, I think it took us a little bit to figure this out.*"

Digital Tools. Almost all teachers reported children in their classroom having an opportunity to play with the Ramps digital tools. In one classroom where children did not have a chance to try the apps, the teacher expressed feeling short on time and not being able to fit them into the schedule. Teachers generally reported that children liked the Coconut Canyon app, which was one of the apps developed in this round. While the app posed some degree of challenge for children, it also provided opportunities for learning. For instance, one teacher shared how children were able to communicate their understanding of how the different textures affected the coconut's movement. In another classroom where children tended to find the app difficult, particularly understanding the game mechanics of being able to change the textures in the pathway, children were still able to learn vocabulary. Another reported challenge for some children

"They really like Coconut Canyon. And I really think that it helped that Coconut Canyon helped reinforce the texture. I would hear them say to each other, it was crazy, like, you know, well if you put it on mud, it'll go slow, but not as slowly as grass. But if you want it go fast, you put it on the metal. And this was really awesome because a lot of it was independent because there are a lot of things going on."

occurred in later levels where more than one pathway was shown because children tended to focus only on the top pathway. In turn, this required some teacher scaffolding. However, with continued play, children got better at making predictions.

Shadows Unit

Overall Learning. Most of the core ideas for the Shadows Unit were evident across the observed activities. As in the Ramps Unit, the extent to which these core ideas were promoted varied and mostly aligned with the distribution in the learning blueprint. A majority of the observed shadow activities/lessons (86%) promoted at least one core idea. One core idea (*what is a shadow/how are shadows made*) was observed most frequently (68%). Core ideas exploring how *shadow sizes changed when the light source or the blocker were moved closer/farther* were also observed, though less frequently. The emphasis on the first core idea was strong in the curriculum given prior evidence suggesting that young children needed scaffolding to understand how shadows were made and that highlighting the positioning of objects (the object in between the light source and the surface blocking the light to create a shadow and the shadow being cast in the opposite side of the light source) helped children understand how shadows were made and be able to explore other core ideas such as latter ones about movement.

> *Teacher: who can help me remember what I need to create a shadow?*
>
> *Child 1: you need light*
>
> *Teacher: what else?*
>
> *Children all shouting out "an object"*
>
> *Child 2: it will block the light*
>
> *Teacher: what is the third thing?*
>
> *Teacher: We have all these what are we missing? pointing to the pictures*
>
> *Child 3: Surface!*

Hands-On Activities. Overall, teachers reported that the children in their classroom really enjoyed the hands-on activities in the Shadows Unit. In fact, a couple of teachers stated this was their and the children's favorite unit. These teachers expressed excitement about the content being new to them and the children in their classrooms; they noted they had not seen shadows included in their curricula nor had they thought of introducing it prior. Some teachers also noted that the children really enjoyed learning about shadows because it was something they were naturally interested in and also something they could explore across many contexts (e.g., in the classroom, at recess, at home, during neighborhood walks). For example, during classroom activities children used different objects to create shadows, and often teachers encouraged them to notice what components are needed to make a shadow. During one activity children explored turning the flashlight on and off and the teacher guided children to observe as their shadows appeared and disappeared, "Uh oh, what happened? Where is your shadow? What do you need to make your shadow?" Children continued to have fun switching the flashlight on and off, noticing what happened and were then excited to ask their classmates and teacher, "Oh, where is my shadow?"

While most teachers expressed liking the various materials (e.g., various lamps and objects to make shadows) and activity ideas (e.g., shadow dance and shadow theater), others expressed finding it harder to integrate these activities into their classrooms because they necessitated specific conditions. For instance, a couple of teachers said that small group activities were harder to implement because it was hard to darken the room for a small group while having enough light for other children to engage in other activities. Below we share some of the modifications shared by teachers.

For the **Shadows Unit**, modifications made included these:

- A few teachers needed to make activity modifications related to challenges finding and/or making dark enough areas in their classrooms to support shadow creation and exploration. This was especially difficult during small group activities when other areas of the classroom needed to be lit for other free play/learning centers, but the small group table needed to be dark. Classrooms that have multiple lights and light switches were able to manage this, but others had more difficulty. This was challenging for other teachers and led to them converting some of the small group activities to whole group activities in order to address this problem.
- Teachers made modifications to the timeframe of the activities. For example, one felt like the Shadow Theater activity was too long, so she shortened the steps a little in order to better fit in multiple small groups and still have time for free play.
- There were two teachers who frequently chose to extend explorations in their classrooms. They made modifications that allowed children to take "*more time to practice and review foundational concepts, like how a shadow is made*."
- In addition to the shadow puppet templates provided, one teacher also used stencils that she had to show how the cut-out part is letting the light through and is the form that you see projected. She got this modification idea from the Shadow Play app—for example, the duck cut-out in the app—and so she thought it would be a good thing for which to use real stencils. She found this to be an activity improvement that allowed her children to understand better.

