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Abstract

Math skill in early childhood is a key predictor of future academic achievement. Parental engagement in math learning contributes to the growth of children's math skills during this period. To help boost parent-child engagement in math activities and children's math skills, we conducted an RCT lasting 12 weeks with 758 low-income preschoolers and their primary caregivers. Parents were randomized into five groups: 1) a control group, and groups that received 2) a digital tablet with math apps for children; 3) analog math materials for parents to use with children, 4) analog math materials with weekly text messages to manage parents' present bias; and 5) analog math materials with weekly text messages to increase parents' growth mindset. Relative to the control group, neither the analog math materials alone nor the analog materials with growth mindset messages increased child math skills during the intervention period. However, the analog math materials combined with messaging to manage present bias and the digital tablet with math apps increased child math skills by about 0.20 standard deviations ($p=.10$) measured six months after the intervention. These two treatments also increased parents' self-reported time engaged in math activities with their children.

Keywords: Economics of Education, Behavioral Economics, Early Childhood Development, Randomized Controlled Trial, Math Skills, Inequality

JEL Codes: I24, I26, I29

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1. Introduction

Math skills in early childhood is a key to academic achievement later in life (Duncan et al., 2007; Reynolds, 1994). Income-based math achievement gaps often emerge even before the start of formal schooling (Heckman, 2006; Waldfogel & Washbrook, 2011). One reason for differences in children's math skill is differences in how much parents engage their children in math-related learning activities at home. The importance of parental² engagement to children's skill development has long been recognized by economists (e.g., Becker, 1965; Hill & Stafford, 1974; Leibowitz, 1974 and 1977) and other social scientists (Coleman, 1966),³ though much of the existing evidence relies on survey or time diary evidence and statistical techniques to approximate causality (i.e., Bernal, 2008; Bernal and Keane, 2011; Carneiro and Rodriguez, 2010; Del Boca et al., 2012; Del Bono et al., 2016; Fiorini and Keane, 2014; Houtenville and Conway, 2008; Hsin and Felfe, 2014; and Villena-Roldan and Ríos-Aguilar, 2012). Research shows parents engage their young children in relatively little math learning in the home environment and this is especially true for low-income parents.⁴

In the present study ("Math for Parents and Children Together or "MPACT"), we implement a 12-week RCT with 758 low-income families designed to boost parent-child engagement in math learning and children's math skills. We aim to test whether high-quality digital apps and analog math materials could increase parental math engagement and child skills and whether the impact is enhanced with text messages aimed at managing parents' behavioral

² Throughout this paper we use the term "parent" to refer to any caregiver for a child in our sample. In 2020 4% of caregivers are someone other than the child's mother or father.

³ Note that there are large literatures on parent's involvement in their children's schools, on the general question of whether parents matter, and on parenting style; these are not addressed here.

⁴ A large research literature documents the correlation between the home learning environment and children's skills (e.g., Kleemans et al., 2012; Niklas & Schneider, 2014; LeFevre et al., 2009, Marinova et al., 2021).

biases. Parents were randomized into five groups: 1) a control group, and groups that received 2) a digital tablet with high-quality math apps for children to use with or without parents; 3) high-quality analog math materials (the “MKit”) for parents to use with children, 4) the Mkit plus weekly text messages to manage parents’ present bias; and 5) the Mkit plus with weekly text messages to increase parents’ growth mindset. To capture any changes in parent-child engagement in math learning and children’s math skills, we assessed children’s math skills using the Woodcock-Johnson test at baseline, the end of the 12-week intervention, and six months after the intervention ended; we also collected a self-reported measure of parental time spent on math engagement at the baseline and the end of the intervention.

Relative to the control group, both the math app treatment and the MKit plus present-bias treatment increased children’s math skills by about 0.20 standard deviations ($p=.10$) six months after the intervention ended while the other treatments did not increase children’s math skill. These two treatments that increase math skill also increased parent’s reports of the time that they spent engaged in math activities with their children (by a quarter and a third of a standard deviation) while the two treatments that did not increase math skill also did not increase parents’ reports of the time they spend in math activities with their children. A plausible hypothesis is that the increase in parent engagement is a mechanism leading to an increase in math skill.

To study why the MKit and growth mindset treatments fail to raise math engagement and test scores, we examine questions in the parent surveys and show that (1) a large proportion of parents in the MKit group reported losing the MKit and that they used the MKit infrequently or not at all and (2) most parents already have a high level of growth mindset at baseline, which substantially reduces the marginal benefits of any intervention that tries to cultivate a growth mindset.

This paper contributes to several literatures. First, we contribute to the literature studying parental engagement and children's skills by providing plausible evidence that an increase in parent engagement is associated with an increase in math skill. This is important because most of the evidence on this relationship focuses on the impact of parent-child reading on children's literacy scores (e.g., see Barone et al., 2019). Math skills appear to be especially important to children's later achievement (Duncan et al., 2007) but the barriers to early math skill development may be different from the barriers to literacy skill development. For example, more parents have math anxiety than anxiety about literacy and evidence suggests that parents with math anxiety can induce this anxiety in their children (Maloney, et al., 2014). Compared to information about how to improve children's literacy skill, information from experts, including scholars, teachers, and other practitioners, about how to improve children's math skill is somewhat abstract. Advice about improving literacy skill mainly includes reading to your child every day. In contrast, advice about improving children's math skill urges parents to engage in "math talk," read stories with math-related content, play board games, and do other activities that develop math skills among preschoolers.⁵ There is a vast difference in the cognitive load and the need for prior knowledge to execute the literacy advice (read a book everyday) compared to this math advice. In addition, the materials needed to help a child build literacy skill is clear—books—while it is much less clear what materials are needed to help a child build math skill.

Our results also add to the nascent but growing research showing that parents' present bias is an important impediment to parents' investments in their child's skill development

⁵ For example, a National Academy of Sciences report on math learning (National Research Council, 2009) advises that parents should "observe their children carefully, seeing what they do and encouraging and extending their fledgling use of number symbols and processing; Say the number word list. For example, they can count small food items or the number of cups at the table; Ask children to tell them about their problem solving. For example, they can ask 'What did you mean by that?' or 'Why did you do it that way?'; Engage in activities that involve playing with blocks, building things, and board games."

(Mayer et al., 2019; Kalil et al., 2023). Research has shown that disadvantaged parents, such as those in MPACT, face a host of stressors, such as income instability, childcare problems, or transportation issues, that place cognitive and emotional demands on their attention in the present and leave little energy for thinking about the future (Gennetian & Shafir, 2015; Mani et al., 2013; Shah et al. 2022; Spears, 2011) resulting in a greater possibility for the procrastination that results from present bias. Their children also have lower scores on reading comprehension tests.

Mayer et al. (2019) find that a treatment to reduce present bias increased the amount of time that parents spent reading to their child using a digital library on an electronic tablet by 1 standard deviation. This treatment impact was much greater for parents who are more present-biased than for parents who are less present-biased. Kalil et al. (2023) also demonstrated experimentally that present-bias messages designed to boost reading time among low-income parents of young children led to a .32 SD increase in parent reading time over an 11-month period. We contribute to this literature by documenting that our present-bias treatment arm also is effective for boosting parent-child math engagement and child math skills.

Lastly, this study adds to the literature on the role of technology in human capital development (see Escueta et al., 2020 for a synthesis of experimental evidence). Little research exists on whether technology can increase young children's skills. To the extent that technology is high quality, fun, and engaging it may directly increase skill without increasing parent engagement or it also might reduce frictions to parent effort, thereby increasing the time that parents are engaged and/or the quality of the time they spend in educational activities with their children. The MPACT results highlight the role that technology could play in raising the skills of disadvantaged preschool aged children.

