Development of an Early Mathematics Assessment to Evaluate the Promise of a Program for Families

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Section 1: Objectives or purposes

This paper will discuss the development of an early mathematics assessment developed to evaluate the impact of a home intervention designed to promote young children's mathematics learning. The study was part of the summative evaluation of the CPB-PBS Ready To Learn Initiative (RTL), which is supported by the Department of Education, and seeks to develop engaging, high-quality educational programming and resources for young children living in low-income households. The RTL Initiative aims to deliver early mathematics resources on established technologies (e.g., computers) and emerging digital platforms (e.g, tablet computers and smartphones) to create experiences that leverage the unique capabilities of these platforms for young children's learning.

Researchers, policymakers and educators agree that learning mathematics early in childhood is crucial to ensure children's school readiness (e.g., Duncan et al., 2007; National Association for the Education of Young Children, 2012; National Mathematics Advisory Panel, 2008). This has led to the development of preschool classroom interventions, which have been shown to positively influence early mathematics learning (Ginsburg, Lee, & Boyd, 2008). Unfortunately, however, research suggests that children from disadvantaged communities often do not have the same opportunities to develop key foundational mathematics skills as their more affluent peers (Lee & Burkham, 2002; National Mathematics Advisory Panel, 2008). While efforts to improve formal early learning environments are essential, supporting children's learning of early mathematics at *home* is also crucial and has shown promise as well (Starkey, Klein, & Wakeley, 2004).

Across the educational spectrum, parent and caregivers' beliefs align with research that shows that educational media and technology, when used in developmentally appropriate ways, can promote children's learning (Rideout, 2014, Gorges et al, 2014). This study aimed to examine the impact of a home intervention that included high quality digital resources for children and parents and provided supports to help guide parents towards scaffolding their child's engagement and learning.

Section 2 - Perspective(s) or theoretical framework

Increased attention has been brought to the importance of children developing a solid mathematical foundation during their early years and while efforts to promote mathematics early in childhood continue to grow, there is a lack of validated and reliable assessments of mathematical ability. The few early mathematic assessments currently available are strong assessments that have been developed based on research evidence and validated extensively (e.g., Clements et al, 2008; Ginsburg & Baroody, 2003), however, they assess a broad set of mathematics skills and yield overall mathematics scores. An analyses of these assessments indicated that they were not the best match for the current intervention as they assessed a greater constellation of skills than targeted in this intervention. This study focused on a specific set of mathematics skills that were targeted subsequent to an in-depth review of available media content (see Appendix A for target skills). In order to properly assess these skills, our team developed an assessment that was aligned to these skills, but not aligned to the media resources themselves to ensure proper examination of effects (and avoid over-alignment). We followed guidelines for assessment development (Mislevy, Risconcente, 2006) and conducted a series of analyses to examine item performance.

Due to their prevalence in early childhood settings and consistent with the first curricular principle stated in the *Principles and Standards for School Mathematics* (published by the National Council of Teachers of Mathematics), the most dominant mathematics concept in preschool curricula is number concepts and operations. However, these same principles and standards also demonstrate the importance of this study's other mathematical foci (i.e., 3D and 2D shapes and patterns). Despite the fact that the early learning math skills included in the intervention are considered to be developmentally appropriate and fundamental, existing measures do not include subtests that focus on such specific skills and therefore were thought to not be sensitive enough to detect learning in these sub-domains. Therefore, researchers developed a concept map and an independent assessment based on early mathematics literature (i.e., developing items that assessed the target skill in documented ways) and modeling the format used in existing and validated early childhood mathematics assessments.

Section 3 - Methods, techniques, or modes of inquiry

Prior to the development of the Home Study assessment, a content development team curated and identified the media that would comprise the intervention's 12-week experience (episodes, games, interstitials and at home hands-on activities). This resulted in a master content document outlining the details surrounding the representation of each math skill in the resources, including the frequency, intensity and duration of exposure. This detailed document was then used to guide the cultivation of the 12-week intervention, which consisted of weekly mathematical adventures. The five targeted math focal areas were Patterns, 2D and 3D Shapes, Measurable Attributes and Spatial Reasoning, Ordinal Numbers and Counting.