Digital Tools. Children had the opportunity to play the suite of Shadows digital tools. Teachers generally had positive feedback about these apps and were able to explain certain features of apps they liked best. Teachers noted and appreciated the math connections evident in Shadow Cave. Related to math learning, one teacher shared that her class learned about the parallelogram through this app (shapes), and children had opportunities to practice vocabulary such as closer and farther (visual/spatial language). One teacher mentioned that the initial levels were easy for some children, while a few other teachers reported that some children struggled to fit the shape to the outline of the shadow and needed support for this. In addition, children liked the open-ended levels where they could build their own objects and enjoyed being able to draw on their shadows to make creations. Similarly, Puppy Park was engaging for many children and provided opportunities for problem solving/engineering. They were able to try different solutions to create shade for all of the dogs and were persistent when they did not get it at first. Some children experienced difficulty when stacking/building the structures to make shade that would reach all of the dogs. One teacher reported that she liked the scaffolding the app provided for children, and she found herself using the same language such as, "good problem solving." In one classroom, as the teacher was supporting a child to attend to the different sizes of shadows, she asked, "What do you notice about the shadow of the short bush and the shadow of the long bush?" And once the child made a choice, she confirmed, "Nice work! I see that the shadow you chose can cover both dogs."

Plants Unit

Overall Learning. In comparison to the Ramps and Shadows units, a slightly smaller percentage of the observed activities/lessons (70%) promoted at least one core idea. This may be due to researchers observing a variety of teacher-created activities that in many cases seemed inspired by or modeled after NGPS activities, however did not seem to directly align with any particular one. Three plant core ideas were evident and promoted often during the observed Plants Unit activities. These included identifying *plants' parts and their functions and understanding that plants grow over time and what they need to live and grow*.

Teacher: Last time we measured our plant do you remember how tall it was?

Child: It was small.

Before the weekend (checked the journal to see where it was) it was this tall, all counting together 13 units long.

Teacher: Let's measure it now. Where should I put this to start measuring?

Teacher: Did it grow?

Child: Yes.

Teacher: When will it get to be that tall? (Height of the line?) What's your prediction?

Child: 10 days!

Teacher: What do we need for it to grow?

Child: Water and sun! (Teacher high-fived student).

Teacher: Can you get the water sprayer?

Teacher: What do plants need to drink?

Hands-On Activities. Overall, teachers reported that the children in their classroom really enjoyed the hands-on activities in the Plants Unit. Multiple teachers stated that children were naturally interested in plants and that the unit's activities connected nicely with parts of their curriculum. Most teachers shared their curriculum addressed this topic but that the activities in the program allowed them to focus on it more deeply. For example, across many activities children observed the growing plants in their classroom and engaged in discussion about what plants need to live and grow.

Additionally, one teacher noted that the activities also involved a lot of art, which she considered a plus. One main difficulty that seemed to occur across classrooms was related to unforeseen challenges regarding plant's growth (some took longer than expected or did not grow as expected). This led to some modifications (see below). Other modifications mostly included extending activities when aspects were particularly engaging or successful.

For the **Plants Unit**, modifications made included the following:

- When seed growth did not go according to plan, a couple of teachers needed to adapt plans so that their children would have plants to observe and measure over the course of the unit. For example, one teacher ended up planting grass seeds when her bean seeds did not grow quickly enough. Relatedly, another teacher decided to plant lima beans instead of the beans provided by the study team since she knew that they typically grow very fast.

- One teacher restructured her weeks because of delayed plant growth and the timing of her implementation of another unit of study curriculum. She implemented week 1 twice before moving onto week 2's activities; the class then moved onto week 4, and the class finished off the unit with week 3's activities. This allowed them more time to explore where plants grow before moving onto the discussion about Plants We Eat, which complemented a better transition to their next unit with their Department of Education's curriculum. The teacher appreciated that the program's ideas "*build off of each other but they're not so set in stone that like if you're working on something else in the classroom, you can kind of like be flexible*."

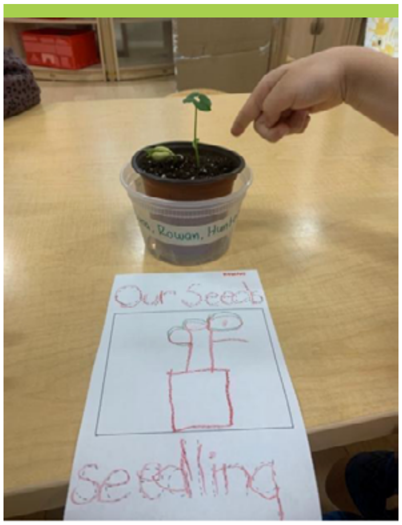
- One teacher expanded the Our Garden Mural activity into a larger art activity by having children paint their own plants and creating it into a bulletin board display for their hallway. She had the children gain visual inspiration from a study book, *Plants Feed Me*, and shared, "*I love the collaborative aspect of a mural, and I feel like we don't do that enough. So that was really fun for them to see like how it kind of built upon each other's little pieces.*"

Plant mural.

