THE POTENTIAL OF DATA COLLECTION AND ANALYSIS ACTIVITIES FOR PRESCHOOLERS: A FORMATIVE STUDY WITH TEACHERS

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ABSTRACT

To support preschool children's learning about data in an applied way that allows children to leverage their existing mathematical knowledge (i.e. counting, sorting, classifying, comparing) and apply it to answering authentic, developmentally appropriate research questions with data. To accomplish this ultimate goal, a design-based research approach [1] was used to develop and test a classroom-based preschool intervention that includes hands-on, play-based investigations with a digital app that supports and scaffolds the investigation process for teachers and children. This formative study was part of a co-design process with teachers to elicit feedback on the extent to which the series of investigations focused on data collection and analysis (DCA) and the teacher-facing app were (a) developmentally appropriate, (b) aligned with current preschool curricula and routines, (c) feasible to implement, and (d) included design elements and technology affordances teachers felt were useful and anticipated to promote learning. Researchers conducted in-depth interviews (n=10) and an online survey (n=19) with preschool teachers. Findings suggest that teaching preschoolers how to collect and analyze data in a hands-on, play-based, and developmentally appropriate way is feasible and desirable for preschool teachers. Specifically, teachers reported that the initial conceptualization of the investigations were developmentally appropriate, aligned with existing curricular activities and goals, was adaptable for the age and developmental readiness of young children, and that the affordances of the technology are likely to allow preschool children to engage meaningfully in data collection, visualization, and analysis. Findings also suggest that this approach to supporting preschool teachers and children to learn about and conduct DCA merits further study to ensure productive curricular implementation that positively influences preschoolers' learning. These findings were used to revise the investigations and app, which showed positive outcomes when used in classrooms [2], which add to the scant literature on DCA learning for pre-schoolers and provides insights into the best ways to integrate technology into the classroom.

KEYWORDS

Early childhood, Mathematics, Data, Teachers, Technology.

1. INTRODUCTION

This formative study is the first in a series intended to inform the development and testing of an intervention to promote preschoolers' engagement with and learning of mathematics and computational thinking (CT). This was the first of several iterative cycles within a design-based research [1] approach focused on developing and testing the hands-on and play-based curricular investigations and accompanying teacher-facing digital app. By teacher-facing, we emphasize that this is a tool intended for teachers to primarily control, as opposed to a game or simulation that children play independently. This innovative project aims to build critically needed knowledge about the extent to which preschool teachers think that data collection and analysis is

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developmentally appropriate and aligns with preschool curricula and routines. Also, the elements of hands-on, play-based activities and accompanying app will likely engage preschoolers in collecting and analyzing data, and ultimately supporting the learning of mathematics and computational thinking.

The intervention's curricular investigations are designed to engage preschoolers in the data collection and analysis (DCA) process to answer questions of interest. A key component of the intervention is a teacher-facing digital app to support the collaboration of preschool teachers and children in collecting data, creating simple graphs, and using the graphs to compare data, make pre-dictions, and answer questions. The curricular investigations offer an applied context for using mathematical knowledge (i.e., counting, sorting, classifying, comparing, contrasting) to engage with real-world problems and lay the foundation for developing math and computational thinking skills.

The intervention includes a series of nine hands-on and play-based problem-solving investigations. The use of a digital app by teachers with their students scaffolds the investigation process and sup-ports specific data collection and organization steps (i.e., collecting, recording, and visualizing data). To be clear, the use of the technology here is to make the process easier, not to in any way to automate the teaching process that should remain focused on developing children's conceptual understanding [3, 4]. As part of each investigation, teachers work with children to input their data into the app and use the resulting digital graphs to help children interpret and discuss the results and answer authentic research questions. The activities also include opportunities to represent data with pictures (pictograph), hands-on manipulatives (object graphs), and with children's bodies (body graphs).

This project includes three iterative cycles of development and testing of the intervention. This paper reports on the first cycle of development and testing in which researchers conducted a formative interview and survey study with preschool teachers to elicit feedback on: (1) the extent to which the data collection and analysis investigations and a teacher-facing digital app are developmentally appropriate and aligned with existing preschool curricula and routines; (2) the design elements of the investigations and teacher-facing digital app that teachers think will foster usability and learning; and (3) the affordances and challenges of using DCA investigations and a teacher-facing digital app to support learning.