The remainder of this paper proceeds as follows. Section 2 describes the MPACT experiment. Section 3 discusses data and descriptive results. Section 4 discusses the experimental findings, and Section 5 concludes with discussion.

2. The MPACT Experiment

The 12-week MPACT intervention was completed in three rounds, with each round consisting of about a third of the total sample of children. MPACT was done in rounds because of the intensity of the recruitment process and the costs associated with giving families electronic tablets. The rounds began in fall of 2017, spring of 2018, and fall of 2018. All documents used in MPACT were available in Spanish and English.⁶

2.1 Design of Treatment Arms

An important potential explanation for why low-income children begin kindergarten with lower math skills than higher income children is that low-income parents lack information about developmentally appropriate ways to engage their children in math learning. Three of the MPACT treatments provided parents with an “MKit.” The MKit included a math activity booklet with twenty-two developmentally appropriate math activities for parents and children to do together, a game board and game pieces, a number grid, and a goal tracker.⁷ The MKit also included instructions for how to do the activities and tips for how to get the most out of the

⁶All aspects of MPACT were approved by the University of Chicago Institutional Review Board. The MPACT field experiment is registered in the American Economic Association Registry for Randomized Controlled Trials, and the unique identifying number is AEARCTR-0002512.

⁷The goal tracker is a grid in which parents could keep track of the days on which they did math with their children

activities.⁸ These materials were given to families in an MKit backpack.⁹ The MKit booklet focused on five specific skill areas within the numeracy domain: number recognition, counting, comparing size and quantity, adding and subtracting, and patterns.

The materials in the MKit were developed by our research team and informed by the recommendations in chapters 4 and 5 of a report by the National Academy of Sciences (Cross et al., 2009) and other professional recommendations for how parent can engage with their children to increase child numeracy skills. The content of the MKit was extensively piloted to assure that parents understood the activities and were enthusiastic about doing them. At the follow-up survey of parents (described below), 92% of parents said that they would recommend the MKit to a friend, and over 80% disagreed with the statement, “I did not need the MKit because I already know how to do math activities with my child.” When asked how much they would be willing to pay for the MKit, 74% said they were willing to pay \$10 and over 40% said they were willing to pay \$20. Parents in the MKit treatment group received only the MKit. This treatment was intended to test whether providing materials alone to parents would improve children’s math skills.

Because procrastination induced by present bias is another potential reason that low-income parents engage their children less in math learning activities, a second treatment group, the “present bias group,” received an MKit plus up to four text messages per week intended to overcome parents’ present bias. By reducing parents’ procrastination in engaging their child, the present bias treatment was intended to increase children’s math skill more than the MKit only

⁸ The MKit also provided suggestions for how to make the activity harder after the child mastered the skill. The booklet families received also included information on the importance of parents spending time in math activities with their child for the child’s future success.

⁹An example of an activity in the booklet instructs the parent to ask the child to choose a number between 1 and 10 and then along with the child to make up a dance with that number.

treatment.¹⁰ Although the wording of the messages differed each week, all the text messages were meant to either encourage parents to set a goal for how much time they would engage their children in math activities and to stick to the goal. An example of a message in this treatment is, “It’s Goal Day. Set a goal for how many days this week you will do math activities with [CHILD_NAME]. Ask [him/her] to help you write it down on the MKit chart.”

A third treatment group, the “growth mindset group,” received an MKit plus up to four text messages per week that were intended to promote a growth mindset within the parent. While individuals with a growth mindset believe that skill can be developed through information and hard work, individuals with a fixed mindset believe that skills are inherent and not changeable. Individuals with a fixed mindset tend to achieve less than those with a growth mindset (Blackwell et al., 2007; Claro et al., 2016; Mangels et al., 2006). Most research on growth mindset has focused on people’s mindsets about their own intelligence. Parents with a fixed mindset might invest less in engaging their child in learning activities because they will expect a lower return on that investment than parents with a growth mindset. The few studies that have considered the role of parental mindset on child achievement have found that having parents with growth mindsets is associated with greater child achievement (Haimovitz & Dweck, 2016; Rowe & Leech, 2019; Andersen & Nielsen, 2016). An example of a growth mindset message is, “Math ability is not fixed. If you talk about math with [CHILD_NAME] every day, [his/her] math ability will grow.

Parents in the fourth treatment group, the “math app group,” did not receive an MKit. Instead, they received an electronic tablet preloaded with eight apps intended to teach math skills

¹⁰ For more literature studying present bias, please see Meier & Sprenger, 2010; Eckel et al., 2005 on overall effects, Chabris et al., 2008 for dieting, exercising, and smoking and Sutter et al., 2013; Castillo et al., 2011 for investments in human capital.

to three-to-five-year-old children. The math apps could be used by the child alone or by the parent and child together. Thus, this treatment could increase child math skills either because the child learned directly from the apps or because the apps increase the parent-child engagement.¹¹ We reviewed dozens of math applications for three-to-five-year-old children and selected applications that were available in both Spanish and English; worked on the tablets that we selected, with few problems; and covered roughly the same math skills as the MKit. We piloted the applications to ensure that children could use the tablets and the apps with few technical issues, and that the applications were enjoyable. None of the math applications that we reviewed required parent engagement with the child to use the application, but we did not instruct parents that the apps were exclusively for the child's use. The choice of the math apps is described in the Appendix.

Parents in the control group only received an MPACT backpack with a story book rather than math materials at the beginning of the intervention. They also received text messages reminding them when they would be surveyed and when their child would be assessed. The Appendix includes an excerpt from the MKit.

2.2 Randomization

We recruited 29 publicly subsidized preschools throughout the City of Chicago to participate in MPACT. In these preschools eligible parents had a child between the ages of three and four years who was enrolled in the preschool, had a primary language of either English or Spanish, and who was willing to consent to participate. Parents also had to have a mobile phone

¹¹ Tablets were set up so that parents could not access the internet from the tablets; therefore, no other apps or materials could be downloaded.

and be willing to receive text messages.¹² Language restrictions were due to limitations on the languages in which we could produce the MKit and find suitable electronic applications.

In the eleven centers that allowed it, all eligible parents were automatically enrolled in MPACT but were given a chance to opt out of participation.¹³ Eighteen preschools did not permit opt-out recruitment. In these centers, research assistants recruited parents in person by approaching them at drop-off and pick-up time to ask if they would be willing to participate. Participation rates were high at both opt-out (99%) and opt-in (71%) preschool centers.¹⁴

We randomized in two stages. In the first stage, we randomly assigned preschool classrooms to either a treated classroom or a control classroom. We assigned 15 classrooms (5 in each round) to be a control classroom. All sample children in these classrooms were assigned to the control group. In the second stage, we randomly assigned students in the treatment classrooms to one of the treatment groups. We implemented this two-stage randomization so that we could detect peer effects, which we do not discuss in this paper.

3. Data and Descriptive Results

The sample for estimating treatment effects on child math skill includes children who were assessed at baseline, the end of the 12-week intervention, and six months after the end of the intervention, who had no learning disability identified by either the assessor or the preschool, and who were able to complete the assessments. We assessed children at the end of the intervention to evaluate the efficacy of treatments. We also conducted a follow-up assessment six

¹² In other studies that we have done with a similar sample of Head Start parents, about 90% of parents reported having a working phone on which they could receive text messages (Kalil et al., 2019)

¹³ Only the principal parent or guardian participated in MPACT.

¹⁴ The number of eligible parents was provided by preschool centers, and it is the number of parents who met the eligibility criteria for opt-out centers or the number of children in the classrooms for opt-in centers.

months after the intervention to explore changes in children's math skills without active interventions.