- One teacher shared how since the plant measurement aspect of the program was such an enjoyable success in her classroom, she decided to repeat this activity a variety of times, both in small groups and as a whole group. She would frequently gather the children on the rug and compare in a more informal way. It created a kind of "race between the plants" since some grew a lot and others remained short.

- Another extended the Plants Unit by having children create their own "seed book." They would create an entry for "seeds" by writing the word at the bottom of the page and then drawing a picture of it. Then they would do the same for when it became a sprout, a seedling, etc. As described by the teacher, "*And it was nice because then they had a little booklet of everything…it also helped their writing a little bit because it was something that they were excited to do and they had their little magnifying glasses*."

Seeds sprouting in a baggie.



Bean plant seedling.

Digital Tools. Similar to other units, children had opportunities to play the Plants digital tools in a variety of contexts. Some played in pairs or independently during center time. In another case, the teacher introduced the app during circle time and called a few children up to play. While teachers shared features that they liked about each of the Plants apps, many teachers pointed out how two apps, specifically Farmers Market and Berry Garden, were particularly engaging for children and provided opportunities to learn math and engineering. This finding is significant because these two apps were developed to meaningfully integrate science and math and science and engineering, respectively. For instance, teachers noted that Farmers Market was great for measuring with many children understanding how to line up the measuring strip. However, some children were challenged by other math skills, such as one-to-one correspondence, and needed teacher support. For example, they could align the measuring strip to the total, but when counting how many units, they sometimes lost track. Some children also had a hard time differentiating which llama (playing role of customers in the app) wanted which plant (e.g., a carrot that is five units tall) and identifying the plant with the same number of units. Berry Garden was a favorite among children. Despite this app being challenging for children, the level of challenge was appropriate as it still sustained children's attention and they continued to keep playing. Moreover, teachers expressed how the app successfully promoted engineering skills. In order to solve the problem, children had to think about how to best use the given materials to protect the strawberries. In addition, sometimes children played collaboratively and provided support to one another as they tested and revised solutions. Over time, children got better and could more efficiently determine solutions to protect the strawberry plants.

> **"I feel like Berry Garden probably had the biggest learning curve for them, and that's probably why they didn't tire of it. Because it took them a bit to recognize that. They had to use their materials wisely, like if you built too far away from your plant, then you wouldn't have enough fence to cover. So I think there was a lot of trial and error in that one which was probably more engaging for them I think."**

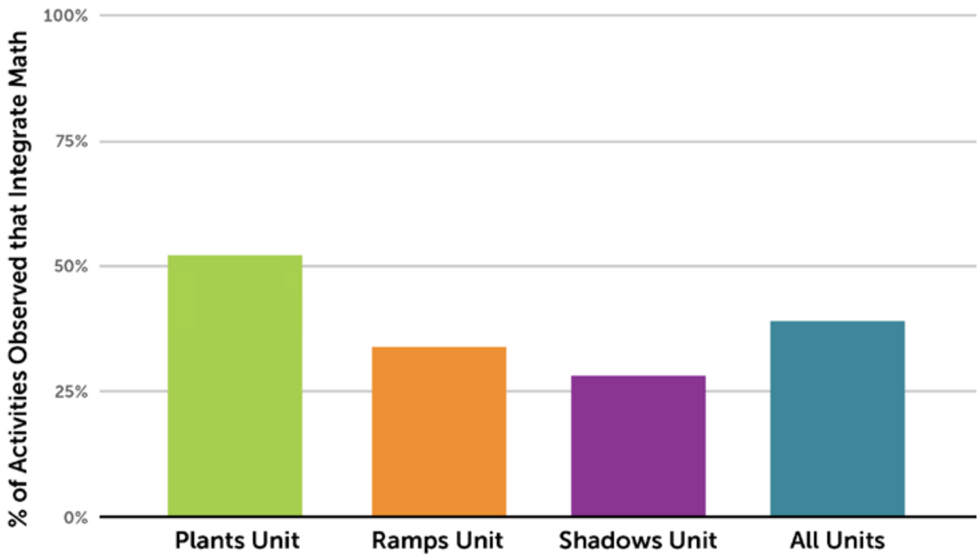
One teacher created additional introductory activities for the Berry Garden app; she gathered the children on the rug with a printout of the apps' rabbit and some strawberries. Then she put blocks around them and acted out a potential scene from the app. This made the children very excited to then participate on the iPad. One teacher incorporated a data tracking component to the unit different from the one suggested by the Plant Journal. They wrote the dates along the x-axis with the stages of plant growth along the y-axis. The teacher described "*data*" as "*information that you collect*" to make observations. She said, "We're collecting information on our plants and how they're growing." Children named their plants, each plant was given a specific color, and then they would measure it and document their results along a graph by marking it with a star.

Plant data graph.