2. LITERATURE REVIEW

There is a pressing need to invest in preschool STEM (science, technology, engineering, and mathematics) education, as research shows early childhood is a time when learners begin to develop positive attitudes toward science and mathematics [5] and form their STEM identity and professional interests [6]. Early exposure to high-quality inquiry-based STEM experiences also boosts children's motivation, persistence, and self-efficacy, which can spark and sustain children's interest in pursuing STEM opportunities later in life [7, 8, 9]. This is critical, as there is an urgent need for highly skilled workers in STEM fields that include a 21st century data-capable workforce [10]. This has led to a growing interest in computational thinking (CT) [11, 12] and spurred recent efforts to prepare students from the early grades through high school by developing curricula to foster CT in prekindergarten through grade 12 education. Although definitions for CT vary, it is generally understood to be a problem-solving process that requires the collection and use of data to answer authentic questions. A literature review of apps to support coding for pre-schoolers found that apps do positively support learning in this domain [13]. The common elements of CT for preschoolers are inquiry-based and include asking questions and then collecting, organizing, representing, and analyzing data with the goal of efficiently addressing authentic, real-world problems [14,15].

2.1. Data Collection and Analysis (DCA) For Preschoolers

It is fair to ask: *is data collection and analysis (DCA) a developmentally appropriate content area for preschool-aged children*? The results of this study help to answer this question, though prior research also supports the use of DCA content with preschool children [11 Clements 2008]. In fact, recent research suggests that the development of mathematical knowledge and early statistical reasoning begins at a younger age than is typically acknowledged [12 English 2013]. Educational interventions that are designed based on an understanding of young children's cognitive development can support children's engagement with complex mathematical concepts while they are still quite young [16, 17, 18, 19, 20, 21].

Very little research exists on how to teach data collection and analysis (DCA) during the preschool years, despite the fact that the mathematics education literature indicates that preschoolers can engage in simple, teacher-led investigations. In fact, DCA activities are not new to early childhood classrooms, as instances can be found of teachers and children engaging in DCA activities, such as measuring each child's height and then displaying the varying heights on a chart. Children are also often found sorting and counting objects and then displaying them so that they can easily see and "analyze" which set has more. But to do this well, teachers need to set up the activity and scaffold which variables to consider, which data to collect, and how to represent the data in such a way that children can use it to effectively answer questions and draw conclusions [19,22]. To guide the process, each investigation in the intervention follows a simple set of steps that include formulating the question, collecting data, analysing data, and interpreting results [23].

This study puts a renewed emphasis on DCA activities in preschool and investigates the promise of DCA as developmentally appropriate activities that can support preschoolers' mathematics and CT learning. Future studies will investigate how implementation aides in the learning process [2]. Table 1 shows descriptions of the proposed classroom investigations, which were shared with teachers during this study.

Table 1. Description of Proposed Investigations

Investigation	**Description of Investigation**
Data Shuffle	The goal of the Data Shuffle investigation is for children to use their bodies to make two object graphs. The first graph is an animal graph and the second is an animal movement graph.
Hungry Caterpillar	Using the Very Hungry Caterpillar story, children make object graphs using their bodies and pictographs to represent the fruit and food eaten by the caterpillar each day. Children then use the app to make additional graphical representations of the data.
Clothing Investigation	The goal of the Clothing Investigation is to use attributes (qualities) of clothing to sort children into groups that can then be represented graphically and discussed. Children then use the app to make additional visual representations of the data.
Centers Investigation	The goal of the Centers investigation is for children to recognize, count, and compare the colors, shapes, and materials at three center time stations. Children then use the app to make additional visual representations of the data.
Feelings Freeze	The goal of the Feelings Freeze investigation is for children to collect data to answer the question, "How are the members of our class feeling?" Children graph the data and compare the graphs over time to notice changes.
Measurement Investigation	The goal of the Measurement investigation is for children to collectively use their bodies – full bodies arms outstretched, full bodies narrow, and their shoes – to measure distance. Their measurements are entered into the app to create a pictograph or bar graph for analysis and discussion.