We initially recruited 1459 children. Eleven children dropped out before randomization. Of the remaining 1448 children, 93 were siblings of enrolled children. We dropped siblings, leaving 1355 children in the sample. After randomization, 61 children dropped out of the study. These children were mainly enrolled in a preschool that closed after randomization but before we could collect any data on either parents or children. Ten children remained enrolled in the preschool but were chronically absent, so we were not able to collect data on either these parents or children. Another 97 children could either not be assessed reliably because of either cognitive or behavioral problems or because they were reported as having learning abilities by their primary caregivers. Improving these children's math skills is beyond our interventions' scope, so we drop them from the analytical sample as well. This left 1187 children who were assessed at baseline, which is composed of 349 children from the first round, 408 children from the second round, and 430 children from the third round.

The first column in Table A1 shows that children were randomized evenly across the MKit, growth mindset and present bias treatment groups. The control group is larger because all the children in the control group classrooms were assigned to the control group. We assigned fewer children (122) to the math app group because of the high cost of purchasing, distributing, and reclaiming tablets compared to the cost of the MKit, which families kept at the end of the treatment.

Column 2 in Table A1 shows that of the original 1187 children who were randomized, 758 (63.9%) had data on baseline and two rounds of follow-up assessments. This is the sample

that we use in our primary analysis below. The percent of children with complete data in the sample ranged from 59% for the math app group to 67.8% for the growth mindset group.

We also surveyed the parents of these children at both baseline and at the end of the 12-week intervention. Data on demographic characteristics of children and their families come from this survey data as do parents' reports of how much time they spend engaged with their children in math learning activities. All parents of the 1187 children who were initially assessed were asked to take the baseline parent survey. Of this sample, 896 parents participated in the baseline survey. As with the child sample, parents were evenly distributed across the MKit, growth mindset, and present bias treatment groups with more parents in the control group and fewer in the math app group (Table A1, Column 3). Among parents, 721 participated in both the baseline and end of intervention survey (Table A1, Column 4). This represents 60.7% of the original sample of parents and 80.5% of the parents who took the baseline survey. The 721 parents who participated in both surveys are the parent sample used in the analyses below.

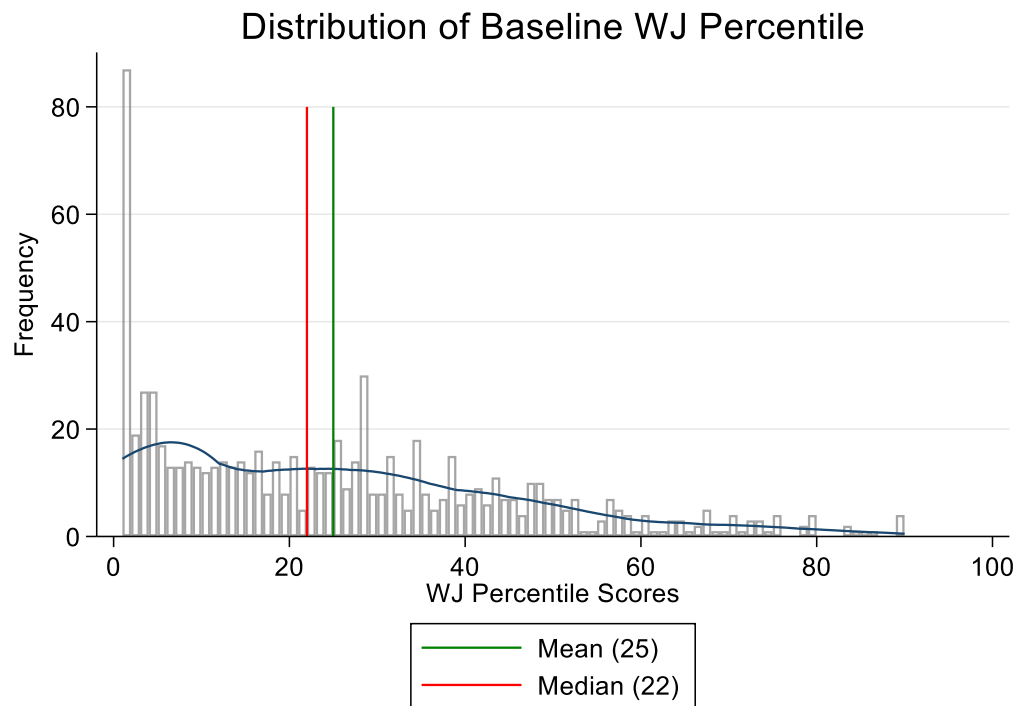
To address the potential for selective attrition we compared several characteristics of the child sample at baseline, the end of the intervention, and six months after the end of the intervention. We also compared several characteristics of the parent samples at baseline and at the end of the intervention. In neither case were any of the characteristics statistically significantly different across samples at $p=.10$. These results are shown in tables A2 and A3.

Our primary outcome is math skills. To measure this, we use the Woodcock-Johnson IV Applied Problems subtest (WJ). As noted above, the MKit focuses primarily on numeracy. This WJ subtest also focuses on numeracy, including counting, subitizing (i.e., ability to recognize the number of objects without counting them), adding and subtracting, sequencing, and matching numbers to their quantities. This contrasts with geometric and spatial competencies, which

includes recognizing and naming shapes, construction of shapes, spatial imagery, and measurement. Children were assessed at the baseline, the end of the intervention, and six months after the end of the intervention to determine whether any gains from the treatments were retained over that time.

The WJ percentile indicates a child's rank in math performance compared to a nationally norm-referenced group of children of the same age. A percentile of 50 means that the child performed at the median in the national pool of children at the same age. Figure 1 shows the distribution of baseline WJ percentile for the 758 children with complete assessment data in the MPACT sample. At baseline the average child in MPACT scored at the 25th percentile. This is consistent with other studies that show that children from low-income families score lower than children from high-income families, even before compulsory schooling begins (Fryer & Levitt, 2006, 2013; Magnuson & Duncan, 2016; Reardon & Bischoff, 2011; Waldfogel & Washbrook, 2011).

Figure 1. Distribution of baseline WJ percentile for children participating in MPACT



Notes: Sample is for 758 children who participated in all 3 assessments.

We also consider a secondary outcome, parent engagement in math activities with their child, that may be a mechanism for any change in math skill. As with most other studies, we do not have an objective measure of how much time parents spend with their child. We asked parents how many days over the previous week they helped their children count, recognize numbers, recognize shapes, and add or subtract.¹⁵ How many days parents engaged in math activities with their child depended on the activity. Just 2% of parents said they never helped their child count, but 37% said they never do addition and subtraction activities with their child. Parents help their child learn shapes and recognize numbers less than they help their child count but more than they do addition and subtraction. Because exposure to math concepts is a function

¹⁵ Responses were never (with a value of 0), 1 or 2 days (assigned a value of 1.5), 3 or 4 days (assigned a value of 3.5), and 5 or more days (assigned a value of 6)

of both the amount of time and the type of activity, with advanced math activities producing greater math skill (Skwarchuk, 2009, Skwarchuk et al., 2014, Thompson et al., 2017), we create a score that weighs each kind of engagement by the inverse of the reported average frequency of the engagement at baseline meaning that time spent in counting activities gets less weight than time in addition and subtraction. This assumes that parents who engage their child in more difficult tasks have a greater intensity of engagement. The measure of intensity of math engagement measure ranges from 0 to 12 with 0 indicating no math engagement and 12 indicating the highest level of intensity of math engagement. The baseline intensity of math engagement has a mean of 6.35 and a standard deviation of 2.79.

Table 1 shows descriptive statistics of characteristic of both the children and parents in our primary analysis samples by treatment group status. Table 1 also reports a joint f-test test comparing children or parents in any treatment group with those in the control group for each characteristic. These characteristics are balanced across treatment groups and the control group. None of these sample characteristics differed significantly by round.