Connections between Science and Mathematics

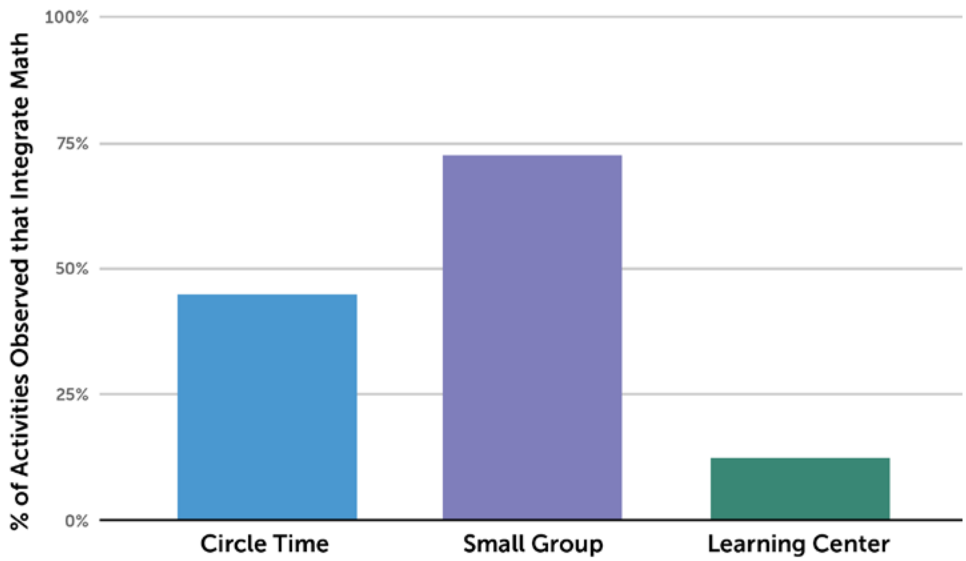
Of the 63 science activities observed in the study, 24 (38%) integrated mathematics. More than half of the Plants unit activities observed (52%) integrated mathematics, while roughly a third of the Ramps (33%) and Shadows (27%) units activities observed integrated mathematics. See Figure 1. The distribution across units was in part aligned with decisions made during the co-design process; a higher number of the science activities co-designed for the Plants unit (64%) involved mathematics, relative to the Ramps (11%) and Shadows (52%) units.

Figure 1. Percent of Science Activities Observed that Integrate Math Across Units



Notably, almost two thirds (72%) of the Small Group science activities observed included links to mathematics, whereas 44% of the Circle Time science activities observed and only 12% of the Learning Center science activities observed included links to mathematics. See Figure 2. This finding warrants further investigation given that slightly more of the co-designed Circle Time activities (47%) included links to mathematics, relative to Small Group activities (34%) and Learning Center activities (19%). One possible explanation for this discrepancy may be that teachers felt more comfortable integrating and scaffolding the mathematics concepts in conjunction with the science learning goals during Small Group activities because they are likely to support children individually more easily.

Figure 2. Percent of Science Activities Observed that Integrate Math by Activity Context



Rational Counting. Two mathematical concepts addressed in co-designed activities were counting and cardinality. Unlike other concepts, such as measurement and visual spatial skills (described in sections below) which were addressed in some but not all units, rational counting was integrated across all units. Counting and cardinality are not only concepts teachers often promote and may feel better equipped to integrate, they also require extended scaffolding. During observations, researchers noted that counting and cardinality were integrated easily and often briefly, during short interactions.

We also noted that counting and cardinality was observed most often in Plants unit activities (12 activities), relative to Ramps (nine activities), and Shadows (two activities) unit activities. This is likely related to the overlap between rational counting and measurement. Plant activities heavily integrated measurement, and as children measured, they often organically engaged in counting.

Comparison. Two other mathematical concepts addressed in the co-designed activities were comparison of size and comparison of quantities. Similar to rational counting, these concepts were

Teacher sets up a tray with a lot of seeds, a magnifying glass, and containers. She described the different ways to sort them: size, how they feel, and color.

Teacher: Sorting means we are making groups of them. You find one kind and you can put it here. If we find another one of the same kind we can put it where?

Child: Here and places with the other one.

Teacher: How about this one? Now where can we put them?

[Children start a new pile in a different section.]

Teacher: These are all beans.

[The children are excited to get more seeds. They don't say much, so the teacher prompts them to say things aloud. Children are just going at it sorting by types of beans]

Teacher asks them to count how many there are, and the child counts out loud.

addressed across all units, although less frequently. While integrated across all units, comparison was also observed most often in Plants (five activities) and Shadows (nine activities) unit activities, relative to Ramps (1 activity) unit activities. Plants and Shadows unit activities tended to integrate comparison of size rather than comparison of quantity. The focus of size comparison in Plants and Shadows unit activities was anticipated given plant investigations often involved children measuring plants and comparing measurements over time, and Shadows unit activities often prompted children to compare shadow sizes when objects or light sources were moved closer/farther away (see excerpt 5). While ramp activities also involved comparison, the focus was often on surface texture (a core science idea that does not involve mathematical comparison) and broadly comparing the steepness of two or more ramps.