Using this foundational work as a guide, the assessment development team, comprised of researchers with experience in early learning and assessment development, began creation of an assessment development concept map that corroborated and more deeply identified the mathematical focal skills, secondary skills and sub-skills that were developmentally appropriate to include in the development of the assessment. As an initial step in determining the related sub-skills for the chosen focal skills, the team reviewed the mathematical framework upon which Head Start's teaching practices are built and the standards behind Douglas Clement's Building Blocks curricular system (designed to meet the PreK-Grade 2 standards developed by the National Council of Teachers of Mathematics) and used these resources to identify the sub-skills belonging to each focal skill.

The assessment concept map was organized according to each week of the experience, where each week had target math skills. The team noted which media assets were used each week, as well as the focal and secondary math skills present in those assets. For each of the focal and secondary math skills, the team determined which of the previously identified sub-skills were addressed in the resources. The next steps involved rating each sub-skill's presence in the intervention and analyzing their distribution and density by tabulating the focal, secondary and related sub-skills across each week.

With this conceptual map as a guide, team members began the item creation process. Items involved general, non-resource aligned, game-like activities that require assessors to read a verbal prompt and children to provide a verbal response, point, or engage with manipulatives. Subgroups of researchers created items and then reviewed and iterated as a larger team to ensure the items (a) adequately assessed the target skills, (b) included a variety of developmentally appropriate formats, (c) adhered to universal design principles, and (d) varied in terms of difficulty.

Once all the items had been reviewed using the above criteria, the team worked with an expert graphic designer to find and/or generate developmentally appropriate images to create an assessment flipbook. The team ensured that the prompts were written in a developmentally appropriate manner and a copy editor reviewed them to ensure stylistic uniformity. Finally, developmentally appropriate math manipulatives were created or purchased when necessary.

After the assessment flipbook and manipulatives were developed and curated, the team pilot-tested the items with approximately 10 preschoolers from a classroom similar to those where families were recruited. During this pilot administration, any difficulties related to item administration were noted as well as children's engagement and responses to determine item difficulty levels and whether responses included expected outcomes. Findings from this pilot administration informed further revisions. Revised items were then shared with early childhood and mathematics researchers outside of the immediate assessment team for review. Once feedback was obtained, additional edits were made and the assessment was finalized.

Section 4- Data sources, evidence, objects, or materials

The study sample included 197 preschoolers from 14 centers (10 in the New York Metropolitan Area and 4 in the San Francisco Bay Area) serving low-income communities. Upon completion of recruitment, participating children were randomly assigned to either the PBS KIDS (treatment) condition or the Business As Usual (comparison) condition (see Appendix C for sample information). Study families were predominantly Latino (57%), Asian American (19%), and African American (13%).

Section 5 - Results and/or substantiated conclusions

To analyze the child assessment data and examine item functioning, we conducted a series of factor analyses using MPlus Version 7 (Muthén & Muthén, 2012). We conducted an Exploratory Factor Analyses (EFA) using the pre-test assessment data and subsequently conducted a Confirmatory Factor Analyses (CFA) using the post-test data. For each of the resulting factors, we calculated a raw score and converted it into T score (with a mean of 50 and standard deviation of 10) for ease of interpretation. We also calculated Cronbach's alpha coefficients using SPSS 19 (IBM Corp., 2010) to examine internal consistency as well as factor correlations to examine discriminant validity.

The exploratory factor analysis (EFA) conducted on the pre-test data revealed that a three-factor solution provided the best fit to the pretest data. See Appendix D for detailed information regarding model fit. Appendix E includes difficulty and discrimination values for all items by factor. Results from the EFA indicated that the items largely demonstrated adequate pattern coefficient "loadings;" there is generally one dominant factor that each item loads on; and each factor has a logical, substantive meaning based on the family of items that load on them (see Appendix F). Findings from the CFA suggest that with no modifications, the model displayed good fit and confirmed the three-factor structure (see Appendix G). The reliability estimates (Cronbach's Coefficient alpha) of the three subscales – on both the pretest and posttest – range from 0.65 to 0.84 (see Appendix H). Factor 1 included 17 items addressing Ordinal Numbers, Spatial Relationships and 3D Shapes; these items measured young children's ability to order ordinal numbers, match ordinal numbers to cardinal numbers, identify the position/location of an item and identify 3D shapes using manipulatives. Factor 2 included 6 items addressing Measurable Attributes and Pattern Creation; these items measured young children's ability to make comparisons based on measurable characteristics (e.g., shorter vs longer) and their ability to create patterns. Finally, Factor 3 included 12 items addressing Counting, 2D Shapes and Pattern Continuation; these items measured young children's ability to count, identify 2D shapes and their characteristics, and extend patterns. Appendix I includes descriptives for each factor by condition and for the full sample.