Table 1: Descriptive Statistics at baseline and Balance Tests

Child variables (N=758)	Control (N=220)	Math app (N=72)	MKit (N=153)	Growth mindset (N=162)	Present bias (N=151)	F Statistic p-value
Female	55.9%	48.6%	56.9%	56.8%	51.7%	.68
Age (month)	46.93 (5.98)	45.86 (6.06)	46.38 (6.15)	46.37 (6.04)	46.86 (5.63)	.64
Intensity of math engagement	6.01 (2.72)	6.81 (2.36)	6.49 (2.87)	6.17 (2.81)	6.32 (2.7)	.25
WJ percentile	23.34 (20.96)	23.73 (19.2)	28.58 (21.27)	23.97 (19.37)	24.45 (20.91)	.17
Parent variables (N=721)	Control (N=202)	Math app (N=87)	MKit (N=136)	Growth mindset (N=143)	Present bias (N=153)	F Statistic p-value
Female	92.5%	95.3%	93.4%	95.1%	93.5%	.83
Age	31.31 (7.14)	31.95 (7.44)	32.16 (7.1)	31.36 (6.78)	31.52 (6.6)	.82
Non-Hispanic Black	31.2%	31%	29.4%	27.3%	34%	.79
Hispanic	62.9%	63.2%	66.9%	68.5%	61.4%	.68
Percent with less than HS degree	26.7%	20.7%	28.7%	23.8%	30.1%	.47
Percent with HS degree	24.3%	24.1%	27.9%	30%	25.5%	.76
Percent with BA or higher degree	9.4%	6.9%	5.9%	7%	9.2%	.72
Percent who speak Spanish at home	56.9%	54%	56.6%	61.5%	53.6%	.69
Household income in previous year	\$20436 (15295)	\$20862 (15709)	\$18205 (14200)	\$18768 (15372)	\$18396 (15200)	.51

Note: The data are from baseline math assessment and parent survey. The child characteristic data are limited to the sample of children who have baseline and two follow-up assessments. The parent characteristic data are limited to the sample of parents who responded to both baseline and follow-up parent surveys. The number of respondents to each question varies because not all parents answered all questions. The F-Statistic p-value column represents the p-value on a joint hypothesis test with a null hypothesis of equal means across treatment conditions. *** p<.01, ** p<.05, * p<.10.

4. Main Results

4.1 Treatment Effects on Math Skills

To estimate the effect of the MPACT treatments on math skill we estimate the following model:

$$Y = \beta_0 + \beta_1 T_1 + \beta_2 T_2 + \beta_3 T_3 + \beta_4 T_4 + \gamma + \epsilon \quad (1)$$

where Y is the WJ percentile score measured at the end of the intervention or six months after the intervention ended, T_1 to T_4 are indicators of the assignment to the four MPACT treatment groups, γ are control variables including the baseline measure of the outcome and classroom fixed effects, and ϵ is an error term.¹⁶ Because the control group is the omitted group, the coefficient for each treatment is the average change in children's WJ percentile score for that treatment compared to the control group.

Table 2 shows the estimated effect of the MPACT treatments on children's WJ age-adjusted percentile. The first column in Table 2 shows that at the end of the 12-week intervention no treatment had a positive effect on math scores at any significance level. Children in the growth mindset group scored slightly lower than the control group ($p=.10$).

Column 2 shows that at six months after the intervention, the math app treatment increased the WJ percentile scores by 3.96 percentile points compared to the control group, which is equal to an effect size of 0.20 standard deviations ($p=.10$). The present bias treatment

¹⁶ We use classroom assignment at the time of randomization. One percent of children moved to a different classroom when the baseline assessment was administered, and 3% of children were in a different classroom at the time of the first follow-up assessment.

had a treatment effect of 3.47 percentile points, which is equal to an effect size of 0.18 standard deviations ($p=.10$).

Table 2. Effect of MPACT treatments on children's WJ percentile

	(1)	(2)
	End of intervention	6 months post intervention
Math app	-.1 (2.8)	3.96* (2.37)
MKit	-2.89 (2.25)	1.12 (2.08)
Growth mindset	-3.78* (2.11)	0.06 (1.99)
Present bias	1.79 (2.24)	3.47* (1.96)
Constant	10.52*** (1.62)	9.12*** (1.52)
Control Mean	27.89	22.02
Control SD	23.96	19.38
N	758	758

Notes: The control group is omitted. Regressions include baseline measures of the outcome and classroom fixed effects. Standard errors are reported in parentheses.

* $p<0.1$, ** $p<0.05$, *** $p<0.01$

We use randomized inference as an alternative way to estimate significance levels (Athey & Imbens, 2016; Fischer, 1925). This method of estimating p-values may be superior to parametric estimates when the sample has been randomized into treatment groups. To do this we created a set of counterfactual treatment effects by statistically altering treatment assignment across the sample. We then rank these treatment effects to see where our actual estimate lies

within the distribution of possible effects. The p-value is the percentile of our estimate compared to counterfactual estimates. Our results did not change using this alternative way to calculate the p-values.

4.2 Treatment Effects on the Intensity of Math Engagement

Parental engagement in math-related learning activities is essential in developing children's math skills, so one potential channel through which our interventions changed children's math skills is the change in parental engagement. We use the same model as equation 1 to estimate the impact of the treatments on the intensity of parent's math engagement with their child. Recall that this is measured at the end of the intervention.

Table 3 shows that the math app and present bias treatments increased the intensity of parents' math engagement. Parents in the math app group increased the intensity of their math engagement by a third of a standard deviation more than the increase for the control group ($p=.01$). Parents in the present bias treatment group increased the intensity of their math engagement by .26 standard deviation more than the increase for the control group ($p=.05$). Parents in the MKit and growth mindset treatments did not increase the intensity of their engagement in math activities with their children by a substantial or statistically significant amount. These results are consistent with the argument that increasing parent engagement in math activities increased math skill.¹⁷

¹⁷ We also analyzed the treatment effects individually on how many days over the previous week parents helped their children count, recognize numbers, recognize shapes, and add or subtract. Results in Table A4 show that the math app and present bias interventions significantly increased the frequency of three math activities, while the MKit and growth mindset interventions only significantly increased the frequency of one math activity each. It confirms our conclusion that the math app and present bias treatments are more powerful in increasing parents' math engagement than the other two treatments.

Table 3. Effect of MPACT treatments on intensity of parental math engagement

	(1)
	Intensity of parental math engagement
Math app	.96*** (.34)
MKit	.35 (.33)
Growth mindset	.45 (.32)
Present bias	.73** (.31)
Constant	3.36 (.32)
Control Mean	6.16
Control SD	2.76
N	665

Notes: The control group is omitted. Regressions include baseline measures of the outcome and classroom fixed effects. Standard errors are reported in parentheses. *p<0.1, **p<0.05, ***p<0.01

Because this study relies on parents' self-reports of how much time they spend in math activities with their children, a potential concern is that parents differentially exaggerate their engagement due to differential priming from the treatments. Research has demonstrated that socially desirable behaviors are overstated in surveys (e.g., Paulhus, 2002; Touraneau & Yan, 2007; Krumpal, 2013). Research comparing objective measures of parents' time to parents' reports of their time use show that parents on average overestimate the time they spend in educational activities with their children (Mayer et al., 2019) but also that parents who report spending more time generally do spend more time in educational activities with their children.

For MPACT the question is whether the treatments result in different levels of self-reports of engagement. If true it would have to be the case that the math app and present bias treatments provide greater priming than the MKit and growth mindset treatments. However, the math app treatment like the MKit treatment did not provide any messaging about math engagement even though engagement increased in the math app but not the MKit group. In addition, the two treatments that increased reported engagement were also the treatments that increased assessment scores, suggesting that engagement really did increase in these groups.