Measurement. Measurement was almost exclusively observed during Plants unit observations. Typical interactions involved children comparing the size of their plant to either someone else's or to how tall it was since it was last measured. Many of them then used cubes to represent how tall their plant was (often first predicting how tall it would be). A few also involved using a measuring strip to measure the height of their plant, with a focus on proper alignment of the tool.

Visual Spatial. Spatial language was used to explore shadow core concepts. Specifically, during these shadow activities, children used spatial language to explore both the relationship between the position of a blocker and the size of the object's shadow and the position of the light source and the size of the object's shadow as it moved closer and farther from the light source.

[...children counted how many units tall their plant was and then compared with classmates. They were excited to compare and notice how tall their plants were growing. The teacher circulated to engage and provide support as needed.]

Teacher: "Wow! How tall is your plant?"

Teacher: "Great job counting—I like how you counted one by one."

[Once they counted how many units tall their plant was, children began to share with classmates and compare.]

Child 1: "Mine is nine units tall; how many is yours?"

*Child 2: "Mine is 11 units tall; it is the **tallest**."*

*[The teacher encouraged children to **compare their plant heights**]*

Teacher: "Wow! I like how you are comparing how tall your plants are. Which is taller—seven units or nine units?"

[A huge wall was covered with white paper, and a lamp was placed on a bookcase with enough space for children to dance in the middle of the wall and the lamp to create their own shadows. A music player was also there and was playing music. Two boys came over to dance, although only one stayed the whole time. They seemed very happy dancing and looking at their shadow.]

At some point the teacher came by and asked the questions below. The boys responded to all of these with actions and also continued dancing afterward.

Teacher: How can you make it bigger?

Teacher: Now smaller?

Teacher: How can you make one shadow? Hide behind each other!

Teacher: Now make a shadow that is silly.

Teacher: Do you want to grab something to make shade for the bear?

(Three animals are uncovered on the rug.)

Teacher: We need to build it. What are you going to build?

Child1: A house for the animals.

(Child 1 puts a block that's open in the middle.)

(Child 2 puts a block on wrong side, so it's not blocking the light.)

(They put blocks all around first on the wrong side, then move it to the side with the lamp.)

Teacher: What is something big that we can use to finish covering the tiger? I still see some light here.

(They create a structure all around the tiger, but there is still some light—it's not tall enough to completely cover it.)

Teacher: Can you grab a book for us to try and use? Can you get a book?

Teacher: Do you think that we made shadow on this side or this side if the sun is over here?

Child: This side. (Points to light side.)

(Child 1 props a book up against the block structure.)

Teacher: Is he hot or cool now?

Child 1: He's cool!

Teacher: I love that problem solving, friends.

Connections Between Science and Engineering

Of the 63 science activities observed in the study, 12 (19%) integrated engineering. Although we observed fewer Ramps unit activities, more (44.44%) of the Ramps activities observed integrated engineering compared to those activities observed in the Plants unit (8.70%) and Shadows unit (9.09%), respectively. This aligns with the learning blueprint in which the Ramps unit (6 of 53, 11.32%) included the highest percentage of engineering integrated activities followed by activities in the Plants unit (3 of 42, 7.14%) and Shadows unit (3 of 50, 6%).

Across the three units, engineering was most frequently present in Small Group activities/lessons observed (33.33%) followed by Circle Time (22.22%) and then Learning Center (7.69%). Two engineering practices associated with the Improve cluster (3.2 and 3.3) along with one practice in the Create cluster (3.1) were the most frequently tagged (16%).

Engineering practices 3.1 and 3.2 being observed more often aligned with the learning blueprint, given that a significant number of the designed activities have these practices embedded. Moreover, these two practices complement one another as 3.1 focuses on children designing solutions to a problem while 3.2 centers on testing a solution to determine if it solves a problem. The least frequent practice observed (4.2) is part of the Improve cluster (4%), which was not a focus of the designed activities as reflected in the learning blueprint.

Findings: Home Implementation

Overall Experience

During interviews with families, parents generally shared positive feedback about their experience trying out the activities with their children. They liked that the activities were simple, fun, and focused on learning together. They also noted that the activities connected to everyday things, so they are likely to continue doing some of the activities, such as looking for shadows while taking a walk or growing plants together.

Families appreciated that these activities created a platform for them to make *connections between home and school learning*. Parents also reported that sometimes these activities gave opportunities for siblings to engage together, which parents valued. For example, one family included their younger child in the activities, and this gave the older sibling the chance to teach their younger sibling.

"I like how it's not only at home, but it's also at school, so they're learning the same and get to practice more and do it for a longer time. Altogether it goes hand in hand. I can see how she's getting more knowledge that way".