2.2. The Use of Technology with Preschool Children

Using data collection and analysis to solve problems involves a multi-step process that places a heavy cognitive load on young children. To effectively engage young children in the steps of data collection, data organization, and interpretation of data can be challenging, and requires thoughtful scaffolding. To be successful, children must collect and organize their data and then represent that data in a way that allows them to directly compare quantities across categories [24]. Prior research indicates that preschool teachers regularly use tablets for multiple purposes [25], but that teachers attitude toward and confidence with using technology affects its implementation and use [26]. Digital tools can support teachers to effectively scaffold this process by breaking it down into discrete steps and in recent years, preschool teachers have reported more positive attitudes toward using technology with young children [27]. Having the ability to quickly and easily create graphs also enables teachers to focus on viewing and discussing the data with children, rather than spending time drawing and representing the data by hand. Yet, it is critical to ensure that the developed technology meets the needs of teachers, a goal for this particular study.

Yet, research about how the features of digital representations help or hinder preschoolers' engagement in DCA activities is lacking. While there is evidence that preschoolers can understand graphs as representations of quantity, Clements and Sarama [28] note a lack of evidence as to what supports young children's data analysis competencies; though importantly, subsequent work has suggested that computers hold promise for helping young children learn DCA. Likewise, as [29] suggests, we focus on how to design learning experiences with technology. With this focus in mind, this study seeks to leverage teacher experience to design this intervention help teacher implement and engage pre-schoolers in DCA, ultimately, helping to inform the ongoing intervention development and inform the literature base about how to foster DCA skills with technology.

3. METHODS

This study was the first in this project's overall design-based research approach [1]. Building off the design-based research approach [1], our work used an evidence-based curricular design framework [30] to guide the process of intervention development. By including multiple perspectives in the iterative design process, we hope to increase the usefulness and quality of the resulting intervention. Prior to this study, the research team created a "learning blueprint" that articulated the targeted learning goals based on prior descriptions of the learning trajectory for young children [28]. The learning blueprint serves as a "anchor" that is tied directly to each learning activity and assessment task children experience.

The primary goals of the study were to (1) investigate teachers' perception of data collection analysis as developmentally appropriate and aligned with preschool curricula and routines; (2) identify the design elements of learning activities and teacher-facing digital app that foster usability and support the teaching and learning of DCA; and (3) elicit teacher perceptions of the affordances and challenges to using the investigations and teacher-facing digital app to support children's learning, including the educators' perception of the comprehensibility of the DCA activities and their willingness to implement the DCA activities. This survey and interview study followed an initial phase of development that produced the prototype versions of both the curricular investigation activities and the digital app. Our team then leveraged this information to inform curricular revisions prior to two classroom-based implementation studies [e.g. 2].

3.1. Research Questions

This study focused on the following research questions:

1. *Developmental Appropriateness and Curricular Alignment*: To what extent do preschool teachers perceive the use of data collection and analysis as developmentally appropriate and aligned to preschool curricula and routines?
2. *Design Elements to Foster Use and Learning*: What design elements of the learning activities and digital tool (such as collaborative data collection and visual data display) do teachers think will increase (a) usability and (b) preschoolers' ability to understand how to use data to answer questions?
3. *Affordances and Challenges*: What do teachers view as the potential affordances and challenges to successful engagement in data collection and analysis?

3.2. Participants

Teachers were recruited from Head Start and state-funded prekindergarten programs in Massachusetts, Rhode Island, and New York. Participants included 29 teachers who work with children ages 4 and 5 (n=10 participated in an interview with a researcher; n=19 completed an online survey). Participating teachers completed either the interview or the survey, but not both, to provide feedback on the hands-on curricular investigations and digital app. Teachers were recruited in the Spring of 2020 at the beginning of the global pandemic so recruitment, survey administration, and interviews were conducted digitally or virtually. Demographic data about participating teachers was not collected.

3.3. Instruments

Teacher Interview (n=10*)*. During a 45-60-minute interview conducted via remote meeting software (e.g. Zoom, Ring Central), researchers showed participants a series of PowerPoint slides and short videos that demonstrated the hands-on, play-based lessons and teacher-facing digital app prototype for each curricular investigation. Participants then responded to questions about the appeal of using the investigations, anticipated challenges, ease of implementation, developmental appropriateness, and curricular alignment.