To examine the promise of the intervention in improving young children's mathematics learning, we conducted a series of multilevel models using the Stata software environment (Version 13) and the mixed command using full maximum likelihood estimation. Even though randomization occurred at the child-level, multilevel analyses were fit to account for the nested structure of the data (children nested in classrooms and classroom nested in centers) because children were recruited from and were enrolled in preschools during the duration of the study. Results from main impact models indicate that children who participated in the intervention exhibited stronger improvements in the mathematics skills assessed in Factor 1 (Ordinal Numbers; Spatial Relationships; 3D Shapes), relative to children in the control group (B1 = 5.26, $p < .000$; g (effect size) = .51, $p < .000$). The condition variable accounted for 50% of the child-level variation (89%) in outcome (post-test assessment scores). No significant results were detected for

Factor 2 (Measurable Attributes; Pattern Creation) or Factor 3 (Counting; 2D Shapes; Pattern Continuation). See Appendix J for full results.

Section 6 - Scientific or scholarly significance of the study

Findings from the study provided evidence of content validity and indicated that the assessment developed was sensitive to detect effects of an early childhood home intervention over a short period of time. Additionally, the factor analytic studies allowed us to investigate this more deeply by examining effects on specific skills and subsets of skills. By documenting an assessment development process that can be utilized in a variety of different contexts, we hope to support other efforts that may need to develop assessment methodology given current constraints with available assessments. In addition, the assessment developed as a part of this study is one that can be used by others who wish to assess the early mathematics skills it targeted. Finally, findings from this study help build the evidence base and extend our understanding of how parents and children can engage with media and digital resources to promote early learning and ensure *all* children are ready for school.

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Appendix A

Concept map focal and sub skills

Focal Skill		Sub skill
Patterns	I.	Pattern completion
	II.	Pattern extension
	III.	Pattern creation
Shapes (3D and 2D)	I.	Recognition/name of two and three-dimensional shapes in varying positions and of different sizes
	II.	Identification of characteristics of shapes (e.g., number of sides, angles, edges, vertices, faces; shapes of faces)
Measureable Attributes/Relational Concepts/Spatial Concepts	I.	Match objects according to a measurable attribute
	II.	Compare several objects based on a measurable attribute (e.g., length, height)
	III.	Identify the position or location (i.e. in front of, behind, next to)
Ordinal Numbers and Counting	I.	Matching cardinal numbers to ordinal numbers
	II.	Placing ordinal numbers in sequential order
	III.	Counting objects

Appendix B

Criteria definitions for High Medium and Low designations for presence of sub skills

Rating	Criteria
High	Many opportunities for exposure or examples of the skill were provided throughout an episode or opportunities to practice throughout a game
Medium	Some opportunities for exposure or examples of the skill were provided throughout an episode or opportunities to practice throughout a game
Low	Few opportunities for exposure or examples of the skill were provided throughout an episode or opportunities to practice throughout a game

Appendix C

Total sample of children and descriptive statistics for age by condition

Condition	N	Mean Age	SD	Minimum	Maximum
Overall	197	4 y 5 mo.	0.28	4 y 0 mo.	5 y 2 mo.
PBS KIDS	101	4 y 6 mo.	0.28	4 y 0 mo.	5 y 1 mo.
Business as Usual	96	4 y 4 mo.	0.28	4 y 0 mo.	5 y 2 mo.