Family Guide

Most parents referred to the guide and liked the ideas and suggestions for activities. They found the guide easy or useful when trying out activities. Many families followed the activities as described and completed most of the activities provided in the guide, while others got inspiration but then did activities that worked best for their family. This included unstructured activities during everyday routines such as impromptu looking for shadows on a walk or building structures to make ramps. Some parents found the guide somewhat hard to follow, so they preferred to make up her own activities that aligned with their child's interests. Other parents modified activities by using different materials than those suggested in the guide but were easy to find in their home and still worked with the activity.

Parents tended to access the guide on a tablet or their smartphones. Those who used a tablet indicated that they did not use their phone due to lack of memory, incoming notifications that would distract their child, and the tablet having a better battery life. Those who preferred their phone mentioned that it was easier for them since they always have their phone and it is more easily used by an adult. One parent did mention that they would access the guide through a computer so that they were able to print out the activities.

Most parents mentioned accessing the guide from their home, with one parent accessing it at work to plan and print out the activities. A few families engaged with the activities after school, with a couple incorporating the outdoor activities while they were heading home or incorporating them in their daily routines.

In regard to particular features of the guide, parents most frequently mentioned the structured activity steps as being the most helpful. Parents appreciated having the guidance on how to complete the activities but also the ability to adapt them to best suit their family. A couple of parents mentioned how the presentation of the science core ideas helped them understand the program's concepts and feel more comfortable supporting their child.

Experience Across Units

Ramps Unit

Overall Learning. During family interviews, many parents reported that their child was able to learn both from playing the apps and trying out the hands-on activities. Related to the apps, one commonly cited example was around children noticing different textures, smooth and bumpy in particular, and how that related to how far and fast an object traveled. For one parent/caregiver, the child "learned more with the everyday examples than the apps," yet the apps provided an opportunity that "helped to reinforce what [the child] was seeing," illustrating how these curricular components complement one another and support children's learning. In one family, the parent was unsure whether the child learned anything new, but playing with the app could reinforce what the child learned. A couple of families also expressed how their children learned and used new vocabulary. For example, one parent shared how their child recognized and communicated steep versus gentle ramps.

> **"He learned that things that are more circular roll better than things with flatter sides, like things that are rectangular. That's why he loves the bottle activity."**

In relation to the hands-on explorations, some parents shared what their children learned about in this unit or the ways in which their children expressed how they learned (e.g., saying or repeating things). In a few families, children noticed ramps more often, with some being able to extend it to a particular science core idea or make an everyday connection. For instance, one child related ramps and steepness to everyday things saying, "a ramp couldn't be too steep for a wheelchair to go down so the person doesn't fall off the ramp." Another family shared how the child pointed out surface textures on their walks to the park stating, "Here it goes faster because of the street, and here not too fast because of the grass." Some parents pointed out the link between learning at school and home with one sharing that the child will come home to tell the parent/caregiver about "speed and going farther and going faster and gravity."

Hands-On Activities. Parents indicated that children enjoyed trying out the Ramps activities and shared some details about which were interesting or challenging for their children and why. For example, parents reported that the Obstacle Course activity resonated with their children, and while it could be challenging, it also promoted a sense of accomplishment once set up.

> **"I think his favorite one was the obstacle course one. He struggled with it at first. It's in one of the videos; you can see it, but I taped a box to the table and was like, 'You have to get from here to here. You can't move the box. You have to use these. Go around it.' And so he just was trying different things and then eventually figured out like, oh, I can use tape and I can put this together. He really, really liked that one. It was a, you could tell, a proud [child name] moment of like, I got it. Like, I figured it out." Families also talked about children liking the Roll or Slide activity, which provided opportunities to observe how common objects moved along the pathway and notice the difference in movement. One parent shared that her child "ended up with three groups; some slid, some rolled, and some did both."**

Parents noted some challenges with the activities. For example, one family shared that the Family Guide was difficult to understand, so they explained, "We tried to do one activity with ramps, but we just made our own idea. We like to do things that are fun and learning at the same time, so we see what is around us." Families also mentioned that some activities were challenging to follow the directions, their children did not express an interest in the activity, or they were unfamiliar with the context such as Yoga Ramps.

Digital Tools. Overall, parents generally reported their children liking the digital resources in the Ramps unit. Some noted more general features of the app, such as the interactive nature, as well as the inclusive approach of having characters of color. One parent/caregiver shared that "apps are fun because they're learning in a fun way" since children can try things without getting frustrated even if they do not get it right. Parents shared that their children liked the different textured materials they could explore in the pathways in Coconut Canyon. One parent mentioned their child understanding the science concept of objects moving faster on a smoother pathway and slower on a rougher pathway. While another parent did not think their child completely understood the difference in how the object moves on the three different surface textures, they did note that the child was able to recognize the object traveling too far and needing to switch the material. Families shared how children engaged in testing different materials in Coconut Canyon, which promoted both science and engineering practices. One parent explicitly stated observing their child "brainstorming through the different texture" indicating that the child engaged in science and engineering practices to create a solution.