The three treatments in which parents received the MKit materials were intended to increase parent engagement by providing materials and information about how to engage children in math activities. We surveyed parents about the MKit usage in the first round of the experiment. Among 125 eligible parents who were in the first round of the survey sample and were in one of the three groups receiving the MKit, 106 parents reported their MKit usage at the end of the intervention. These 106 parents were evenly distributed across three treatment groups that received the MKit. In the MKit only group 17% of parents reported that they misplaced or lost the MKit at times versus only 6% of parents in the growth mindset group and 11% of parents in the present bias group. Only 37% of parents in the MKit only group finished half of the MKit activities compared to 47% of parents in the growth mindset group and 54% of parents in the present bias group. Though we did not survey parents on the MKit usage in the following rounds, the results from the first round provide suggestive evidence that only providing the MKit is not sufficient to substantially increase parent-child math learning.

The growth mindset treatment was intended to increase children's WJ scores by increasing the extent to which parents believed that engaging their child in math activities would improve their child's math skill. However, at baseline our survey data show the median growth

mindset value was 4.6 on a 6-point scale with 6 being a very strong growth mindset, and fewer than 11% of parents reported a growth mindset value of less than 3. This suggests that almost all parents believed that children could learn new things if they were taught those things. This left little room for a treatment intended to increase growth mindset to change parent engagement.¹⁸

5. Discussion and Conclusion

5.1 “Fade-in” Treatment hypothesis

A puzzle in our findings is that for both the math apps and present bias interventions, we find no treatment effect immediately at the end of the intervention, but significant positive treatment effects six months later. This pattern seems contrary to many interventions in which treatment effects are the highest immediately at the end of the intervention, and then “fade out” over time.

One potential explanation for this is that some behavior changes only produce treatment effects at all after a long intervention period. For instance, someone trying to lose weight by jogging might not lose weight after a few days, or even a few weeks of running. However, several months later, they will lose weight. This treatment effect has a “fade-in” pattern over

¹⁸ Based on our pre-analysis plan, we initially aimed to analyze heterogeneous treatment effects on children's math skills by child's gender, baseline math skills, and baseline level of parental engagement. We expect all treatments to have a greater benefit for children with lower math skills and whose parents have the least intensity of math engagement at baseline because they have the greatest opportunity for improvement. The motivation to explore heterogeneity by child's gender also follows along this line, in the sense that the gender gap in baseline math skills can affect the efficacy of treatment differently for boys and girls (Doss et al., 2022). Unfortunately, our response rate left us underpowered to conduct these analyses reliably. We ran an exploratory analysis, and the pattern suggested that the math app and present bias interventions are more powerful for children with lower math skills and less parental engagement at baseline, like boys who have significantly lower baseline math skills than girls ($p=.05$) and children whose intensity of math engagement is below the median at the baseline. Further research with a larger sample is needed to confirm this pattern.

time because the effect of the behavior change must accumulate over time. This pattern is consistent with the results for MPACT.

A fade-in pattern could be modeled via a “step-function” of math skill production, where the math engagement needs to pass a threshold to increase math skills. In MPACT this would happen if the math engagement in the math app group and the present bias group accumulated during the 12-week intervention was unable to increase children’s math skills compared to the control group but additional math engagement over another six months sufficed to increase math skills for children in these groups. Parents kept the MKit once the intervention was over so it is conceivable that parents continued to use the MKit after the intervention ended, increasing the accumulated math engagement enough to raise test scores. This scenario is most likely to happen in the present bias group, where parents already showed a significant increase in the math engagement at the end of the intervention. Similarly, the math apps that were loaded on the tablets were available at little or no cost so parents could have downloaded these from the app store for their children to use after the intervention ended. Use of the math apps beyond the 12-week intervention could also have resulted in greater math skill.

5.2 Conclusion

In this paper, we estimated the effect of four separate treatments that were part of the MPACT intervention on parental engagement with math and preschool children’s math skill. Three of these treatments were intended to increase parents’ engagement in math activities with their children to increase children’s math skill. The fourth treatment, the math app treatment, was intended to increase children’s exposure to math concepts through digital apps that did not necessarily require (but neither did preclude) parental engagement.

We found that neither the MKit treatment nor the growth mindset treatment increased either the intensity of parental math engagement with their child or their child's math skills. On the other hand, the math app treatment and the present bias treatment both increased both the intensity of parent's math engagement with their child and their child's math skill by a meaningful although marginally statistically significant amount. The estimated effect for these treatments is large compared those found in other studies. For example, in the Head Start Impact Study the average treatment effect of being randomly assigned to Head Start was 17.9% of a standard deviation ($p=.01$) on parents' reports of engaging in math activities with their child after one year of being enrolled in Head Start (Padilla 2020; see also Bloom & Weiland 2015).

These findings confirm results from other papers studying parental engagement. Information alone that simply tells parents they should engage with their children, even if the materials for engagement are also provided, is unlikely to change parent behavior because many parents who received materials did not use them. Our recent research with a similar sample shows that low-income parents experiencing psychological stress or financial scarcity do not attend to information that they receive (Kalil, Mayer, & Shah, 2022), so it may not be surprising that in this low income sample many parents did not attend to the materials that they received without additional behavioral messaging.

These results also indicate that even in a low-income sample, few parents have a fixed mindset. Therefore, interventions that focus on fostering a growth mindset are unlikely to alter many parents' attitude about the importance of exposing children to math concepts. This implies that such interventions are unlikely to change parent behavior or child skill.

The MPACT results also indicate that a potential barrier for parents to use math related materials when they are available is present bias. When parents received the MKit plus

behaviorally informed messages to manage present bias they reported doing more of these activities. This is consistent with our previous research (Mayer et al., 2019; Kalil et al., 2023) showing that an intervention to reduce the procrastination associated with present bias increased the amount of time that parents read to their children using an electronic app and that the effects are the greatest for parents who at baseline were the most present biased.

Finally, the math app treatment produced surprisingly large effects on parent engagement at the end of the intervention ($p=.01$) and test scores six months after the intervention ($p=.10$). The math apps selected in our intervention do not require parental engagement because they have features to direct children to learn by themselves. However, we observed a large treatment effect on math engagement in this group suggesting that the math apps may change parents' roles from a teacher to a moderator during the child's math learning process. Such change may reduce frictions to parents' engaging in children's learning, relieve the stress and burden of parent engagement, and require less effort from parents making the learning process more enjoyable for both parents and children. Moreover, providing families with a tablet with math apps may cost less than other interventions to improve math skill. These results thus point to new avenues for efficient policy intervention to increase children's math skills at home.

References

- Agee, M. D., & Crocker, T. D. (1996). Parental altruism and child lead exposure: Inferences from the demand for chelation therapy. *Journal of Human Resources*, 31(3), 677-691. <https://doi.org/10.2307/146271>
- Andersen, S. C., & Nielsen, H. S. (2016). Reading intervention with a growth mindset approach improves children's skills. *Proceedings of the National Academy of Sciences*, 113(43), 12111-12113. <https://www.jstor.org/stable/26472210>
- Aram, D., & Biron, S.. (2004). Joint storybook reading and joint writing interventions among low SES preschoolers: differential contributions to early literacy. *Early Childhood Research Quarterly*, 19(4), 588-610. <https://doi.org/10.1016/j.ecresq.2004.10.003>.
- Athey, S., & Imbens, G. (2016). Recursive partitioning for heterogeneous causal effects. *Proceedings of the National Academy of Sciences*, 113(27), 7353-7360.
- Attanasio, O., Boneva, T., & Rauh, C. (2019). *Parental beliefs about returns to different types of investments in school children* (No. w25513). National Bureau of Economic Research. <http://www.nber.org/papers/w25513>
- Barnett, W. S., Jung, K., Yarosz, D. J., Thomas, J., Hornbeck, A., Stechuk, R., & Burns, S. (2008). Educational Effects of the Tools of the Mind Curriculum: A Randomized Trial. *Early Childhood Research Quarterly*, 23(3), 299–313. <https://eric.ed.gov/?id=EJ807583>
- Barone, C., Chambuleyron, E., Vonnak, R., & Assirelli, G. (2019). Home-based shared book reading interventions and children's language skills: A meta-analysis of randomized controlled trials. *Educational Research and Evaluation*, 25(5-6), 270-298, <https://doi.org/10.1080/13803611.2020.1814820>