Teacher Survey (n=19*)*. Teachers completed the online survey independently. Teachers viewed the same videos that were included in the teacher interview, as well as written summaries focused on the preparation and materials needed for each investigation. For each investigation, teachers then answered a combination of multiple choice and open-ended questions about the appeal of the investigation, anticipated challenges, ease of implementation, developmental appropriateness, and the extent to which they perceived the investigation as meetings its learning goals. Because of time limitations, each teacher viewed four of the six investigations during their interview, with the investigations counter-balanced across participants.

3.4. Analysis

This mixed methods analysis included qualitative summarization of interview responses nad open-ended survey responses, in addition to descriptive quantitative findings from survey ratings. Audio recordings of teachers' interview responses were transcribed and then analyzed such that teachers' closed-ended responses were descriptively summarized and their open-ended (transcribed) responses were qualitatively analyzed. Researchers qualitatively coded and examined the responses to each open-ended item, looking for patterns that emerged, and summarized participants' responses. To examine the intersection of qualitative and quantitative data, we used a mixed method analysis involving the creation of a "joint matrix" [31] to highlight patterns of implementation and suggest modifications [30]. These findings provided feedback about the investigations' usability and comprehensibility, and informed program revisions in preparation for a classroom-based study [2].

4. RESULTS

4.1. Teachers' Overall Feedback

Results of the interview and survey indicated that data collection and analysis activities are an authentic part of early childhood classrooms that provide an effective way to introduce computational thinking in preschool. Specifically, a majority of teachers indicated that they view data collection and analysis as being engaging for children, relevant to their preschool curricula and learning standards, and feasible to implement in early childhood settings. A large majority of teachers also viewed the prototyped curricular investigations as fun, related to their curriculum, and feasible to do in their classrooms. Teachers noted that DCA content builds on and extends the mathematics that children are already learning, and they felt the play-based and real-world elements of the investigations would be engaging for children. Importantly, some teachers mentioned that they currently have learning standards related to DCA that their school requires them to meet, but they were often unsure of how to meet those requirements in practice. These teachers noted that the investigations provided them with a better understanding of what developmentally appropriate DCA activities can look like. In addition, teachers noted that they felt the investigations could support formative assessment (e.g., gauging where individual children are in developing their counting or sorting skills) while simultaneously engaging learners across developmental levels. This is particularly important in Head Start classrooms where students can range in age from 3-years-old to 5-years-old, making activities that effectively engage all learners particularly valuable. For example, one teacher stated "*These all seem like really great ideas and I think it would be so helpful for teachers to have this supplemental app to help with assessment purposes and just in general to make this area of learning more fun to learn for younger children!"*

As part of the survey, teachers also rated how well each investigation meets its focal learning goals. Learning goals varied across the investigations and included mathematics goals such as classifying, sorting, and counting data to answer questions; and computational thinking goals such as describing what different parts of data visualizations represent, making comparisons between individual parts of data visualizations, and using data visualizations to answer questions. Teacher feedback strongly indicated that the DCA investigations successfully met the targeted learning goals. Across all investigations, the majority of teachers responded that each learning goal had been met by the proposed activity. After reviewing four investigations, one teacher wrote in their survey: "*I feel this activity and all the ones viewed so far are giving me new and creative ways to introduce graphing and the app would be very helpful*."

4.2. Developmental Appropriateness and Curricular Alignment (Research Question 1)

Developmental Appropriateness

Results suggest that—with the right scaffolding—teachers felt that introducing computational thinking (CT) through data collection and analysis (DCA) is developmentally appropriate for preschool children and is well aligned to preschool curricula and routines. Teachers noted that the content of the investigations aligned with their mathematics curricula, specifically in the areas of number sense, operations, and measurement. With regard to how well this would fit into their curriculum, teachers said:

> *They have to use their words to describe the graphs, and as far as science, they're learning about animal characteristics, different body parts, different movements of animals. And then math, they're comparing, they're sorting. You can take away from a number on the graph, you can add a number. It fits perfectly within all realms of what we need in our curriculum.*
>
> *Something I always look for in activities is to see if they are adaptable to our curriculum…I think that's a strong suit of this activity, that it is very adaptable.*

Anticipated Difficulty of DCA Content

In order to better understand how developmentally appropriate DCA investigations are for preschool learners, we asked teachers to evaluate how easy or difficult it would be for children to complete particular activities (or aspects of activities) within each investigation. Our analysis focused on a set of common themes related to sorting, representing, and interpreting data, as well as making predictions.