Ramps Unit Digital App	 Coconut Canyon
Successful Engagement and Learning	• Children liked the different textured materials and that they could modify and change the materials. • Children observed how the coconut moved along the different surfaces, and some children understood that the coconut tended to move faster on the smoother surface and slower on the rough surface.
Challenges and Suggestions	• Some children found the game repetitive as they moved through all of the levels.
Sample Parent Reflections	"She liked the textures of the grass and the dirt, and she understood that if you wanted to make something go faster, you had to choose something smooth, and if you wanted it to go slower, you'd choose the dirt."

Shadows Unit

Overall Learning. Throughout the Shadows unit, parents shared different instances of opportunities for their child to explore science concepts related to shadows. Parents talked about their children being more aware of their shadows and *noticing shadows as they moved about their daily routines*. They noticed shadows when they are outside walking in the neighborhood and while playing with friends.

> **"We'd be like in the playground, and she'd make friends and tell them to look for their own shadows. It's like she follows her shadow all the time now when we go outside. She'll be like, 'Do you see it? Do you see it?'"**

Parents reported that children were excited to play with the flashlights in the evening to observe the shadows on the wall and *notice how the size of the shadow changes as they move closer to and farther from the object*. For example, one parent shared that her son likes to teach his younger sister, and he would explain to her, "If I move my hand closer, it's going to get bigger, but if I move my hand farther … and then he'd make shapes on the wall for her." Another family would similarly make shadows using the light on their phone, and the parent shared that when playing together with her son he said, "My shadow is bigger than me when I am closer to the lamp, and my shadow is the same as me when I am farther from the lamp."

Children began to *understand what components are needed to make a shadow*. One parent explained that she was discussing how the shadow is created with the sun and where the shadow will be given the location of the sun, and her child proudly told her that he already knows this! "He knows where the light needs to be to make the shadow."

> **"I was trying to explain to her something about the buildings in NYC and how the sun hits them, but things like that, she would start asking other questions about other things—more science and engineering-related questions. She was starting to realize things and make more sense about things."**

Children also had opportunities to *engage in science practices as they made observations of shadows* and how they are changing in their environment. One family appreciated that these science activities *encouraged their child to ask questions and be curious* about more and different things.

Hands-On Activities. Overall, parents reported enjoying the Shadows unit activities. When discussing the particular activities, a few parents indicated that the activities designed for outside were easier to do and at times felt more natural when looking for shadows, etc. For example, one family liked Silly Shadows Walk as they enjoyed this activity on their evening walk and included a game to catch each other's shadow. Another parent talked about enjoying time outdoors with I Spy Shadows and explained that her daughter tells her, "Mom, take a picture of me here because there is a shadow." One family noted that they liked Shadows Moves Dance, in particular. The participating child and his older brother liked dancing outside, so it was something that they could do with each other. The same parent shared, "Now he recognizes shadows when we're outside or inside. He calls them out and tells me about them and if they're big or small."

Families also discussed some challenges that arose when trying out activities. Some activities took more time for preparation, such as the Shadow Box Theater, and this impacted children's focus at times. Some families noted that it could be hard to make shadows inside depending on the time of day (e.g., too bright), and that this promoted them to do more outdoor activities. A few families shared that it could be challenging to make animals on the wall with their hands, as some children got frustrated when they did not have the dexterity to make the particular animal they wanted, or it did not "look like" the animal they were intending.

Digital Tools. Many parents reported that their children spent time playing with the digital resources and shared some examples of what they learned or enjoyed related to the Shadows apps. Parents shared that their children began noticing and talking about shadows in their environments more often (especially their own shadow) and how different objects can make shade, such as noticing the shadow of a puppy walking by, which is similar to the context in Puppy Park.

"Before, she did not pay much attention to the shadows made by the trees or the people walking or herself. She didn't pay much attention to her shadow. And now she pays more attention. If a puppy walks by, [she says] 'Mommy look at her shadow' or when she walks too."

Parents also noted that children began to understand that different light sources can make a shadow, such as the sun in Puppy Park and the flashlight in Shadow Cave. Parents liked how the apps have different levels and reported that this feature tended to keep children's attention. For example, in Puppy Park they noted that the increasing complexity of levels presented a productive challenge, while the open-ended levels in Shadow Cave gave opportunities for children to create their own shapes and drawings, as well as practice and learn about shapes. For example, one parent shared that her daughter "is now comparing different shapes; before she only knew about square, but now she's learning or paying attention to shapes." The apps also provided engaging contexts for children to learn and explore, as children liked the premise of Puppy Park where they create shade for puppies and make them comfortable and happy.