- Barone, C., Fougère, D., & Martel, K. (2020). *Reading Aloud to Children, Social Inequalities, and Vocabulary Development: Evidence from a Randomized Controlled Trial*. IZA Discussion Papers 13458, Institute of Labor Economics (IZA). hal-03097888.
- Becker, G. S. (1965). A Theory of the Allocation of Time. *Economic Journal*, 75(299), 493-517.
- Benavides-Varela, S., Roma Siugzdaite, D. M. G., Macagno, F., Cattarossi, L., & Mehler, J. (2017). Brain regions and functional interactions supporting early word recognition in the face of input variability. *Proceedings of the National Academy of Sciences*, 114(29), 7588-7593.
- Bernal, R. (2008). The effect of maternal employment and child care on children's cognitive development. *International Economic Review*, 49(4), 1173-1209.
- Bernal, R., & Keane, M. P. (2011). Child care choices and children's cognitive achievement: The case of single mothers. *Journal of Labor Economics*, 29(3), 459-512.
- Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, 78(1), 246-263.
- Bloom, H. S., & Weiland, C. (2015). *Quantifying variation in Head Start effects on young children's cognitive and socio-emotional skills using data from the National Head Start Impact Study* (ERIC Number: ED558509). MDRC.
https://www.mdrc.org/sites/default/files/quantifying_variation_in_head_start.pdf
- Boneva, T., & Rauh, C. (2018). Parental beliefs about returns to educational investments: The later the better? *Journal of the European Economic Association*, 16(6), 1669-1711.
- Bryan, G., Karlan, D., & Nelson, S. (2010). Commitment devices. *Annual Review of Economics*, 2(1), 671-698.

- Carneiro, P., & Rodrigues, M. (2010). Evaluating the effect of maternal time in child development using the generalized propensity score. *Economics of Education*.
<https://2010.economicsofeducation.com/user/pdfsiones/077.pdf>
- Casad B. J., Hale, P., & Wachs, F. L. (2015). Parent-child math anxiety and math-gender stereotypes predict adolescents' math education outcomes. *Frontiers in Psychology*, 6,
<https://doi.org/10.3389/fpsyg.2015.01597>
- Castillo, C., Mendoza, M., & Poblete, B. (2011, March 28–April 1). Information credibility on Twitter [conference presentation]. *Proceedings of the 20th International Conference on World Wide Web, WWW 2011*, Hyderabad, India, 675-684. 10.1145/1963405.1963500
- Chabris, C. F., Laibson, D., Morris, C. L., Schuldt, J. P., & Taubinsky, D. (2008). Individual laboratory-measured discount rates predict field behavior. *Journal of Risk and Uncertainty*, 37(2), 237-269.
- Claro, S., Paunesku, D., & Dweck, C. S. (2016). Growth mindset tempers the effects of poverty on academic achievement. *Proceedings of the National Academy of Sciences*, 113(31), 8664-8668.
- Clements, D. H., & Sarama, J. (2007). Effects of a preschool mathematics curriculum: Summative research on the Building Blocks project. *Journal for research in Mathematics Education*, 38(2), 136-163.
- Coleman, J. (1966). *Equality of Educational Opportunity*. Inter-university Consortium for Political and Social Research [distributor]. <https://doi.org/10.3886/ICPSR06389.v3>
- Cross, C. T., Woods, T. A., & Schweingruber, H. E. (2009). *Mathematics learning in early childhood: Paths toward excellence and equity*. National Academies Press.

- Cunha, F., Elo, I., & Culhane, J. (2013). *Eliciting maternal expectations about the technology of cognitive skill formation* (NBER Working Paper No. w19144). National Bureau of Economic Research.
- Cunha, F., & Heckman, J. (2007). The technology of skill formation. *American economic review*, 97(2), 31-47.
- Del Boca, D., Monfardini, C., & Nicoletti, C. (2012). *Children's and Parents' Time-Use Choices and Cognitive Development during Adolescence* (Working Paper No. 2012-006). Human Capital and Economic Opportunity: A Global Working Group.
- Del Bono, E. D., Francesconi, M., Kelly, Y., & Sacker, A. (2016). Early maternal time investment and early child outcomes. *Economic Journal*, 126(596), F96-F135.
- Doss, C., Fricke, H., Loeb, S., & Doromal, J. B. (2022). Engaging girls in math: The unequal effects of text messaging to help parents support early math development. *Economics of Education Review*, 88, 102262.
- Eckel, C., Johnson, C., & Montmarquette, C. (2005). Saving decisions of the working poor: Short-and long-term horizons. *Research in Experimental Economics*, 10.
DOI:10.1016/S0193-2306(04)10006-9
- Fryer Jr, R. G., & Levitt, S. D. (2006). The black-white test score gap through third grade. *American Law and Economics Review*, 8(2), 249-281.
- Fryer Jr, R. G., & Levitt, S. D. (2013). Testing for racial differences in the mental ability of young children. *American Economic Review*, 103(2), 981-1005.
- Gennetian, L. A., & Shafir, E. (2015). The persistence of poverty in the context of financial instability: A behavioral perspective. *Journal of Policy Analysis and Management*, 34(4), 904-936.

- Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2012). The relation between spatial skill and early number knowledge: The role of the linear number line *Developmental Psychology*, 48(5), 1241. <https://doi.org/10.1037/a0028593>
- Fiorini, M., & Keane, M. P. (2014). How the allocation of children's time affects cognitive and noncognitive development. *Journal of Labor Economics*, 32(4), 787-836.
- Haimovitz, K., & Dweck, C. S. (2016). What predicts children's fixed and growth intelligence mind-sets? Not their parents' views of intelligence but their parents' views of failure. *Psychological Science*, 27(6), 859-869.
- Hill, C. R., & Stafford, F. P. (1974). Allocation of time to preschool children and educational opportunity. *Journal of Human Resources*, 9(3), 323-341. <https://doi.org/10.2307/144690>
- Horvitz, D. G., & Thompson, D. J. (1952). A generalization of sampling without replacement from a finite universe. *Journal of the American Statistical Association*, 47(260), 663-685.
- Houtenville, A. & Conway, K. (2008). Parental effort, school resources, and student achievement. *Journal of Human Resources*, 43(2), 437-453.
- Hsin, A. (2008). *Parenting, investments in children, and the social reproduction of skills and status*. University of California Press.
- Hsin, A., & Felfe, C. (2014). When does time matter? Maternal employment, children's time with parents, and child development. *Demography*, 51(5), 1867-1894.
- Kalil, A., Liu, H., Mayer, S., Rury, D., & Shah, R. (2023). Nudging or Nagging? Conflicting Effects of Behavioral Tools. *Conflicting Effects of Behavioral Tools (January 4, 2023)*. University of Chicago, Becker Friedman Institute for Economics Working Paper, (2023-02).