For each investigation, teachers were asked to rate how difficult they anticipated the mathematics demands within the investigations' activities would be for preschoolers (see Table 2 with anticipated difficulty levels for selected activities). These ratings varied, with some rated as being very easy (ranging from 6-50% of activities) and others rated as being difficult (ranging from 11-22%). The teachers' ratings matched the expected levels of difficulty for each investigation based on early mathematics learning progressions [32]. However, no activities were rated as being "very difficult," suggesting that the mathematics demands included in each investigation are developmentally appropriate for this age group. Further, the perceived difficulty of the activities rated as being "difficult" could be intertwined with the perceived challenges related to behavior management during the activities, which is not a trivial concern for teachers working with young children.

Table 2. Levels of Anticipated Activity Difficulty by Investigation

Mathematical Skill	Investigation	Very Easy	Easy	Difficult	Very Difficult
Identify colors and shapes of items in a box frame (n=18)	Centers	22%	78%	--	--
Count objects in box frame (n=18)	Centers	17%	83%	--	--
Sort their own clothing (n=18)	Clothing	50%	50%	--	--
Sorting themselves (n=19)	Data Shuffle	21%	68%	11%	--
Sort dress up clothing (n=18)	Clothing	11%	78%	11%	--
Body Graph (n=19)	Hungry Caterpillar	10%	74%	16%	--
Collect data in small groups (n=18)	Centers	11%	72%	17%	--
Analyze data in small groups (n=18)	Centers	11%	67%	22%	--
Represent data by arranging data points on the graph (n=18)	Centers	6%	71%	23%	--
Comparing Graphs (n=18)	Clothing	5%	67%	28%	--
Make predictions (n=18)	Centers	--	61%	39%	--

Sorting Data. Although most teachers reported that the number of sorting categories within a particular investigation or activity (ranging from 2-7 categories across investigations) was appropriate, responses varied and teacher comments offered additional insight into determining the "just right" number. For example, 95% of teachers rated the number of categories in Hungry Caterpillar (5-7 categories) as being "just right" and 79% of teachers said the same about Data Shuffle (3-5 categories). In their responses, teachers indicated three key considerations for sorting: children's previous experience with sorting and where they are developmentally, teacher scaffolding and support, and the steps required to complete the sorting process. For example, teachers said:

> *Depending on what level they're at, they can just do it [sorting] by color and then we can go through the different shapes, or do it by shapes and then advanced ones would start doing it by size, so that would fit all levels throughout the year. It's a very easy thing to tie into anything that we are teaching or playing.*
>
> *Sorting the dramatic play costumes can be done in few or many groups depending on how advanced the students are who are doing it. You can keep it simple or get as challenging as you feel necessary.*
>
> *I really love how this ties right into their play. I think children learn best through play and sorting clothes in dramatic play is just that!*

Representing Data. Results suggest that the DCA investigations provide engaging and developmentally appropriate opportunities for preschool children to graphically represent data. Teachers liked the use of body graphs (with four teachers reporting that they already use them) and felt that – with help from their teacher – children would be able to use the app to graph the data they have collected. As with sorting data, the process of representing data can be messy, especially if multiple children are doing it at the same time. But teachers also expressed confidence that children would be able to create data representations with scaffolding and support. Moreover, multiple teachers felt children would eventually be able to complete most of the graphing steps independently. One way to support this process, while minimizing the potential for chaos and confusion, is to arrange children in smaller groups at the start of an investigation, allowing the teacher to more easily individualize the supports that their students may benefit from.

Interpreting Data. Results suggest that interpreting data may pose more of a challenge to children than sorting and representing data; however, teachers generally agreed that the DCA investigations provide important opportunities for children to develop this skill in age-appropriate ways. Six teachers indicated that children may initially struggle with comparing different graphs that represent the same data; 10 teachers reported that children would struggle with identifying changes in data over time; and 7 said it would be difficult for children to use graphed data to answer questions. Teacher comments also suggest that interpreting data could be particularly challenging for English Language Learners (ELLs). However, for each of these areas, teachers expressed confidence that most children could experience success with scaffolding and targeted teacher supports. Finally, as noted earlier, teachers reacted positively to the idea of creating body graphs and felt that having children use their bodies to represent data is a great way to engage young and tactile learners. One teacher remarked that when using body graphs, it is important to give children opportunities to see the full picture of the graphed data. One way to support this is by employing a "fishbowl" strategy, where one group of students stands outside the body graph and observes another group of students inside the body graph. The students would then switch roles, giving each child opportunities to both participate in creating the body graph and seeing the graph overall. Another way to allow children to observe a body graph that they personally participated in is to take a photo of the graph and allow children to examine the photo after the activity is complete.