Shadows Unit Digital Apps	 **Shadow Cave**	 **Puppy Park**
Successful Engagement and Learning	• Children explored how the size of the shadow changed as they moved the object closer and farther from the flashlight. • Children practiced and learned about shapes.	• Children made connections between the app and real-world experiences such as noticing that the sun is a key component in making shadows and that an object has to block the sunlight to make a shadow. • Children learned that taller (or bigger) objects make a longer (or bigger) shadows and that combined objects make a different shadow. • The context of making shade for puppies resonated with children.
Challenges and Suggestions	• Sometimes children were not as interested in this app as compared Puppy Park. • Sometimes children got frustrated with mechanics—trying to align the shadow with the outline on the cave wall.	• Include an adaptive component to this app so that children can pick up where they left off and do not need to continue through all levels every time they play.
Sample Parent Reflections	"He also really likes this game. He can make the shapes and then see how to move the shadow. He knows that the shadow will become bigger when the object moves closer to the light and smaller when the object moves away from the light."	"[Child] learned quickly how to complete the different levels. He makes decisions about what objects to use—and got very good at knowing which object will make the right shadow to make shade for the dogs. He learned how to place objects together to make a bigger shadow."

Plants Unit

Overall Learning. During interviews with families, most parents talked about specific concepts they thought their child learned from trying out activities in the plants unit while some other parents noted more globally that they thought their child learned something. Some of the specific skills mentioned included measurement, what plants need to grow, harvesting plants, and the life cycle of a plant. Some parents attributed this learning to the hands-on activities and exploration fostered by the unit while others talked more about what they learned from playing with the digital resources. Some parents also mentioned their recognition of how children also learned about these concepts at school.

> **"I think he learned a lot about plants, with what we are doing here and at school. It was a support to what he was doing. He learned that not everything grows on trees. Like the carrot that grows in a "lawn." He thinks he's an expert in plants. He stops in the street and tells me, "Look, this is a flower," "Look, this plant died because it rained too much." Before we would walk by plants, and it wouldn't interest him."**

Hands-On Activities. Overall, parents had wonderful things to say about their experience implementing the Plants unit, and many could see ways in which they would continue using the activities to explore and learn about plant growth with their children. During interviews, parents shared different instances of activities that they tried together. For example, a few parents reported that How Many Plant Colors resonated with their children. They enjoyed the idea of selecting colorful fruit, either from their refrigerator, the grocery store, or a local farmer's market.

> **I think [Child] really liked the How Many Plant Colors one. For that one, we got some vegetables from the local farmer's market, and he was excited to look at them on the table and identify them—like what part of the plant is this and that. He liked to see the actual plants, and that part was exciting."**

Some parents talked about My Seed Book as an activity they liked to do together. Families spoke about how children really liked the practice of sorting and categorizing the seeds in different ways.

Even though there was not a hands-on activity that involved planting seeds and growing plants, many parents chose to do this with their children at home. All of these parents shared how this was an enjoyable learning experience for their child and family and did not seem to notice that it was not actually one of the guide's activities (despite the fact that their box of materials did include seed packets to be used for another activity). Some of them also mentioned how this was an activity done in their child's classroom.

Parents also discussed some challenges they experienced when trying out the activities. For instance, in Plant Part Game Cards, it took extra time and resources to set up in terms of creating the cards on heavy duty paper and cutting them out, etc. Other challenges included the use of particular materials, such as string to measure plants.

Digital Tools. Parents shared varied information on the use of the Plants unit apps during our conversations with them. Some mentioned their children using them a lot while others said their child found them to be too easy or preferred the hands-on activities. Parents shared some instances of how the apps supported playful engagement or science learning. For example, parents appreciated that the apps had different levels or scenarios that kept their child's attention, such as Berry Garden where subsequent levels present increasing engineering design challenges or Farmers Market where there are different fruits and vegetables to harvest, sort, and measure. Children found the premise of the apps to be entertaining, as they liked to protect the strawberries from the bunnies in Berry Garden, and they liked interacting with the animal characters (e.g., llamas) in Farmers Market. Children engaged in testing solutions using different materials (e.g., fences and nets) to protect the strawberries in Berry Garden and at times were persistent in revising their solution to solve the problem. Children also had opportunities to engage in math as they practiced measuring the fruits and vegetables in Farmers Market.

Plants Unit Digital Apps	 Berry Garden	 Farmers Market
Successful Engagement and Learning	• Children liked the productive challenge of protecting the strawberries from the hungry bunnies. • Children explored using different materials to create solutions to protect the strawberries. • The activity promoted interaction between children.	• Children liked the llamas and the animation; these features were entertaining. • Children had many opportunities to practice measurement skills.
Challenges and Suggestions	• Some levels were easy for some children, so there was a suggestion of adding more challenging levels.	• Some children found this app too easy, so they did not choose to play it as much.
Sample Parent Reflections	"[Child] liked the Berry Garden app the most. It was fun, and he could understand how to protect the bunnies. He could do all the levels. Some parts were easy for him."	"Farmers Market is the one she liked more. It has different fruits and vegetables, and she liked how she can measure the fruits. It has the 'units' too. It's like problem solving because it tells you. "I need the one that measures five units," so they have to think which one is five units."

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