Appendix D

EFA and CFA model fit

	Value	
Model Fit Information	EFA	CFA
Chi-Square Test		
Value	987.001	1386.112
Degrees of Freedom	817	899
p-value	< 0.001	< 0.001
RMSEA		
Estimate	0.031	0.053
90% C.I.	0.023, 0.037	0.048, 0.059
Probability RMSEA <= 0.05	1.000	0.155
CFI/TLI		
CFI	0.891	0.779
TLI	0.874	0.768
SRMR/WRMR	0.120	1.351

Appendix E

Table E1. Item Characteristics for Factor 1

		Pretest		Posttest	
Item No.	Item Stem	Difficulty	Discriminatio n	Difficulty	Discrimination
Ordinal Numbers					
1	Point to the pig first in line, the cow second in line, and the chicken third in line.	0.40	0.23	0.49	0.38
6a	Point to the child who is first in line.	0.65	0.29	0.79	0.24
6b	Point to the child who is third in line.	0.11	0.37	0.19	0.57
6c	Point to the child who is fifth in line.	0.16	0.19	0.25	0.45
- 13a	Point to the dinosaur that is fourth in line.	0.10	0.34	0.21	0.46
13b	Now, point to the dinosaur that is second in line.	0.49	0.16	0.43	0.30
18a	I want to go to the fifth floor. What button should I press?	0.11	0.37	0.25	0.48
18b	Next, I want to go to the third floor. What button should I press?	0.16	0.29	0.27	0.53
18c	Then, I want to go to the seventh floor. What button should I press?	0.37	0.37	0.53	0.46
18d	Next, I want to go to the second floor. What button should I press?	0.17	0.20	0.22	0.44

<u>3D Shapes</u>					
8a	Point to the object that looks like a sphere.	0.13	0.08	0.19	0.32
8b	Point to the object that looks like a cone.	0.38	0.35	0.45	0.43
8c	Point to the object that looks like a cube.	0.23	0.35	0.39	0.46
8d	Point to the object that looks like a cylinder.	0.40	0.29	0.51	0.38
22a	Find the sphere.	0.22	0.02	0.23	0.24
22b	Find the pyramid.	0.31	0.28	0.48	0.39
22c	Find the cube.	0.30	0.30	0.45	0.42
22d	Find the rectangular prism.	0.37	0.35	0.51	0.40
<u>Spatial Relationships</u>					
23a	Point to the child standing in front of the table.	0.42	0.30	0.49	0.17
23b	Point to the child standing behind the table.	0.37	0.31	0.43	0.29
23c	Point to the child standing next to the table.	0.55	0.42	0.62	0.40

Item No.	Item Stem	Pretest		Posttest	
		Difficulty	Discrimination	Difficulty	Discrimination
Measurable Attributes					
2	Point to the person who is holding the heaviest bag.	0.76	0.33	0.91	0.29
4	Point to the building that is the tallest.	0.75	0.45	0.87	0.37
9	Point to the monkey that is the highest.	0.84	0.38	0.93	0.29
11	Find the pair of shoes that best fits each person's feet.	0.95	0.12	0.98	0.20
Pattern Creation					
15	Use these bears to make a pattern here.	0.41	0.45	0.61	0.33
16	Make a pattern here using these stars.	0.28	0.27	0.43	0.34
17a	Show me what comes next to finish the pattern.	0.71	0.38	0.83	0.32
17b	Now you keep going with the pattern.	0.56	0.48	0.73	0.35

Table E2. Item Characteristics for Factor 2

Table E3. Item Characteristics for Factor 3

Item No.	Item Stem	Pretest		Posttest	
		Difficulty	Discrimination	Difficulty	Discrimination
<u>2D Shapes</u>					
3a	(Point to the cone.) What is this shape?	0.10	0.35	0.13	0.25
3b	(Point to the cube.) What is this shape?	0.02	0.17	0.06	0.34
3c	(Point to the cylinder.) What is this shape?	0.06	0.34	0.16	0.42
12a	(Point to the triangle.) What is this shape?	0.47	0.48	0.62	0.32
12b	(Point to the rectangle.) What is this shape?	0.74	0.30	0.82	0.23
12c	(Point to the square.) What is this shape?	0.62	0.50	0.74	0.45
20a	Point to all the sides. (Shows three sides.)	0.44	0.20	0.56	0.30
20b	Point to all the sides. (Shows four sides.)	0.48	0.24	0.57	0.37