Making Predictions. As part of interpreting data, children are asked to make predictions based on the data patterns that they see. Teachers' responses were mixed as to how difficult it might be for children to make predictions. Six teachers noted that they ask children to make predictions during other learning experiences; nine reported that many preschoolers are not yet ready to do so. As with the number of sorting categories, predictions may be another example of a skill to target later in the school year or with higher levels of teacher scaffolding and modeling. For example, one teacher noted, "*This may be a tough concept for the children to grasp because the children would have to comprehend what a prediction is. However, with modeling and examples and repetition they would grasp it in time.*"

Adaptability of Content

Teacher comments also highlighted the natural variation in developmental trajectories that exist in early childhood mathematics. Yet overall, the results indicated that the teachers viewed the investigations, and the topic of data collection and analysis more generally, as being flexible enough to be adapted for learners at different stages of mathematical development. For example, teachers mentioned liking that they could begin an investigation with only a few sorting categories, and incorporate more categories in later activities to increase the level of challenge. Designing the investigations with such flexibility is critical for allowing teachers to assess and adapt the lessons to their students' developmental readiness to engage in DCA. For example, each investigation can be implemented at various times of the school year, in different group arrangements, and with different available materials.

Importantly, teachers also felt that the levels of difficulty could be modulated with teacher support and flexibility. For example, teachers said:

> *With teacher support such as encouraging the children to persist with examination of the clothing, this will be an easy task.*
> *With teacher help and the right questions I feel that the children would be able to look at the graphs and notice things that might be the same and notice if there are things that are different, especially with the picture one.*
> *I think if the teacher is helping and the graph is very clear in what it is looking for, then children will not have a problem.*

Curricular Alignment

Teachers noted that the investigations build on what they already do in their classrooms and are well-aligned to their curricula, both in mathematics and in other content strands. One teacher interviewee remarked: "*We're always looking to do things that will fit into the standards we're teaching. Fitting this into number sense, operations, and measurement fits well with what we're doing already*."

4.3. Design Features of the Intervention (Research Question 2)

4.3.1. Key Features of Activities

Investigations are hands-on. Teachers appreciated that the investigations were hands-on and provided opportunities for children to not only engage with visual representations of data, but also to participate in creating these representations.

> *Children are very hands-on; they like to do things that are interactive. Having them sort themselves into groups, they're taking the lead. We're always trying to have them lead an activity.*
> *I really enjoy that it includes physical movement to involve the children and give them a sense that they are all collecting data that is meaningful rather than coming up one at a time to put a mark on a chart paper. I think it has great involvement, there isn't any long periods of wait time, and it gives each child a sense of independence. I like the fact that it involves technology which is an important piece in collecting data as well. It shows children that you have to physically collect evidence first before you can create a graph. I also enjoy how the technology piece is so simple that children can help in creating the graphs. It provides enough learning for all levels of students who are just learning, to collect information, who are able to create graphs, and then showing those who are ready, how graphs can look different.*

Teachers also liked that narrative stories and picture books were used to anchor the investigations (e.g., *Five Creatures* by Emily Jenkins undergirds the Data Shuffle investigation) and that the activities were both hands-on and digital, including both movement and student autonomy.

Materials are easily accessible. With a few exceptions, teachers appreciated that the investigations do not require special materials, allowing them to use the classroom materials they already have or can easily and inexpensively find (e.g., chart paper and name tags; printed cards with emoji faces). In a few cases, teachers noted that they would need to purchase materials (e.g., felt) or would need to modify an activity due to having a limited number of the required materials (e.g., enough fruit manipulatives for each student to participate).

Activities are multidisciplinary. Teachers also appreciated that the investigations promoted child engagement with content and skills outside of mathematics. For example, several investigations begin with the teacher reading a story that relates to the problem or question being investigated, which teachers viewed as being both engaging for children and supporting their emergent literacy skills.