- Kalil, A., Mayer, S., & Shah, R. (2022). Scarcity and Inattention. *University of Chicago, Becker Friedman Institute for Economics Working Paper 2022-76*.
- Kleemans, T., Peeters, M., Segers, E., & Verhoeven, L. (2012). Child and home predictors of early numeracy skills in kindergarten. *Early Childhood Research Quarterly*, 27, 471–477.
<https://doi.org/10.1016/j.ecresq.2011.12.004>
- Kopack Klein, A., Aikens, N., Li, A., Bernstein, S., Reid, N., Dang, M. & Tarullo, L. (2021). *Descriptive Data on Head Start Children and Families from FACES 2019: Fall 2019 Data Tables and Study Design* (OPRE Report 2021-77). Administration for Children & Families.
- Krumpal, I. (2013). Determinants of social desirability bias in sensitive surveys: A literature review. *Quality & Quantity: International Journal of Methodology*, 47(4), 2025–2047.
<https://doi.org/10.1007/s11135-011-9640-9>
- Landry, S.H., Smith, K.E., Swank, P.R., Zucker, T., Crawford, A.D., & Solari, E. F. (2012). The effects of a responsive parenting intervention on parent-child interactions during shared book reading. *Developmental Psychology*, 48(4), 969-86.
<https://doi.org/10.1037/a0026400>
- LeFevre, J., Skwarchuk, S., Smith-Chant, B. L., Fast, L., Kamawar, D., & Bisanz, J. (2009). Home numeracy experiences and children's math performance in the early school years. *Canadian Journal of Behavioural Science / Revue canadienne des sciences du comportement*, 41(2), 55–66. <https://doi.org/10.1037/a0014532>
- Leibowitz, A. (1974). Home investments in children. *Journal of Political Economy*, 82(2, Part 2), S111-S131.

- Leibowitz, A. (1977). Parental inputs and children's achievement. *Journal of Human Resources*, 12(2), 242-251.
- Maloney, E., Sattizahn, J. R., & Beilock, S. L. (2014). Anxiety and cognition. *Wires: Cognitive Science*, 5(4), 403-411. <https://doi.org/10.1002/wcs.1299>
- Maloney, E. A., Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, L. (2015). Intergenerational Effects of Parents' Math Anxiety on Children's Math Achievement and Anxiety. *Psychological Science*, 26(9), 1480-1488. <https://doi.org/10.1177/0956797615592630>
- Mangels, J. A., Butterfield, B., Lamb, J., Good, C., & Dweck, C. S. (2006). Why do beliefs about intelligence influence learning success? A social cognitive neuroscience model. *Social cognitive and affective neuroscience*, 1(2), 75-86.
- Mani, A., Mullainathan, S., Shafir, E., & Zhao, J. (2013). Poverty impedes cognitive function. *Science*, 341(6149), 976-980.
- Marinova, M., Reynvoet, B., & Sasanguie, D. (2021). Mapping between number notations in kindergarten and the role of home numeracy. *Cognitive Development*, 57. [10.1016/j.cogdev.2020.101002](https://doi.org/10.1016/j.cogdev.2020.101002)
- Magnuson, K., & Duncan, G. J. (2016). Can Early Childhood Interventions Decrease Inequality of Economic Opportunity?. *Russell Sage Foundation Journal of the Social Sciences*, 2(2), 123-141. <https://doi.org/10.7758/RSF.2016.2.2.05>
- Mayer, S. E., Kalil, A., Oreopoulos, P., & Gallegos, S. (2019). Using behavioral insights to increase parental engagement the parents and children together intervention. *Journal of Human Resources*, 54(4), 900-925.
- Meier, S., & Sprenger, C. (2010). Present-biased

- preferences and credit card borrowing. *American Economic Journal: Applied Economics*, 2(1), 193-210. doi: 10.3368/jhr.54.4.0617.8835R
- National Center for Education Research, Institute of Education Sciences, US Department of Education Preschool Curriculum Evaluation Research (PCER) Consortium (2008). *Effects of Preschool Curriculum Programs on School Readiness. Report from the Preschool Curriculum Evaluation Research Initiative* (ERIC Number: ED502153). National Center for Education Research. <https://eric.ed.gov/?id=ED502153>
- National Research Council. (2009). Mathematics learning in early childhood: Paths toward excellence and equity.
- Niklas, F., & Schneider, W. (2014). Casting the die before the die is cast: The importance of the home numeracy environment for pre-school children. *European Journal of Psychology of Education*, 29, 327–345. <https://doi.org/10.1007/s10212-013-0201-6>
- Pabilonia, S. W., & Song, Y. (2013). Single mothers' time preference, smoking, and enriching childcare: Evidence from time diaries. *Eastern Economic Journal*, 39(2), 227-255.
- Padilla, C. M. (2020). Beyond just the average effect: Variation in Head Start treatment effects on parenting behavior. *AERA Open*, 6(4), 2332858420969691.
- Paulhus, D. L. (2002). Socially desirable responding: The evolution of a construct. In H. I. Braun, D. N. Jackson, & D. E. Wiley (Eds.), *The role of constructs in psychological and educational measurement* (pp. 49-69). Erlbaum.
- Siegler, R. S., & Ramani, G. B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science*, 11(5), 655–661. <https://doi.org/10.1111/j.1467-7687.2008.00714.x>

- Reardon, S. F., & Bischoff, K. (2011). Income inequality and income segregation. *American Journal of Sociology*, 116(4), 1092-1153.
- Reynolds, A.J. (1994). The Effects of Preschool Plus Follow-On Intervention for Children at Risk. *Developmental Psychology*, 30(6), 787-804
- Robins, J. M., Rotnitzky, A., & Zhao, L. P. (1994). Estimation of regression coefficients when some regressors are not always observed. *Journal of the American Statistical Association*, 89(427), 846-866.
- Rodriguez, E. T., & Tamis-LeMonda, C. S. (2011). Trajectories of the home learning environment across the first 5 years: Associations with children's vocabulary and literacy skills at prekindergarten. *Child Development*, 82(4), 1058–1075.
<https://doi.org/10.1111/j.1467-8624.2011.01614.x>
- Rowe, M. L., & Leech, K. A. (2019). A parent intervention with a growth mindset approach improves children's early gesture and vocabulary development. *Developmental Science*, 22(4), e12792.
- Rubin, D. B. (1996). Multiple imputation after 18+ years. *Journal of the American Statistical Association*, 91(434), 473-489.
- Rubin, D. B. (2004). *Multiple imputation for nonresponse in surveys*. John Wiley & Sons.
- Sarama, J., & Clements, D. H. (2006). Mathematics, young students, and computers: Software, teaching strategies and professional development. *The Mathematics Educator*, 9(2), 112-134.
- Schafer, J. L. (1999). Multiple imputation: A primer. *Statistical Methods in Medical Research*, 8(1), 3-15.

- Shah, R., Kalil, A., & Mayer, S. (2022). Engaging Parents with Preschools: Evidence from a Field Experiment. *University of Chicago, Becker Friedman Institute for Economics Working Paper*, (2022-97).
- Sheridan, S. M., Knoche, L. L., Kupzyk, K. A., Edwards, C. P., & Marvin, C. A. (2011). A randomized trial examining the effects of parent engagement on early language and literacy: The Getting Ready intervention. *Journal of School Psychology, 49*(3), 361-383. doi:10.1016/j.jsp.2011.03.001
- Skwarchuk, S. L. (2009). How do parents support preschoolers' numeracy learning experiences at home? *Early Childhood Education Journal, 37*(3), 189-197.
- Skwarchuk, S. L., Sowinski, C., & LeFevre, J. A. (2014). Formal and informal home learning activities in relation to children's early numeracy and literacy skills: The development of a home numeracy model. *Journal of Experimental Child Psychology, 121*, 63-84.
- Spears, D. (2011). Economic decision-making in poverty depletes behavioral control. *B. E. Journal of Economic Analysis & Policy, 11*(1). <https://doi.org/10.2202/1935-1682.2973>
- Sutter, M., Kocher, M. G., Glätzle-Rützler, D., & Trautmann, S. T. (2013). Impatience and uncertainty: Experimental decisions predict adolescents' field behavior. *American Economic Review, 103*(1), 510-31.
- Tarullo, L., Knas, E., Klein, A. K., Aikens, N., Malone, L., & Harding, J. F. (2017). A national portrait of Head Start children and families: FACES 2014. *OPRE Report, 98*.
- Thompson, R. J., Napoli, A. R., & Purpura, D. J. (2017). Age-related differences in the relation between the home numeracy environment and numeracy skills. *Infant and Child Development, 26*(5), e2019.