Counting					
5	Use your finger to count how many frogs I have.	0.61	0.39	0.77	0.28
14	Count all of the bananas.	0.52	0.45	0.68	0.40
Pattern Continuation					
7	Place the fruit that is missing here.	0.61	0.36	0.79	0.25
10a	Now, make the same pattern using your hands.	0.18	0.28	0.26	0.35
10b	Keep going (with the pattern).	0.14	0.24	0.21	0.34
21	Help me add cubes to continue this pattern.	0.54	0.46	0.68	0.40
19	Find the cube tower that is as tall as the block.	0.29	0.13	0.37	0.21

Appendix F

Table F1. Geomin rotated exploratory factor correlations

	Factor 1	Factor 2	Factor 3
Factor 1	1.000		
Factor 2	0.146	1.000	
Factor 3	0.461	0.403	1.000

Note: The correlations of the Geomin rotated factors listed in Table 1C range from 0.146 to 0.461. These results provide some discriminant validity for the utility of a three-factor solution.

Appendix G

Table G1. Confirmatory factor correlations

	Factor 1	Factor 2	Factor 3
Factor 1	1.000		
Factor 2	0.255	1.000	
Factor 3	0.181	0.175	1.000

Note: The results of the factor correlations from the confirmatory factor analysis further support the results from the Geomin rotated correlations in the exploratory factor analysis. The correlations listed in Table D1 range from 0.175 to 0.255. These correlations are smaller/weaker, which again, provide discriminant validity for the proposed factors.

Table G2. Confirmatory Factor Analysis: Factor 1 loadings

Item	Estimate	S.E.
3a	0.508	0.114
3b	0.823	0.066
3c	0.838	0.073
5	0.461	0.098
7	0.433	0.093
10a	0.493	0.086
10b	0.550	0.143
12a	0.494	0.086
12b	0.413	0.096
12c	0.724	0.085
14	0.617	0.077
19	0.312	0.095
20a	0.378	0.096
20b	0.489	0.085
21	0.622	0.084

Table G3. Confirmatory Factor Analysis: Factor 2 loadings

Item	Estimat e	S.E.
2	0.619	0.103
4	0.774	0.093
9	0.681	0.159
11	0.595	0.164
15	0.613	0.083
16	0.663	0.084
17a	0.593	0.102
17b	0.453	0.069

Table G4. Confirmatory Factor Analysis: Factor 3 loadings

Item	Estimat e	S.E.
1	0.495	0.073
6a	0.392	0.086
6b	0.908	0.042
6c	0.712	0.062
8a	0.511	0.107
8b	0.648	0.067
8c	0.660	0.066
8d	0.577	0.067
13a	0.759	0.070
13b	0.468	0.073
18a	0.757	0.061
18b	0.813	0.049
18c	0.676	0.056
18d	0.728	0.064
22a	0.409	0.097
22b	0.581	0.067
22c	0.610	0.066
22d	0.575	0.069
23a	0.504	0.066
23b	0.639	0.062
23c	0.573	0.072

Appendix H

Table H1. Internal Consistent for Factors

Subscale	No. of Items	Cronbach's Coefficient Alpha	
		Pretest	Posttest
Geometry and Counting	15	0.75	0.65
Comparisons and Mathematical Patterns	8	0.70	0.65
Cardinality and Shape	21	0.74	0.84

Appendix I

Table I1. Descriptive statistics using T-scores for the Home Study Math Assessment Scale Scores

	PBS KIDS PEG+CAT Home Study Experience			Control			Full Sample		
Variable	N	Mean	Std. Dev	N	Mean	Std. Dev	N	Mean	Std. Dev
Factor 1: Ordinal Numbers, Spatial relationships and 3D Shapes									
Pretest	91	48.43	7.23	84	49.03	10.31	175	48.72	8.82
Posttest*	91	54.77	10.63	84	49.30	10.24	175	52.14	10.77
Factor 2: Measurable Attributes and Pattern Creation									
Pretest	94	49.69	9.95	89	46.33	11.27	183	48.05	10.72
Posttest	94	53.29	7.97	89	52.56	8.93	183	52.94	8.44
Factor 3: Counting, 2D Shapes and Pattern Continuation									
Pretest	9	48.60	9.77	8	48.85	10.01	18	48.71	9.86