> *It's seamless, it could fit into many different units. Later in the year we talk about transformation and there's a whole unit about how caterpillars transform into butterflies…it's also applicable in the beginning when we talk about taste and the five senses.*

4.3.2. Key Features of Teacher-Facing Digital App

Teachers felt that the unique affordances of the digital app offered meaningful opportunities for children at different skill levels to easily engage in data collection, visualization, and analysis. A child who needs more support, for example, could use the app with their teacher to enter data they have collected, create a simple graph, and discuss any data patterns they see. Children who are further along in their developmental trajectory could create multiple representations of the same (or different) data, sort their graphed data, make comparisons between different graphs, and make predictions based on the data patterns they see. A few digital affordances were particularly appealing to teachers. For example, the ability to use the camera feature of the tablet to create personalized category labels on graphs, and the addition of an annotation feature that allows the user to draw on graphs, were notably appealing. Another theme that teachers focused on throughout their feedback related to the ways in which the digital app could allow them to individualize their use of technology to children's ages, which range in preschool settings from three to five years old, and readiness for the mathematics content.

Camera Feature. The majority of teachers stated that they would use the app's camera feature, as it allows for customization and helps students to recognize an item by seeing a real photo versus a drawing or cartoon image.

Drawing Feature. Some teachers noted that they liked the app's drawing feature, which allows users to hand draw their graph's category icons or to annotate graphs (e.g., circling columns, writing numerals on top of columns to indicate the total number of units in those categories). These teachers found this feature relevant not only for their use, but also for allowing older or more advanced children draw their own icons.

Sorting Categories by Ascending/Descending Order. Teachers stated that they would use the sorting feature to arrange their graphed data in ascending or descending order; however, three teachers noted that this type of arranging would be relatively advanced and would require additional scaffolding from the teacher in order for children to understand the ordering. Teachers suggested using the sorting feature with older children instead of younger, or during activities that take place later in the school year.

4.4. Challenges and Key Considerations for Implementation (Research Question 3)

Space Challenges. Space constraints emerged as being the biggest perceived barrier to curricular implementation. Specifically, two investigations (Data Shuffle and Hungry Caterpillar) require space for life-sized body or object graphs that teachers need to demarcate on the floor using masking tape prior to the lesson. Although the majority of teachers said that the physical size of their classrooms would allow for this, or that they would be able to find an alternative accommodating space, a few noted that they would need to modify the activity in order to make it work in their classrooms. In addition, teachers reported the need to consider spacing more carefully as the Covid-19 pandemic requires physical distancing of students within classrooms. This indicates that creating body graphs in the classroom might be more difficult currently than in typical times.

Ease of Preparation. Teachers viewed ease of preparation as an important factor in deciding whether to implement an investigation or which investigation to implement (see Table 3). Across all investigations, the majority of teachers reported that their perceived level of preparation would be very easy or easy, although their ratings varied by the complexity of the investigation. For example, all teachers rated the Feelings Freeze investigation as being very easy or easy because it required very few materials. On the other hand, investigations that required such steps as setting up a child-sized grid on the floor with masking tape (e.g., Data Shuffle) or collecting different types of sorting materials (i.e., Centers Investigation) received a wider range of difficulty ratings.

Table 3. Ease of Preparation

Investigation*	Very Easy	Easy	Difficult	Very Difficult
Data Shuffle (n=19)	21%	42%	37%	--
Hungry Caterpillar (n=19)	21%	68%	11%	--
Clothing Investigation (n=19)	53%	42%	5%	--
Centers Investigation (n=18)	6%	77%	11%	6%
Feelings Freeze (n=18)	50%	50%	--	--

** Measurement Investigation was omitted because it required no preparation.*

Our analysis of teacher responses surfaced three key factors driving perceptions of the ease of preparation: space (see previous section), time, and pacing.

Time. The amount of time that teachers anticipated investing into their preparation emerged as an important consideration, though teachers expressed a willingness to invest the time needed to prepare for the activities that they believe will be fun and valuable for their students. For example, one teacher noted that it would her take some time to prepare the investigation materials, but she would be willing to do so because the activity seemed engaging for her children. Importantly, for planning purposes, teachers recommended providing an estimate of how long it will take to read the book paired with each investigation.