- Todd, P. E., & Wolpin, K. I. (2007). The production of cognitive achievement in children: Home, school, and racial test score gaps. *Journal of Human capital*, 1(1), 91-136.
- Tourangeau, R., & Yan, T. (2007). Sensitive questions in surveys. *Psychological Bulletin*, 133(5), 859–883. <https://doi.org/10.1037/0033-2909.133.5.859>
- Van Voorhis, F. L., Maier, M. F., Epstein, J. L., Lloyd, C. M., & Leung, T. (2013). *The Impact of family involvement on the education of children ages 3 to 8: A focus on literacy and math achievement outcomes and social-emotional skills* (Eric Number ERIC Number: ED545474). <https://files.eric.ed.gov/fulltext/ED545474.pdf>
- Villena-Roldan, B., & Rios-Aguilar, C. (2012). *Causal effects of maternal time-investment on children's cognitive outcomes* (Working Paper No. 285). Center for Applied Economics,.
- Waldfogel, J., & Washbrook, E. (2011). Early years policy. *Child Development Research*, 2011. <https://doi.org/10.1155/2011/343016>
- York, B., & Loeb, S. (2018). *One Step at a Time: The Effects of an Early Literacy Text Messaging Program for Parents of Preschoolers* (NBER Working Paper No. 20659). National Bureau of Economic Research. <http://www.nber.org/papers/w20659>
- Zadeh, Z. Y., Farnia, F., & Ungerleider, C. (2010). How home enrichment mediates the relationship between maternal education and children's achievement in reading and math. *Early Education and Development*, 21(4), 568-594.

Appendix A: Supplementary table and figures

Table A1. Sample size of parent and child samples by MPACT treatments

	Randomized child sample	Child sample with complete data	Randomized parent sample	Parent sample with complete data
Control	348	220	256	202
Math app	122	72	102	87
MKit	239	153	170	136
Growth mindset	239	162	184	143
Present bias	239	151	184	153
Total	1187	758	896	721

Table A2. Comparison of baseline characteristics of the child sample by time

	Complete data at baseline	Complete data at end of the intervention	Complete data 6 months post intervention
Female	52.9%	53.8%	54.7%
Age (month)	46.99 (6.34)	46.96 (6.33)	46.59 (5.97)
Intensity of math engagement	6.33 (2.79)	6.36 (2.77)	6.28 (2.73)
WJ percentile	24.24 (20.37)	24.56 (20.42)	24.79 (20.56)
N	1187	1084	758

Note: Pairwise t-tests show that there are no significant differences of baseline characteristics by time ($p=.1$).

Table A3. Comparison of baseline characteristics of the parent sample by time

	Complete data at baseline	Complete data at end of the intervention
Female	92.5%	93.7%
Age	31.38 (6.91)	31.6 (6.98)
Non-Hispanic Black	31.6%	30.7%
Hispanic	63.2%	64.5%
Percent with less than HS degree	26.2%	26.5%
Percent with HS degree	27.3%	26.4%
Percent with BA or higher degree	7.7%	7.9%
Percent who speak Spanish at home	55.7%	56.7%
Household income in previous year	\$19491 (15309)	\$19298 (15132)
N	896	721

Note: Pairwise t-tests show that there are no significant differences of baseline characteristics by time (p=.10).

Table A4. Effect of MPACT treatments on weekly frequency of math activities

	(1)	(2)	(3)	(4)
	Counting	Recognize numbers	Add or subtract	Recognize shapes
Math app	.51** (.22)	.70*** (.23)	.51** (.23)	.38 (.25)
MKit	.35* (.2)	.25 (.23)	0.13 (.22)	.22 (.23)
Growth mindset	-.01 (.19)	.20 (.22)	.61*** (.21)	.10 (.23)
Present bias	.10 (.19)	.53*** (.2)	.55** (.23)	.43** (.22)
Constant	2.10*** (.19)	2.30*** (.19)	1.12*** (.15)	2.08*** (.19)
Control Mean	3.71	3.25	1.65	3.39
Control SD	1.68	1.77	1.68	1.85
N	713	706	670	708

Notes: The control group is omitted. Regressions include baseline measures of the outcome and classroom fixed effects. Standard errors are reported in parentheses. *p<0.1, **p<0.05, ***p<0.01

Appendix B: MPACT materials

MKit. The content of the MKit was developed by BIP Lab staff and it was illustrated by a professional illustrator to be visually pleasing to both parents and children. The MKit includes a booklet that described activities that parents and children could do together to promote math learning. Each page included a section called, “What Your Child Should Learn” that described the skill that each activity was intended to foster. Each activity page also included a way to make the activity more difficult as children mastered each skill and a section titled, “Math Is Everywhere” that described how the skill developed in that activity could be reinforced in everyday activities such as visit to the grocery store. The activities were intended to require almost no materials that could not be found in almost every house, the MKit also included a game board with game pieces and some of the activities described ways to use the game board. The MKit also included a Number Helper and some of the activities relied on this. The MKit also included a page with a “Goal Kit” that parents could use to keep track of their goals for going math with their children. The MKit+present bias treatment is the only treatment in which parents were asked to set a goal.

Figures B1 to B3 show some of the components of the MKit. As the first picture shows, all these components were given to each family in a bag with MPACT written on it.

Figure B1. A View of the MKit as it was given to parents.



Figure B2. An example of a page from the MKit

Count the dots

What your child will learn:
Counting objects • comparisons • adding.

■ **STEP 1**

Ask your child to look at these dot drawings on the MKit card and count how many dots it takes to make each object.

Begin counting with the dot that is black. Be sure to have your child touch each dot while counting. Begin with the object with the fewest dots and continue to the objects with more dots.

■ **STEP 2**

Ask your child, "Which object has the most dots? Which has the fewest dots?"



Caterpillar has dots. Fish has dots.

Figure B3. The game board form the MKit



Figure B4. The MKit Number Helper



Math Apps. To select the applications used in the math app treatment, we began by reviewing educational math applications for children ages 3 to 5. We restricted our search to iPad compatible iOS apps available in both English and Spanish and focused on skills comparable to those highlighted in the MKit, namely numeracy-related skills. We also tried to select apps that balanced high-quality math activities with sufficient animations and sounds to reward the child for progress but not distract from learning. We screened apps to be sure they worked with no technical difficulties on the iPads and were user-friendly for first-time tablet users. We reviewed 50 apps that met these requirements produced in the United States, Australia, England, Spain, and Mexico. From these we identified six apps for use in a pilot study. The apps used in our pilot study were:

Table B1: iPad applications for the pilot study

Pilot Applications for the MPACT math app treatment
123 Go
Lipa Frog
Lola's Math Train
Drive About Number Neighborhood
Monkey Preschool Lunchbox
Learning Patterns

During exit interviews after the pilot, we found that parents and children were able to easily use the iPad apps, parents felt apps were the appropriate difficulty level for their child and that the applications provided enough variety to capture their child's interest even for a longer time period.

After the pilot, we omitted two of the apps included in the pilot (Money Preschool Lunchbox and Learning Patterns) because they focused on skills not included in the MKit, and we added 3 apps (Arithmetics Pro, Animal Math and KidsMath) because they more closely

focused on numeracy. Consequently, the math app treatment included the 7 math apps shown in Table B2.

Table B2 Applications used in the math app treatment

Full Study Applications
123 Go
Lipa Frog
Lola's Math Train
Drive About Number Neighborhood
Arithmetics Pro
Animal Math
KidsMath