Posttest	8 9 8	52.91	8.78	7 8 7	53.04	9.46	5 18 5	52.97	9.08

* $p < 0.000$

Appendix J

Table J1. Findings from Factor 1(Ordinal Numbers, Spatial relationships and 3D Shapes) Impact Model

	N	*Coefficient*	*SE*	*z-ratio*	*Hedges G*
Intercept (γ_{00})	172	50.38	1.87	26.9**	
Condition – PBS kids vs. BAU (γ01)	172	5.26	1.12	4.68**	0.51
Pretest (γ10)	172	0.72	0.07	10.79**	
Home language – Other Only (γ20)	172	-2.12	1.88	-1.13	
Home language – Mixed Only (γ30)	172	-3.21	1.56	2.06*	
Mother – high school diploma (γ40)	172	0.58	1.42	0.41	
Mother – more than high school diploma (γ50)	172	2.2	1.48	1.49	
Child age (γ60)	172	3.64	2.08	1.75	
Child gender (γ70)	172	0.3	1.14	0.26	

Random Effects	Variance Component	*SE*	95% Conf. interval Upper Bound	Lower Bound
Level-1 effects (r_{ij}) (student)	48.07	5.76	38.01	60.79

Level-2 effects (r_{ij}) (class)	5.438	3.90	1.31	22.50
Level-3 effects (r_{ij}) (center)	1.05e-20	0	0	.

* *p* < .05, ** *p* < 0.000

Table J2. Findings from Factor 2(Measurable Attributes and Pattern Creation) Impact Model

	N	*Coefficient*	*SE*	*z-ratio*	*Hedges G*
Intercept (γ_{00})	180	55.70	1.70	32.76*	
Condition – PBS kids vs. BAU (γ01)	180	-1.01	1.06	-0.96	-.04
Pretest (γ10)	180	0.41	0.05	7.47*	
Home language – Other Only (γ20)	180	-2.82	1.68	-1.68	
Home language – Mixed Only (γ30)	180	-0.44	1.39	-0.32	
Mother – high school diploma (γ40)	180	-0.02	1.32	-0.01	
Mother – more than high school diploma (γ50)	180	-1.28	1.41	-0.91	
Child age (γ60)	180	3.87	1.96	1.97	
Child gender (γ70)	180	-1.30	1.08	-1.20	
				95% Conf. interval	
Random Effects		Variance Component	*SE*	Upper Bound	Lower Bound
Level-1 effects (r_{ij}) (student)		6.88	0.36	6.21	7.63

Level-2 effects (r_{ij}) (class)	1.09E-08	3.69E-08	1.43E-11	8.28E-06
Level-3 effects (r_{ij}) (center)	2.13E-10	.	.	.

* *p < 0.000*

Table J3. Findings from Factor 3(Counting, 2D Shapes and Pattern Continuation) Impact Model

	N	*Coefficient*	*SE*	*z-ratio*	*Hedges G*
Intercept (γ_{00})	182	52.58	1.65	31.88***	
Condition – PBS kids vs. BAU (γ01)	182	-0.40	1.00	-0.40	-.11
Pretest (γ10)	182	0.57	0.05	10.46***	
Home language – Other Only (γ20)	182	-2.63	1.64	-1.60	
Home language – Mixed Only (γ30)	182	-0.74	1.36	-0.54	
Mother – high school diploma (γ40)	182	1.67	1.26	1.32	
Mother – more than high school diploma (γ50)	182	2.71	1.31	2.06	
Child age (γ60)	182	2.11	1.90	1.11	
Child gender (γ70)	182	-0.18	1.01	-0.17	

Random Effects	Variance Component	*SE*	95% Conf. interval Upper Bound	95% Conf. interval Lower Bound
Level-1 effects (r_{ij}) (student)	6.42	0.38	5.73	7.21

Level-2 effects (r_{ij}) (class)	1.73	0.87	0.64	4.66
Level-3 effects (r_{ij}) (center)	5.19E-07	0	0	.

* $p < 0.000$