Pacing. Across all investigations, most teachers indicated that the suggested pacing (i.e., whether an investigation is spread out over 1-2 days or 2-3 days) was appropriate; however, there was notable variation (see Table 4). It is likely that the best fit of pacing will vary based on individual classroom routines and length of the school day. Just as the teachers felt that the developmental appropriateness of certain investigations may vary based on when in the school year teachers implement them, it is also possible that the appropriateness of the suggested pacing will vary based on this timing.

Table 4. Pacing (N=19)

	Suggested pacing	Just right	Too short	Too long	Unsure	Missing
Data Shuffle	1 day	11	5	--	--	3
Hungry Caterpillar	2-3 days	15	1	1	--	2
Clothing	3 days	7	1	2	2	7
Centers	2-3 days	7	3	1	--	8
Feelings Freeze	1-2 days	7	4	--	1	7
Measurement	1-2 days	10	1	--	--	8

5. DISCUSSION

Overall, findings suggest that teachers see value in engaging in DCA with preschoolers, view the DCA investigations as developmentally appropriate, and think the integrated teacher-facing technology offers meaningful affordances. These findings suggest that this technology-infused approach to CT and DCA is developmentally appropriate, builds on and extends what children are already learning in mathematics, has cross-curricular applications, and can be adapted to meet the needs of preschool learners along the full developmental trajectory. Furthermore, the teachers viewed the digital app being developed as part of this work as affording students an easy way to visualize and interpret data they collect. Teachers support the idea that young children can and should engage in meaningful data collection and analysis and computational thinking lessons.

We also learned that designing flexibility into each investigation is critical to allow teachers to assess and adapt the learning to their students' developmental readiness to engage in DCA. For example, each investigation can be implemented at various times of the year, in different group arrangements, and with different available materials. Teachers also valued the opportunity to make use of the variety of graphical representations built into the curriculum, using both hands-on materials and the app (e.g., creating a bar graph and arranging the bars on the graph from most to least).

Limitations. However, as the first in a series of studies in this body of work, the findings are limited. This study included interviews and surveys of a small group of preschool teachers in the United States, thus findings may be influenced by the current preschool education system and cultural context. Due to the Covid-19 pandemic, all data collection was done remotely, which may have affected the extent of participants' responses. As an early step in the development process, the activities were not tested by teachers with their students; however, subsequent work testing the intervention in classrooms found positive outcomes [2]. Yet, this first step is critical in the design-based research approach and improved the second version of the intervention activities and digital app. Future work is intended to further test and understand the impacts on classroom teaching and student learning.

6. CONCLUSIONS

Findings from the teacher interview and survey suggest that this technology-infused approach to addressing DCA in preschool is developmentally-appropriate, builds on and extends what preschool children are already learning in mathematics, has cross-curricular applications, and can be adapted to meet the needs of young learners along the full developmental trajectory. These findings were subsequently used to inform revisions of the intervention and app, with the overarching goal of improving preschoolers' learning about data.

Contributions to the field. This study is novel in two regards. First, it documents how a design-based research approach uses smaller, early studies to determine end-users, in this case teachers, needs and further designs to address those needs. It is critical to include teacher feedback in the design of research-based curricula, as development based entirely on theory is limited [33]. Second, the study findings in and of themselves affirm that preschool teachers agree that (1) DCA fits into the preschool classroom, (2) activities can be designed to be developmentally appropriate, and (3) that technology can help assist the process and allow teachers to foster the development of DCA related skills and conceptual understanding.

Researchers can use these findings to better understand the scaffolds and elements of hands-on and play-based DCA activities and design features of a teacher-facing digital app that support preschool teachers in teaching data collection and analysis to their students. Long term, the hypothesis is that familiarizing children with data and learning how to talk about data at an early age may also positively influence children's later math and data literacy skills—a question for future research.

Future Studies. However, questions remain about effective practices and tools to facilitate learning these DCA skills. Subsequent stages of this research project involve testing the investigations in preschool classrooms. This will allow us to (1) further specify and refine our understanding of the practices and tools that support preschool children's engagement in computational thinking through DCA, and (2) refine the curricular investigations – including the digital app – to better meet the needs of preschool children and teachers. Findings suggest that this approach to teaching preschoolers about DCA merits further study to ensure productive implementation that positively influences preschoolers' learning.

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